Fall 2014

Augmented Reality Application Utility For Aviation Maintenance Work Instruction

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(Revised /)

PURDUE UNIVERSITY
GRADUATE SCHOOL
Thesis/Dissertation Acceptance

This is to certify that the thesis/dissertation prepared

By John Bryan Pourcho

Entitled

AUGMENTED REALITY APPLICATION UTILITY FOR AVIATION MAINTENANCE WORK INSTRUCTION

For the degree of Master of Science

Is approved by the final examining committee:

Nathan Hartman

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Approved by: Mihaela Vorvoreanu 12/08/2014

Head of the Graduate Program Date

AUGMENTED REALITY APPLICATION UTILITY FOR AVIATION MAINTENANCE WORK INSTRUCTION

A Thesis

Submitted to the Faculty

of

Purdue University

by

John Bryan Pourcho

In Partial Fulfillment of the

Requirements for the Degree

of

Master of Science

December 2014

Purdue University

West Lafayette, Indiana

This thesis is dedicated to my parents, Robert and Karen Pourcho. Thank you for your encouragement, support and love.

Proverbs 22:6

ACKNOWLEDGEMENTS

This work would not be possible without the help of my advising professor, Dr. Nathan Hartman, the research foundation paved by my committee member Professor Timothy Ropp and his students out of the Hangar of the Future Laboratory at the Purdue University Airport, the advisement and insightful feedback provided by committee member Dr. Patrick Connolly, and the foundational work I did as a member of the Purdue University senior project team, AeroHead Tech, alongside Nathan Christopher, Patrick McGuire and Shawn Ruemler.

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ABSTRACT

Pourcho, John B. M.S., Purdue University, December 2014. Augmented Reality Utility For Aviation Maintenance Work Instruction. Major Professor: Nathan Hartman.

Current aviation maintenance work instructions do not display information effectively enough to prevent costly errors and safety concerns. Aircraft are complex assemblies of highly interrelated components that confound troubleshooting and can make the maintenance procedure difficult (Drury & Gramopadhye, 2001). The sophisticated nature of aircraft maintenance necessitates a revolutionized training intervention for aviation maintenance technicians (United States General Accounting Office, 2003). Quite simply, the paper based job task cards fall short of offering rapid access to technical data and the system or component visualization necessary for working on complex integrated aircraft systems. Possible solutions to this problem include upgraded standards for paper based task cards and the use of integrated 3D product definition used on various mobile platforms (Ropp, Thomas, Lee, Broyles, Lewin, Andreychek, & Nicol, 2013). Previous studies have shown that incorporation of 3D graphics in work instructions allow the user to more efficiently and accurately interpret maintenance information (Jackson & Batstone, 2008). For aircraft maintenance workers, the use of mobile 3D model-based task cards could make current paper task card

standards obsolete with their ability to deliver relevant, synchronized information to and from the hangar. Unlike previous versions of 3D model-based definition task cards and paper task cards, which are currently used in the maintenance industry, 3D model-based definition task cards have the potential to be more mobile and accessible. Utilizing augmented reality applications on mobile devices to seamlessly deliver 3D product definition on mobile devices could increase the efficiency, accuracy, and reduce the mental workload for technicians when performing maintenance tasks (Macchiarella, 2004). This proposal will serve as a literary review of the aviation maintenance industry, the spatial ability of maintenance technicians, and benefits of modern digital hardware to educate, point out gaps in research, and observe possible foundations on which to build the future of aviation maintenance job task cards leading to a the methodology of the proposed study.

1 INTRODUCTION

1.1 Introduction

Students and researchers at the Purdue University Airport have been working and researching for several years to establish a technologically optimized aircraft maintenance hangar operation. Their research has produced several studies denoting the advantages of 3D job task cards over paper-based solutions, enhanced mobility in tablet 3D solutions over their laptop equivalents, and what level of detail within job task cards best suits the technicians using the applications. This thesis study explored and tested the usability of augmented reality in the process of aviation maintenance.

1.2 Statement of the Problem

The current standards for job task cards still employ a paper based medium despite advancements in the accessibility of 3D CAD technology that could improve the visualization process for aviation technicians and possibly decrease human error in the aviation maintenance industry.

1.3 Research Question

Can an augmented reality delivered 3D work instruction replicate on the job training, elevating novice aviation maintenance technicians to perform at an expert level within the constraints of efficiency and human error?

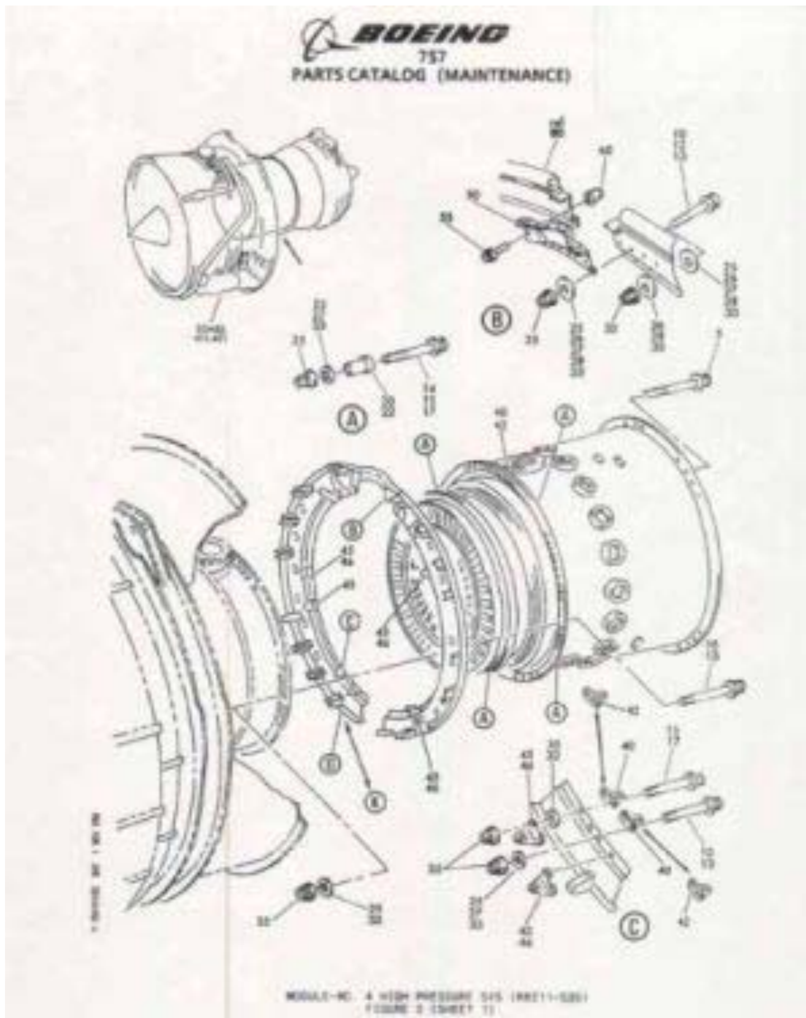


Figure 1.1 Aviation maintenance job task card visual aid. Boeing (2011).

http://www.freedomformforceinternational.org/picks/parts_catalog.jpg

1.4 Scope

The current standard in the aviation industry requires that maintenance technicians follow a task card when work needs to be done on an aircraft. This task card (Figure 1.1) gives the worker a step-by-step guide for each part that may need safeguarding. In order to instruct the workers, the card is made up of textual instructions and static images, which supply any visual cues that may be needed. While these cards have been used for a long time in the aviation industry, there are several problems that must be addressed. These difficulties include: the understandability of the instructions, the clarity of the visuals, and the errors that these issues can cause. Job task cards are outdated in their use of media, making the possibilities improved graphics and functionality can bring a topic worthy of investigation (Hartman & Ropp, 2012).

One thing remains to be said about the field of aviation repair, and that is the mobility and durability of the job task card. Current paper based solutions actually do a very good job of achieving both these goals with its lightweight form and ability to go anywhere the mechanic can go. Laptop computers, though capable, are radically less so, while tablets hold their own in this regard. This is a crucial aspect of the problem at hand, as many times the technician must complete a repair in dimly lit, cramped areas of the plane. The tool must serve the worker as far as mobility is concerned.

Finally, augmented reality holds tremendous potential in the process of work visualization for the aviation technician. Augmented reality, or the overlay of visual data onto concurrent, real-life imagery, has long been a topic of science fiction (Kato & Billinghurst, 1999). However, recent advancements in technology have captured its promising usability in several formats, and the dream can now become a reality. Current augmented reality mobile applications can recognize still images of 3D objects and automatically feed any chosen media to the screen of a tablet or smartphone (Aurasma, 2014). This study utilized this functionality to direct the technician to a dynamic 3D model of the part being worked on to maximize accessible visualization. With augmented reality, workers can now seamlessly connect instruction to part, further increasing perception and reducing interpretation error.

1.5 Significance

To better understand the problem at hand it is important to understand the impact of failure in the aviation industry. Plane breakdowns range in size and value but their combined influence drive both the cost of the market and need for skilled maintenance sky high. According to a study, which summarizes many of the different maintenance and human error categories in the industry, “each year $300 billion is spent on plant maintenance and operation by (this) industry, and 80% of this is spent to correct the chronic failures of machines, systems, and people” (Dhillon & Liu, 2006). The authors define human error as the failure to perform a task that could cause disruption of scheduled operations or damage to equipment, and describe maintenance error as a result of incorrect repair or absence of preventative action.

Furthermore, by breaking down the different costs associated with aviation by company, flight hours and area of the plane requiring maintenance, it is estimated that maintenance cost rises about $0.6 billion per year (The International Air Transport

Association, 2011). These numbers imply a gap in research and point towards swift and necessary action by implementation of a new tool or, at the very least, improved accountability within the process. To better solve this problem, we must investigate further into the causes of human error and the opportunities that they present to move forward.

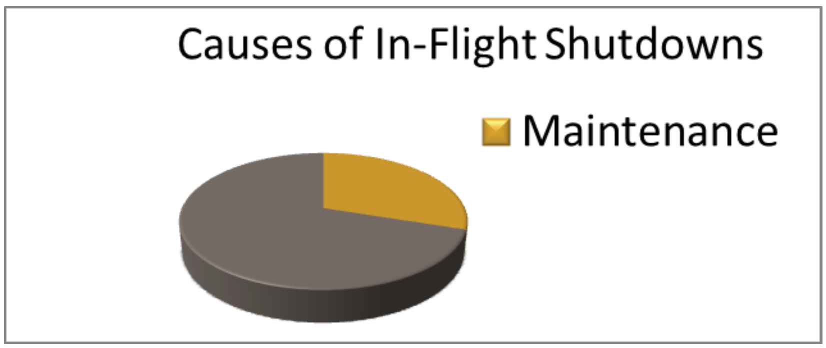


Figure 1.2 Maintenance failure

When errors are made in the aviation industry there are often significant consequences. These consequences range from costly flight delays and inefficiencies in maintenance work to possible injury and death of airline passengers. Studies have shown that one in every five airline accidents are due to maintenance error and 80% of those are related to preflight activities wherein the task cards are used (Wiegmann & Shappell, 2001b). Other studies have shown that 20% to 30% of in-flight engine shutdowns are caused by maintenance errors (see figure 1.2), and these can lead to roughly $675,000 in costs per shutdown (Rankin, Hibit, Allen, & Sargent, 2000). Numbers like this depict the importance of minimizing maintenance errors and should be of paramount interest to the aviation industry.

1.6 Assumptions

The assumptions associated with this study include:

- Participants have had enough familiarity with the section of the aircraft to perform their job.
- Participants have had enough experience to be proper representatives of the aviation maintenance industry.
- The sample size is large enough to represent the population.
- Participants of the study will answer the survey truthfully and thoughtfully.
- Adequate time has been provided for the experiment to take place.
- No outside pressures affected the participants while they completed the experiment and responded to the survey.

1.7 Limitations

The limitations for this study include:

- This study has been prepared for an iPad using the Aurasma application.
- The study has used the Purdue Wi-Fi network PAL 2.0.
- The individual associated with the experimental trial in question completed the survey within an hour of completing the experiment.

1.8 Delimitations

The delimitations for this study include:

- Aurasma is the only applications chosen for augmented reality presentation.

- The 3D models will be created and integrated with the software by John Pourcho.
- Subjects have been restricted to junior and senior level AET majors at Purdue University and expert Aviation Technicians who operate out of the Purdue airport.
- Only one aviation maintenance job task has been compared.
- Only participants who volunteered were permitted to participate in the study.

1.9 Glossary

- FAA Certified Aviation Maintenance Technician – must be 18 years old, speak and understand English and qualify based on a high school diploma or GED and then one of three qualifications: attend an Aviation Maintenance Technician School, work under the supervision of a certified mechanic for 18 months for each type of certificate required, or join one of the armed services to receive the training and experience necessary. Finally, they must pass an oral, written, and practical test (Federal Aviation Administration, 2005b).
- Job Task Card – a set of sequential instructions used by aviation technicians and mechanics to perform maintenance tasks on an aircraft (Aviation Intertec Services, 2011).
- Visual Perception Needs – "Visual inspection and the majority of aviation maintenance job tasks require perception and human reasoning. Unfortunately for AMTs, the search and decision making skills which involve human perception and reasoning are typically flawed" (Haritos & Macchiarella, 2005b).

- Maintenance Error – “a result of incorrect repair or absence of preventative action” (Dhillon, 2006, p. 22).
- Human Error – “the failure to perform a task that could cause disruption of scheduled operations or damage to equipment” (Dhillon & Liu, 2006, p. 22).
    - Decision Errors – “conscious, goal-intended behavior that proceeds as designed; yet, the plan proves inadequate or inappropriate for the situation” (Wiegmann & Shappell, 2001b, p. 4-5).
    - Skill-based Errors – “occur with little or no conscious thought … The difficulty with these highly practiced and seemingly automatic behaviors is that they are particularly susceptible to attention and/or memory failures” (Wiegmann & Shappell, 2001b, p. 4-5).
    - Perceptual Errors – “occur when sensory input is degraded, or “unusual,” … responding incorrectly to a variety of visual/vestibular illusions” (Wiegmann & Shappell, 2001b, p. 4-5).
- Threshold Testing – “presentation of products in order of increasing intensity in order to establish threshold values” (Arrow Scientific, 2009).
- Expert Aviation Maintenance Technician – “someone who has accomplished various aircraft maintenance tasks numerous times; often through a process of overlearning that leads to automaticity for regularly occurring job tasks” (Haritos & Macchiarella, 2005b)

- Virtual Reality – “to completely immerse a user inside a synthetic environment” (Azuma, 1997).
- Augmented Reality – “a machine vision and computer graphics technology that merges real and virtual objects into unified, spatially integrated scenes” (Azuma, Baillot, Behringer, Feiner, Julier & MacIntyre, 2001)

1.10 Chapter Summary

Current aircraft maintenance job task cards can be improved to display a higher form of visual information, thus enabling more data rich communication in the form of technical information and work instruction. Augmented reality may avert problematic traits leading to human error, and drastic monetary consequences and severe safety consequences, which remain among the key concerns within the aviation maintenance industry. This proposal will break down the issues at stake in greater detail and craft an experiment to develop and propose one solution for remedying this situation.

2 LITERATURE REVIEW

2.1 Introduction

This chapter will serve as a literature review grounding the proposed research within the history and gaps in literature of the topics discussed. In particular, this section will comprise of an in depth look at human error in the field of aviation maintenance, the current industry standards for aviation job task cards, required skills and experience for aviation technicians, human information processing on digital screens, and the history and implementation practices currently in use with augmented reality. All in all, this chapter is the definition of a problem the later sections of this thesis will seek to address and the building blocks this research will stand upon to achieve that goal. Fittingly, we will start with the biggest contributor to the problem at hand: human error.

2.2 Human Error

The U.S. Department of Transportation outlined four causal categories of maintenance error. The categories presented were; Organizational Influences, Unsafe Supervision, Preconditions for Unsafe Acts, and Unsafe Acts. The study found that Unsafe Acts or Preconditions for Unsafe Acts accounted for a majority of errors

(Wiegmann & Shappell, 2001b). Unsafe Acts of Operators were loosely defined in the article in two categories: errors and violations.

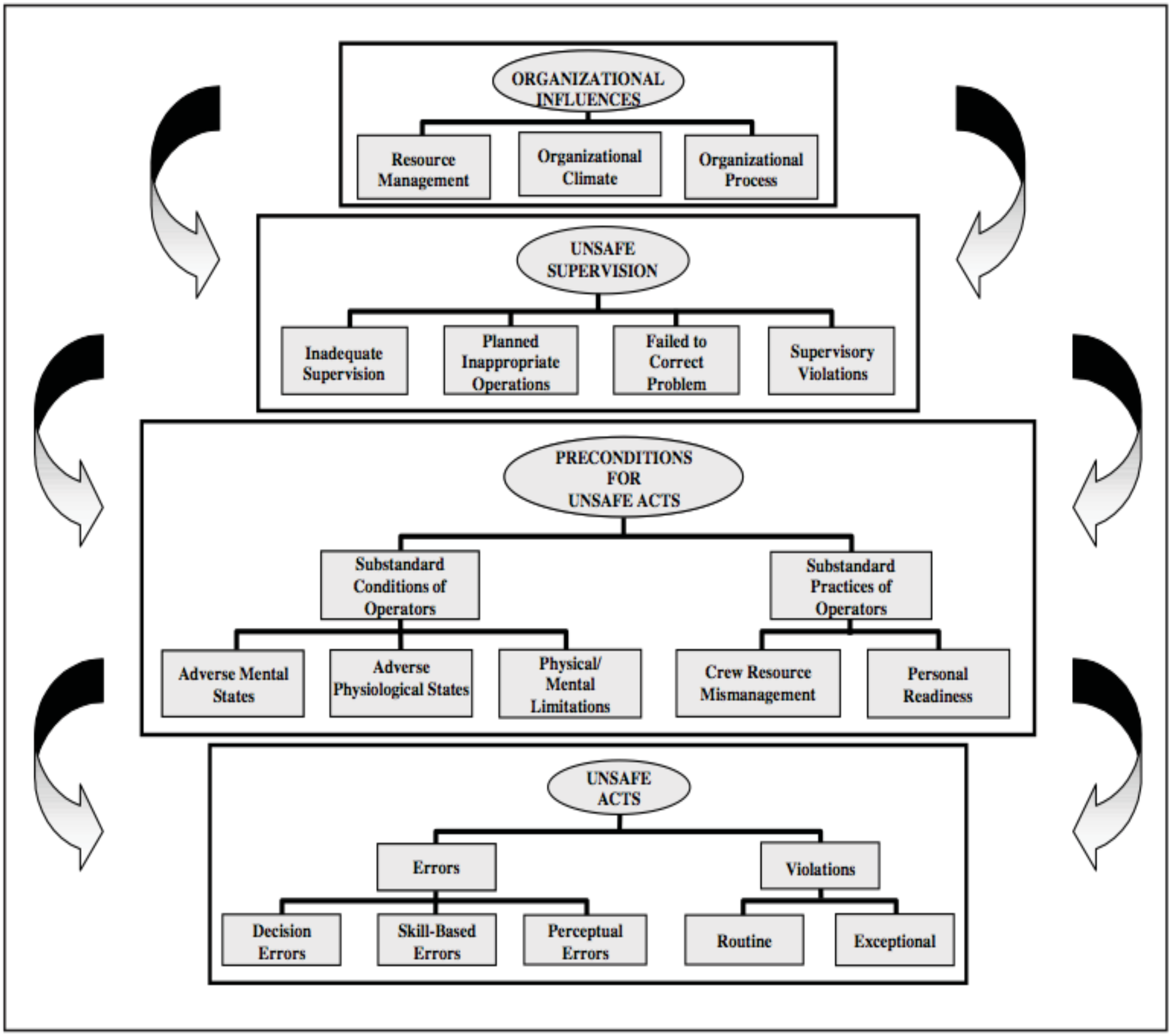


Figure 2.1 Overview of the Human Factors Analysis and Classifcation System (HFACS). Wiegmann & Shappell (2001a). http://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/2000s/media/0103.pdf

While violations are a big problem facing the industry, they are a human relations failure and thus fall outside the framework of problems a task card can fix. Errors, on the other hand, are a common problem that the right tool should at least be able to constrain. Within errors, there are three categories offered: decision errors, skill-based errors, and perceptual errors.

Wiegmann and Shappell (2001b) defined the three categories in this way:

> One of the more common error forms, *decision errors*, represents conscious, goal-intended behavior that proceeds as designed; yet, the plan proves inadequate or inappropriate for the situation. Often referred to as "honest mistakes," these unsafe acts typically manifest as poorly executed procedures, improper choices, or simply the misinterpretation or misuse of relevant information. In contrast to decision errors, the second error form, *skill-based errors,* occurs with little or no conscious thought. The difficulty with these highly practiced and seemingly automatic behaviors is that they are particularly susceptible to attention and/or memory failures… No less important, *perceptual errors* occur when sensory input is degraded, or "unusual," … responding incorrectly to a variety of visual/vestibular illusions. (p. 4-5)

All of these errors can and should be addressed by a more relevant and robust presentation of maintenance instruction. The instruction should be thorough enough to remove decision errors from possibility, attention demanding enough to grip those struggling with skill based errors, and contain enough visual information to clarify any gaps in the perception of the technician that would lead to perceptual errors.

Similarly, a research group testing various ways of identifying, reporting, and managing human error in aviation maintenance found that the majority of aviation maintenance accidents occur due to human error (Latorella & Prabhu, 1997). This is not without note, but the factors behind the error offer a more telling tale. More specifically, they found that omissions and incorrect installations make up the majority of human errors associated with aircraft maintenance. As with the errors given by the U.S. Department of Transportation, a well-conceived and effectively achieved 3D tool would eliminate the factors leading to human error. By making a system that has checkpoints at every step of the repair or installation it is possible to dramatically cut omitted steps, and by presenting the information in a dynamic 3D view one can remove the ambiguity surrounding static engineering drawings, effectually alleviating the confusion that would lead to an incorrect instillation. With the dangers of human error and the possible ways a pioneering application could relieve the obstacles surrounding the current model reviewed, it follows that the present standards for aviation maintenance job task cards need be redefined.

2.3 Industry Standards For Job Task Cards

As the aviation industry has migrated from the 20th to the 21st century many things have changed, but job task cards have largely remained the same. Essentially, a job task card is a set of sequential instructions used by aviation technicians and mechanics to perform maintenance tasks on an aircraft (Aviation Intertec Services, 2011). Historically, job task cards have been created by the aircraft manufacturer and presented in a paper format for the maintenance technicians to use (Figure 2.2). Paper based task cards are still the overwhelming majority of those in use today, though they are created as PDF files. The limitations of the PDF are as follows:

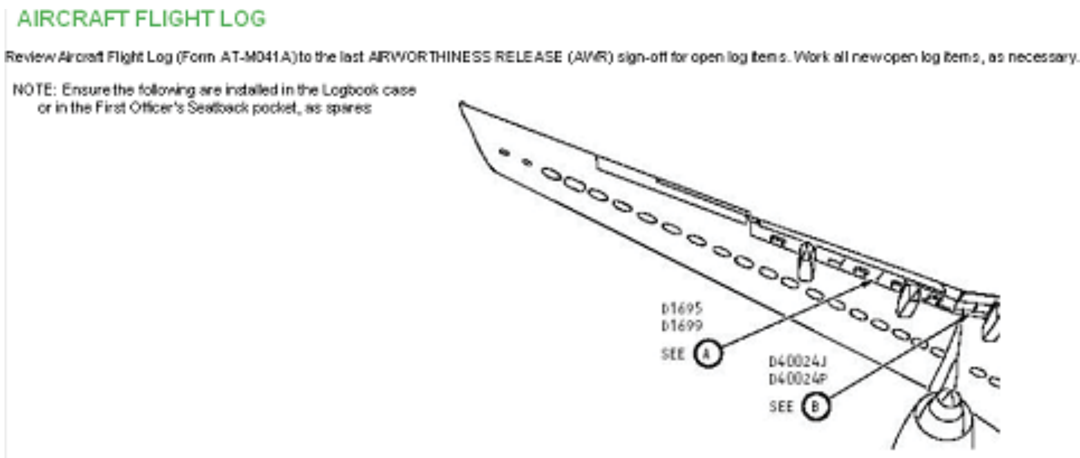
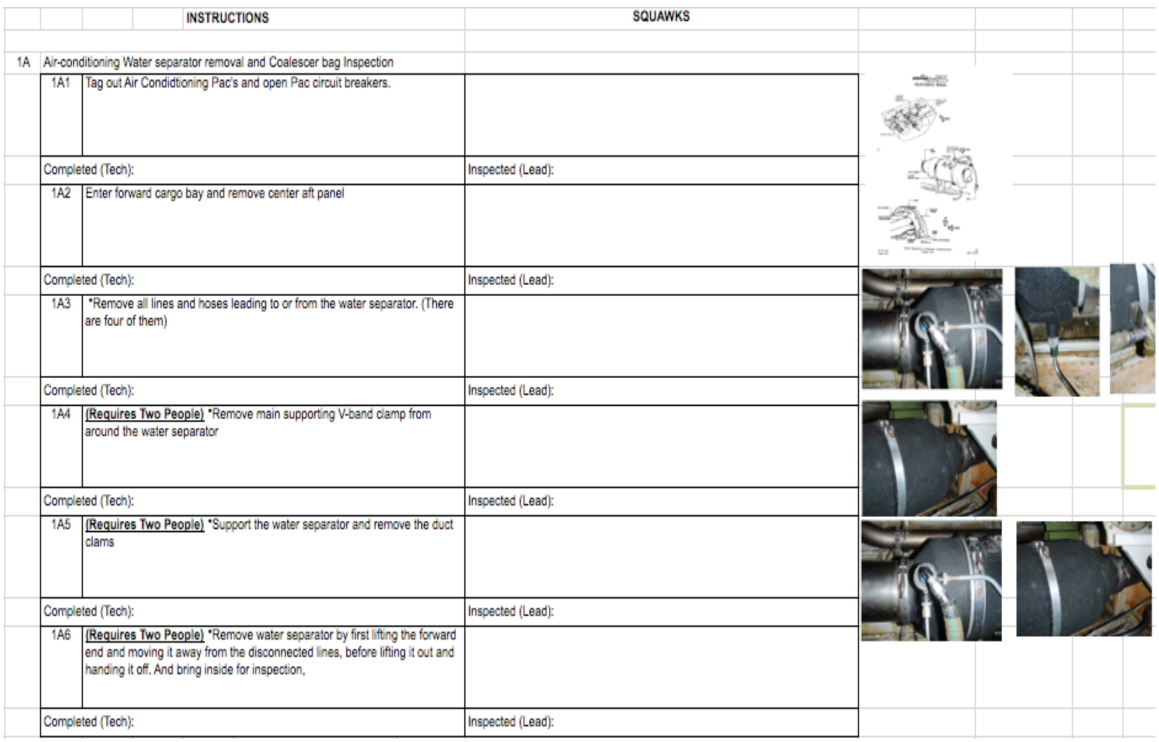


Figure 2.2 Example of a section of an industry job task card, Aircraft IT (2014). Taken from: *http://www.aircraftit.com/MRO/Vendors/TRAX/Modules/Engineering.aspx*

> Depending on the complexity of the equipment being serviced, job cards can run into the hundreds or thousands of pages, with information drawn from multiple data sources. For equipment operators and MRO shops, the generation of job cards is usually a manual task that involves searching for data in multiple systems, sorting the information, then copying and pasting it into the proper job card format. This process is both time-consuming and error-prone, which slows down the maintenance and repair of equipment like aircraft and engines. (Enigma, 2011b. para. 2)

Because the process of creating the task card is tedious, it is not unusual for the instructions to contain mistakes, let alone poor visual aids. Another compounding problem is the given instruction created by the manufacturer might not match the language known by the technician, leaving them to rely solely on the visuals contained to understand their job. These visuals are few and far between (Figure 2.3), and when they do exist they require a great extent of spatial cognition to be read easily. This is standard that should be renovated.



		INSTRUCTIONS	SQUAWKS
1A		Air-conditioning Water separator removal and Coalescer bag Inspection	
	1A1	Tag out Air Conditioning Pac's and open Pac circuit breakers.	
	Completed (Tech):		Inspected (Lead):
	1A2	Enter forward cargo bay and remove center aft panel	
	Completed (Tech):		Inspected (Lead):
	1A3	*Remove all lines and hoses leading to or from the water separator. (There are four of them)	
	Completed (Tech):		Inspected (Lead):
	1A4	**(Requires Two People)** *Remove main supporting V-band clamp from around the water separator	
	Completed (Tech):		Inspected (Lead):
	1A5	**(Requires Two People)** *Support the water separator and remove the duct clams	
	Completed (Tech):		Inspected (Lead):
	1A6	**(Requires Two People)** *Remove water separator by first lifting the forward end and moving it away from the disconnected lines, before lifting it out and handing it off. And bring inside for inspection,	
	Completed (Tech):		Inspected (Lead):

Figure 2.3 Excerpt from a paper based task card for an air conditioning water separator for a Boeing 727 created by an AV TECH student at Purdue University.

However, the assumption should not be made that no improvements have been made to the creation of task cards, for there have been some notable enhancements to the current standard. The Enigma group referenced earlier has posed one such enhancement. Their solution, though not revolutionary, did help the creation process of 2D PDF task cards by developing a web-based applications that:

> … automates the creation of effectivity-based (serial number/tail number-specific) job cards required for performing heavy, shop and line maintenance … to dramatically reduce the time to produce these complex documents; in many cases a job card that would ordinarily take months to prepare can be produced in minutes" (Enigma, 2011b. para. 3).

Though this is a fair step in the right direction, this process does nothing to increase the effectiveness of a technician in the field.

Advancement more worthy of inspection is a toolbox for aviation maintenance created by Boeing. *The Maintenance Performance Toolbox* released by Boeing in 2011 is an online database that can be accessed by maintenance workers. It gives a "3D schematic of the plane, which enables a worker to point-and-click access to all of the information related to a specific airplane location or component" (Boeing, 2011, p. 24). A brainchild of a study they conducted that showed that maintenance personnel spend about 30 to 40 percent of their time researching and documenting maintenance activities (Boeing, 2011), this is a brilliant addition to the field. The information is primarily utilized in the hangar to monitor the plane's maintenance status and to direct technicians to repair the area of the plane needed most.

Furthermore, "Operators can create and customize maintenance documentation sets to capture and reuse best practices and defined procedures. The Toolbox also includes the ability to manage documentation revisions and approval processes and allows for the configuration of promotion and publishing rules" (Boeing, 2011, p. 26). This feature is further enhanced by its ability to view 3D models of the plane, giving technicians a first hand look at what needs to be fixed (see figure 2.4). Although this is advancement for aviation maintenance, more can be done to further improve the visualization process in the field. To further improve job maintenance task cards, this level of visual presentation must be implemented at ground level: with the technicians themselves. Ultimately, testing to see if the improvements lower omission, reorder, and combination of the tasks will verify the product. Therefore, improving the task card will require a look into the skill and experience requirements of its audience.

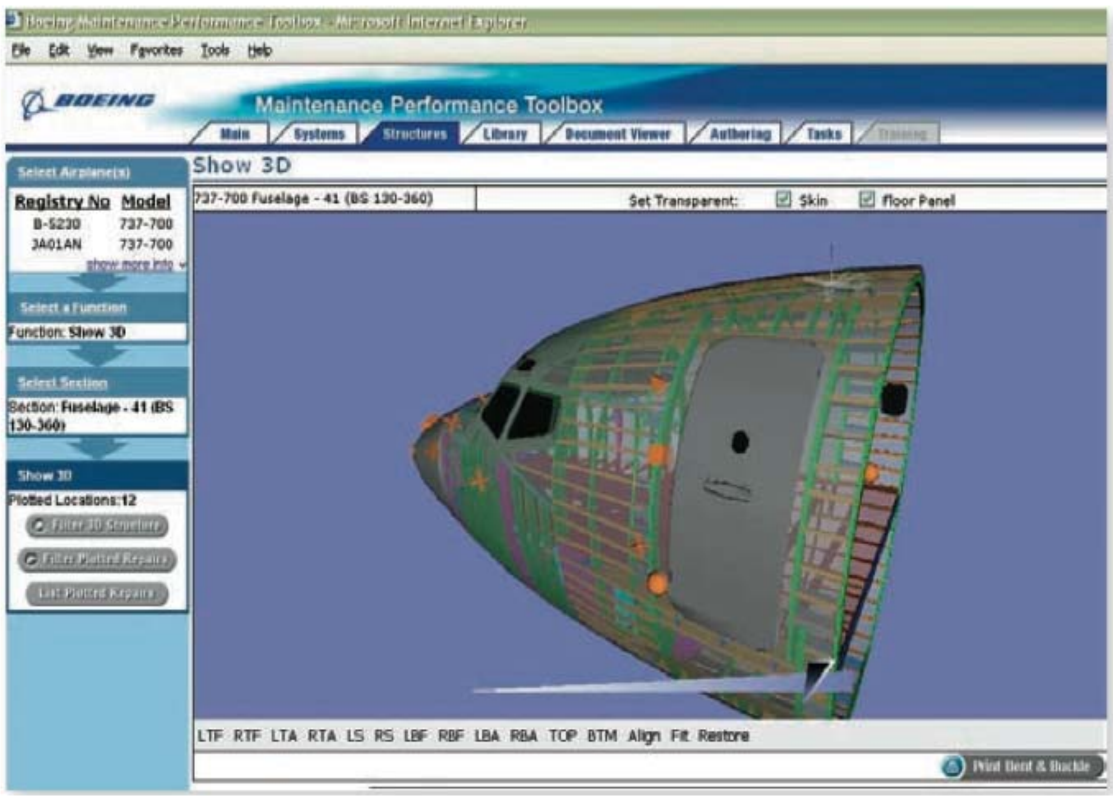


Figure 2.4 Screenshot of Boeing's Maintenance Performance Toolbox. Boeing (2011).
http://www.boeing.com/commercial/aeromagazine/articles/qtr_1_07/AERO_Q107_article4.pdf

2.4 Aviation Maintenance Technicians

Aircraft maintenance can be categorized into four complex, interrelated facets, commonly recognized by the term SHEL. SHEL stands for: software, hardware, environment, and liveware. Aircraft maintenance technicians (AMTs) represent the liveware, or human component of this system (Garland, Wise, & Hopkin, 1999). AMTs service a wide variety of fields in the aviation industry, but they do most of their work in loud, hazardous work environments such as in hangars, on flight lines and at certified repair stations (Haritos & Macchiarella, 2005b). The work itself is strenuous, requiring a high level of physical activity that can decrease performance (Federal Aviation Administration, 2001). In accordance with their certification, AMTs are held to a high standard of workmanship and craftsmanship, which greatly affects their work habits.

2.4.1 Required Skills & Experience

The Federal Aviation Administration lists the experience required to become a power plant or airframe/aircraft mechanic on its website. In order to become an aviation maintenance technician one must be 18 years old**,** speak and understand English and qualify based on a high school diploma or GED and then one of three qualifications: attend an Aviation Maintenance Technician School, work under the supervision of a certified mechanic for 18 months for each type of certificate required, or join one of the armed services to receive the training and experience necessary. Finally, candidates must pass an oral, written, and practical test, which normally requires at least 1900 hours of technical coursework or equivalent experience (Federal Aviation Administration, 2005b).

2.4.2 Expert vs. Novice

Experience is highly touted in aviation maintenance, as evidenced in the requirements above. Haritos & Macchiarella define an expert in aviation maintenance as, "someone who has accomplished various aircraft maintenance tasks numerous times; often though a process of overlearning that leads to automaticity for regularly occurring job tasks" (Haritos & Macchiarella, 2005b). Conversely, the novice is an AMT recently certified, and prone to error. This is enhanced during stressful situations (Neumann & Majoros, 1998). Unsurprisingly, errors occur less often when experts execute a job task (Driskell, Cooper & Willis, 1992). This can be attributed to the fact that AMTs develop a visual inspection schema as they continue to gain experience. This schema allows the technician to more accurately deduce the airworthiness and notice probable faults of the inspected part (Gramopadhye, Melloy, Bingham, Chen, Master, Bhomic, Qadros & Madhani, 2001). Unfortunately, it takes a long time for this schema to develop in novice AMTs.

Because of the tremendous attention demanded by the complexity of the aircraft, "it is imperative that novice AMTs receive guidance during training" (Haritos & Macchiarella, 2005b). Beyond the necessary requirements, AMT novices typically receive training from various methods. Predominant among these is on the job training (OJT). OJT can be classified as an apprenticeship between a novice and a supervising expert AMT. Haritos and Macchiarella find several problems with the current state of OJT and AMT training in general:

> Training has been identified as a primary intervention to improve the effectiveness, efficiency, and overall performance of AMTS. Unfortunately, traditional training methods, such as OJT, may not be capable of fulfilling the requirements for future trends in aviation maintenance and training for maintenance; systems are becoming too complex to allow workers with a novice level of knowledge to perform maintenance. Additionally, expert AMTs are often too busy with maintenance tasks that are operationally necessary to divide their efforts between conducting the OJT and their primary work function. (Haritos and Macchiarella, 2005b)

In addition to the complexity of systems and the schedules of expert AMTs, other issues with the current OJT method include: the stressful and noisy environment OJT takes place in, the frequency of work in confined spaces that allow for only one AMT to work at a time, and difficult tasks, such as engine removal/replacement that require multiple explanations to fully grasp (Haritos and Macchiarella, 2005b). Finally, the feedback experts do give may be infrequent, inconsistent, and unmethodical (Gramopadhye, et al., 2001).

Furthermore, the U.S. Government Accounting Office expect a large number of experts to retire in the coming years, leaving mentorship of the novice population to less experienced AMTs and negatively affecting novice AMT training (United States General Accounting Office, 2003). Novice AMTs could greatly benefit from a solution that counteract the problems associated with OJT training and provide them with concurrent information that would allow them to perform at an expert level earlier and more often.

2.4.3 Aviation Maintenance Task Methodology

The FAA has also summed up the methodology technicians use to complete the task. They define the procedures and analysis required like this:

> A typical maintenance procedure is basically a list of tasks that have to be performed in a particular order. Any single maintenance task consists of various decisions and actions, each of which has human factors implications. Task analysis is the technique used to identify, describe, and evaluate these decisions and actions. What is needed is a breakdown of the whole task into components or steps, with a plan that tells us how to choose the next step. (Federal Aviation Administration, 2008. para. 2)

A look at a flow chart depicting the average task analysis is displayed in figure 2.5. Notably, this chart does not account for existing experience, but it is a good example of standard practice. This process is time consuming; requiring the AMT to repeatedly examine the instructions, further increasing time on task, worker stress and decreasing overall job performance. Neumann and Majoros concluded that 45% of an AMTs shift is dedicated to searching for and reading instructions for job tasks (Neumann & Majoros, 1998).

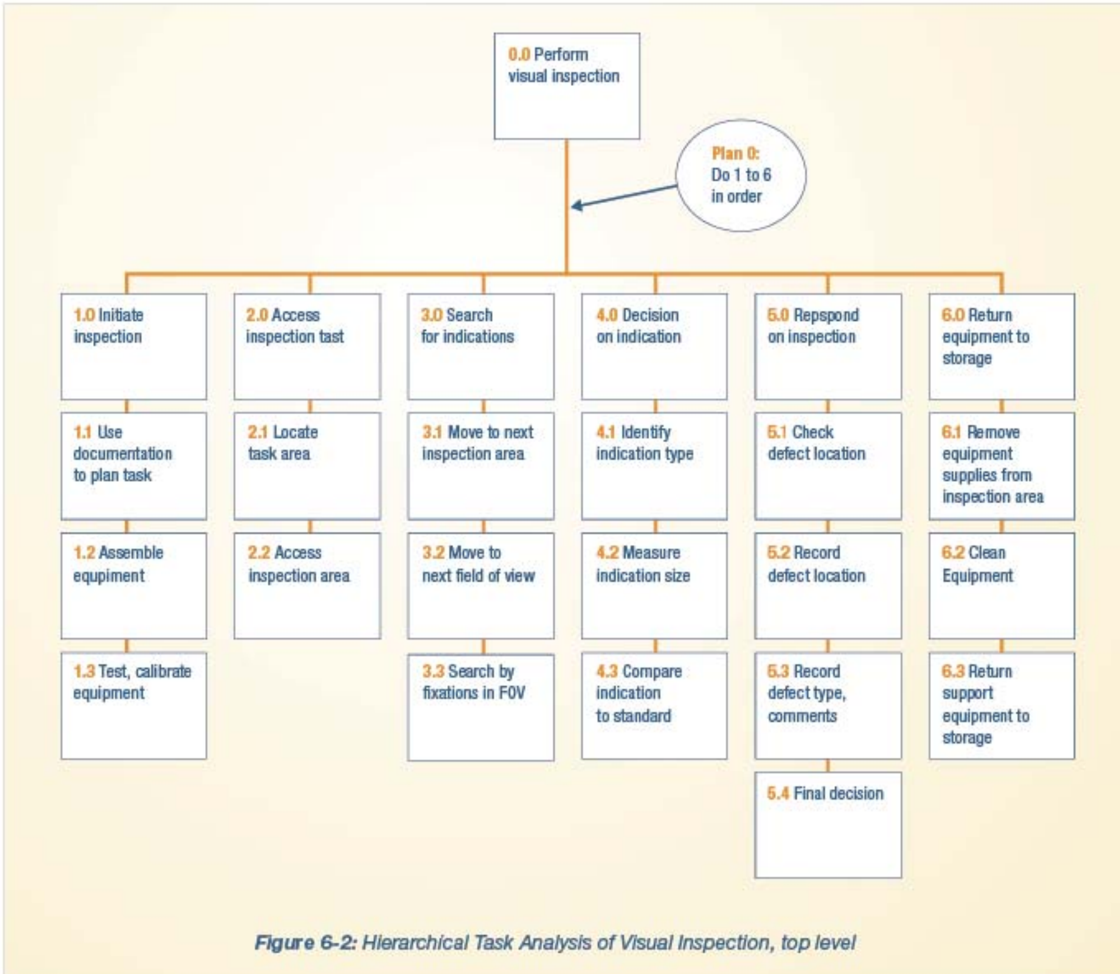


Figure 2.5 Hierarchial Task Analysis of Visual Inspection, top level. Federal Aviation Administration (2008a). *http://www.hf.faa.gov/hfguide/06/06_methods.html*

Visual inspection itself is a method that avails itself to a bevy of human error summed in the unreliableness of personal standards and a lack of training methods available to teach the skills required. Much is asked of the AMT in terms of visual perception and human reasoning. Typically, the search and decision making skills for AMTs are flawed (Drury & Gramopadhye, 2001). Again, this procedure is thorough and tedious, subject to skill and decision based errors as the technician moves through the task too fast or without enough regard for the process. An enhanced visual experience would ease the process of moving through the tediousness of these procedures and allow the technician to work with both tactile and visual knowledge (Jackson & Batstone, 2008). The next topic to discuss is the possibility of improving the spatial cognition of the average technician for consumption of 3D images.

2.5 Comparing Dynamic 3D Simulation to Static Formatting as Related to Spatial Recognition

Most aviation maintenance technicians enter the job with average spatial recognition skills (Drury & Gramopadhye, 2001); these may improve over time with exposure to the actual parts depicted in task cards. However much is asked of them by way of converting static engineering drawings into 3D dynamic objects in their head that they can manipulate in order to locate the correct screw or clamp they must detach. Therefore, replacing the static drawings with dynamic 3D, AR accessed, videos or manipulative part models accessed straight from the viewfinder of a tablet could go a long way into making the aviation repair task easier and more efficient (see Figure 2.6). A research article for the *Information Visualization* journal released in 2005 paved the way for this line of thought in the maintenance field by transposing all the static information given in an engineering drawing onto a dynamic 3D CAD model. The author poses, "…a user without a solid background in using engineering drawings will find it much easier to visualize a 3D model than to mentally reconstruct a model from the views found on an engineering drawing" (Carvajal, 2005, p. 4). This means, that instead of spending time (and therefore, money) visualizing an engineered part, the technician can move quickly to the task at hand.

Spatial recognition can also be improved by training with 3D models. A research study that tested the use of 3D models in the comprehension of cross sections of basic geometric primitives found that, "…spatial visualization skill can be improved through training and provide evidence for the usefulness of interactive computer visualizations"

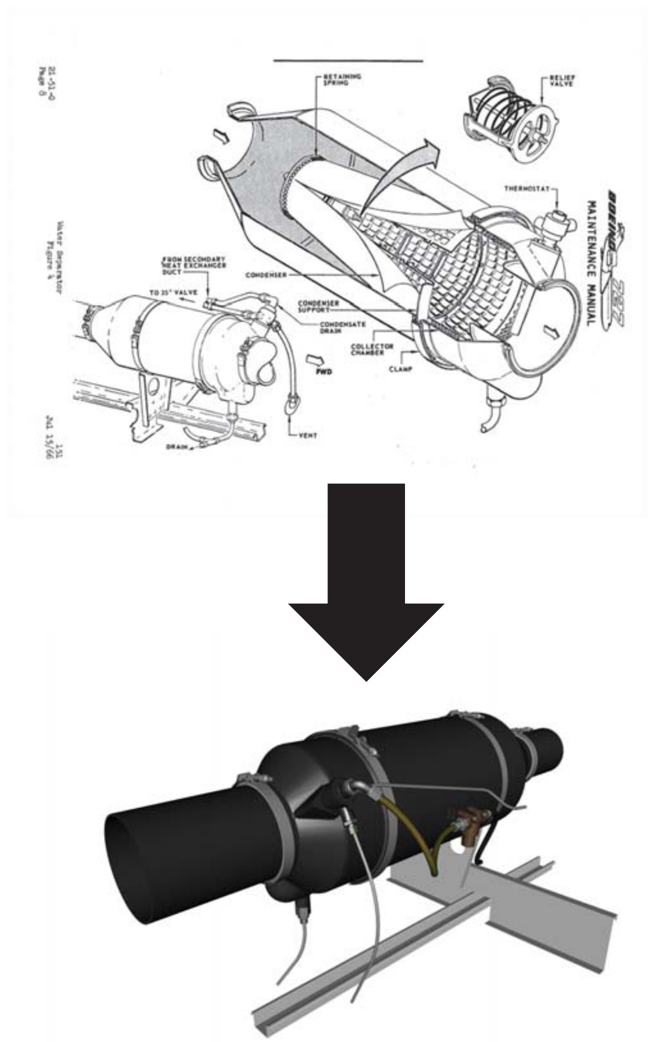


Figure 2.6 A comparison between a static engineering drawing and its corresponding dynamic 3D CAD model.

(Cohen & Hegarty, 2008, pg. 5). This has strong implications for future growth in the industry should 3D training be required for maintenance technicians. If technicians are trained in 3D visualization and also given easy access through AR to similar 3D models to work from, progress could be exponential. Targeted training programs may also speed spatial recognition. One study had students with low spatial ability watch how an object is rotated on a 3D CAD program related to a real physical representation of the object next to the computer screen found that geometric recognition was increased in just two one-hour sessions (Kinsey & Onyancha, 2008).

The U.S. Army utilized this concept when performing maintenance tasks for the High Mobility Multi-Purpose Wheeled Vehicle. They trained their technicians with 3D manipulative parts instead of static paper based tasks and arrived at a significant conclusion, "With Virtual 3D training, students are learning faster, retaining more knowledge, and increasingly performing procedures correctly for the first time" (Jackson & Batstone, 2008, p. 5). Performing procedures correctly for the first time has two implications: the first being the task is learned and achieved correctly, making subsequent tasks on the same part more efficient; and secondly if a part needs to be fixed on the fly by a technician who does not have experience with that specific task they can complete it effectively with little to no delay.

2.6 Information Processing on Digital Screens

If 3D simulations have the ability to cut down on maintenance error, the next step is discovering the best way to deliver these 3D product definition work instructions. Several avenues to represent the future platform of aviation maintenance job task cards worth considering exist, but three stand out in particular – updated paper task cards

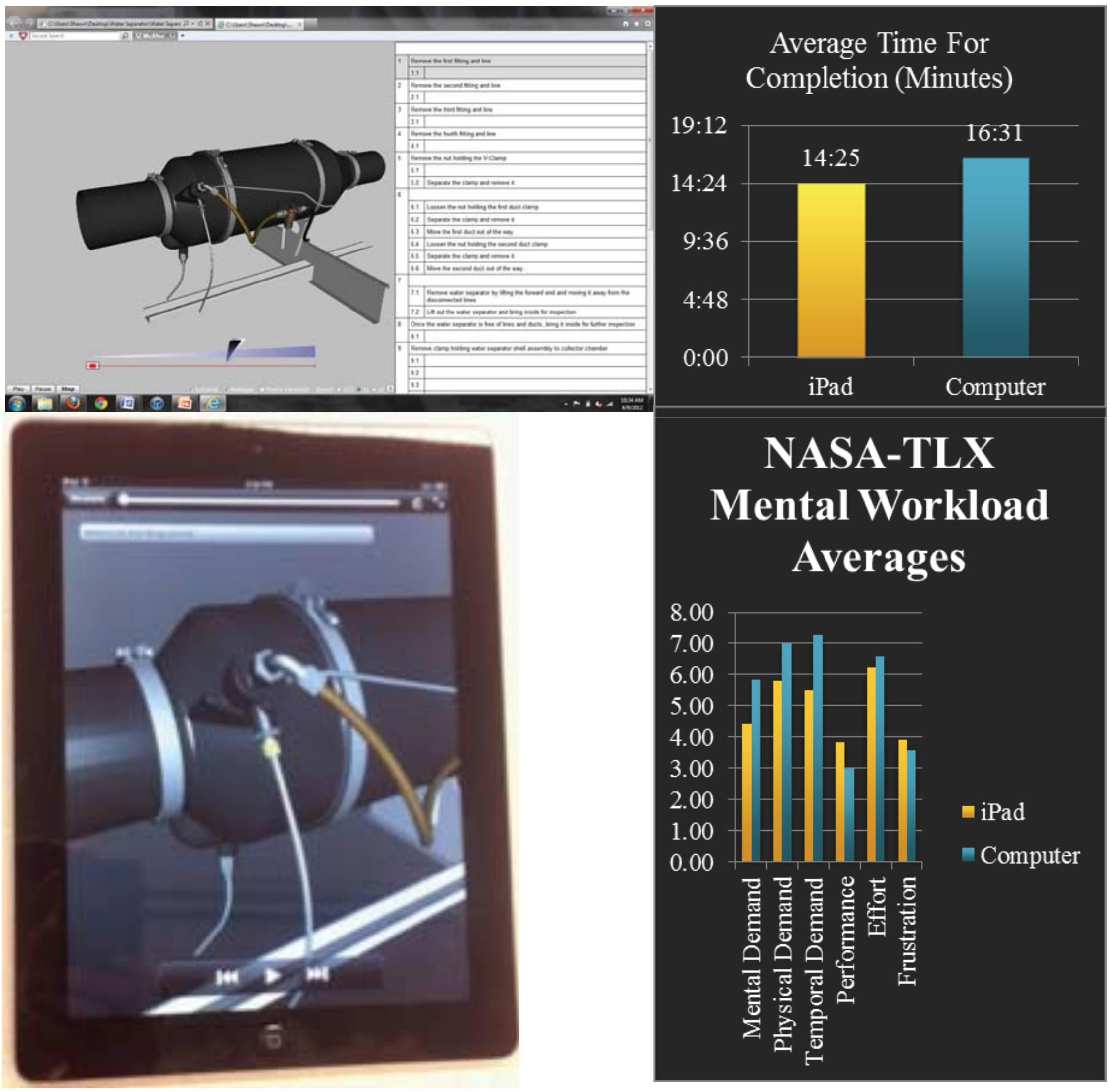


Figure 2.7 Comparing a 3D Task Card powered by Cortona 3D on a laptop vs. an iPad (Hartman & Ropp, 2012)

with enhanced 3D part models of the part for better understanding, a 3D simulation or video on a laptop computer, and finally a 3D simulated task card on a mobile device such as a tablet.

Purdue University seniors in the Computer Graphic Technology program there have been studying this specific question over the past seven years. For the static task cards verses a 3D simulation, a group in the fall semester of 2010 found that technicians who used a computer outfitted with NGRAIN (a task visualization software) were able to complete their task 25% faster than those using the technical manual alone (Hartman & Ropp, 2012). Therefore, attention turned to comparing 3D simulation on a laptop computer versus the same simulation on a tablet. That was the research question facing a team in 2012, which led to interesting results (See Figure 2.7).

The team found that the technicians performed faster and experienced less stress during the testing when using the iPad versus a laptop computer both running the task card on Cortona3D (a software similar to NGRAIN). This matches the experience of researchers investigating the handling of tablets as reading and annotative devices. The authors concluded, “The tablets showed strong performance for reading and annotation. Users liked the freedom to rearrange the tablets, pick them up, and move them around in a manner analogous to paper” (Brush, Meyers & Morris, 2007, p. 7). Unfortunately, this was not the only conclusion from the research.

As denoted in Figure 2.8, the iPad had a statistically significant 8 to 1 ratio of errors when compared against the computer based task card. Based on the results from the experiment, for the iPad to be a more successful tool, it is imperative that several

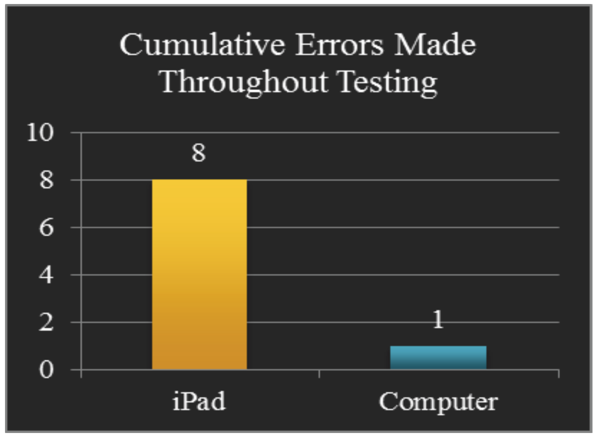


Figure 2.8 Comparing a 3D Task Card powered by Cortona 3D on a laptop vs. an iPad (Hartman & Ropp, 2012)

necessary improvements be made upon it. Although the iPad yielded more errors than the laptop version, enhancements, such as augmented reality implementation and training with the tool, to the product could help decrease these errors. The iPad was faster than the laptop, though not statistically significant; advancement in the application technology may produce significant progress. Yet, there may be hope for the future of 3D task cards on tablets.

The iPad is still a fairly new technology, and most people are not used to employing tablets as a tool, especially in a work environment. People are much more acquainted with the idea of using a laptop as something to facilitate work. Without expertise, the subjects might have seen the iPad more for entertainment as opposed to a tool. This may explain why so many errors were made. The NASA-TLX mental workload test hinted towards this in the decreased mental physical and temporal demand values. Although mental workload was not statistically significant, results and feedback showed iPad users seemed to have a more enjoyable experience overall, but became more frustrated when problems did arise. They seemed to think they did a better job than laptop users, but as the results depict, their judgment was inaccurate.

2.7 Augmented Reality

Augmented reality may be the missing piece in the continuum of 3D job task cards. Augmented reality (AR) is “a machine vision and computer graphics technology that merges real and virtual objects into unified, spatially integrated scenes” (Azuma, Baillot, Behringer, Feiner, Julier & MacIntyre, 2001, p. 2). Unlike virtual reality, which is a fully immersive virtual world, AR is a real-time blend of the real world with the virtual world (texts, computer generated objects, etc.) (Azuma, et al., 2001).

2.7.1 The History of Augmented Reality

The concept of AR has been around for a long time. The first attributed mention of AR was penned in 1901 by L. Frank Baum, an author whose ‘character marker’ was a set of electronic spectacles that overlaid data onto people, eerily reminiscent of the forthcoming Google Glass (Johnson, 2012). Explored at length by the science fiction community, AR slowly became a very viable reality.

In 1966 Ivan Sutherland, the so-called ‘Father of Computer Graphics’ invented the head-mounted display (HMD), as a practical window to the virtual world (Sutherland, 1969). Steve Mann built upon Sutherland’s HMD in 1980 to create the first wearable computer vision system, integrating text and graphics onto photographically mediated reality, calling it ‘Augmediated Reality’ (Mann, 2012). The term ‘Augmented Reality’ wasn't realized until 1990, when it was credited to Tom Caudell, a former researcher for Boeing (Lee, 2012). Finally, Louis Rosenberg demonstrated AR's benefits to human performance in 1992 at the Armstrong U.S. Air Force Research Laboratory while testing Virtual Fixtures, one of the first functioning AR systems (Rosenberg, 1992).

Since then, AR development has progressed, reaching mobile applications in the late 2000's. Unfortunately, early AR mobile applications failed to maximize potential, using scanned barcodes associated with stored hyperlinks and video to achieve simple tasks, as noted by researchers out of Purdue's Hangar of the Future Laboratory in 2013. They comment:

> Augmented Reality (AR) applications have had a slow start, emerging more recently as a novelty smartphone application in search of a problem. However, AR applications have progressed to a usability level where it can be leveraged into work environments more effectively, including technical maintenance processes. (Ropp, et al., 2013, p.3)

New mobile applications for smartphones and tablets such as Aurasma hold promise for application in the Maintenance Repair and Overhaul (MRO) industry. They utilize viewfinder input matched to a database of images that correlate with video and other media that project straight to the screen without the use of barcodes. This advancement may capably apply to the MRO industry if it can be captured as part tool, efficiently connecting aircraft technicians to instruction.

2.7.2 Augmented Reality in Aviation Maintenance

Computer-based training (CBT) is already a large part of the training process for novice ATMs. Regularly utilized as an instructional medium that gives novices an initial understanding of systems, extensive job task training with CBT is limited by the complexity and costs associated in development; it is therefore chiefly utilized for tutorials and role play scenarios (Alessi & Trollip, 2001). Perhaps the biggest drawback of CBT, however, is its environmental restrictions. Because CBT requires computer access and does not actually communicate with a real time work environment, it is regulated to a classroom setting. Novice AMTs need a tool for training that matches the dynamic interactivity and information power of CBT with the mobility and experience of OJT. That tool can be an AR system integrated with dynamic CAD accessibility.

Haritos and Macchiarella denote two ways AR training could reduce errors, thus increasing passenger safety and minimizing incidents and accidents:

> First, AR could allow for an efficient method of retrieving information. The information retrieved could be the equivalent to an expert's recall from long-term memory. Second, AR could compliment human information processing by facilitating a transition to expert levels of knowledge in a shorter span of time. (Haritos & Macchiarella, 2005, p.3)

Validating the first premise, AR systems have been shown to compliment information processing during maintenance by governing attention, improving recall in both short and long-term memory and aiding information integration (Majoros & Neumann, 2001). This isn't surprising, giving the ability of AR systems to overlay relevant graphics and text over the real world. Graphic overlay, indeed, is the chief benefit of AR, allowing the user to access any relevant information such as procedures and inspection criteria immediately from a concurrent source, eliminating the problem of search and find instructions.

That informative immediacy also paves the way for the second premise to be fulfilled. Frequent exposure to that information may create an ideal situation for the AMT to build his or her own long-term memory:

> AR could not only standardize training, but may also redefine OJT by generating rapid and accurate feedback to allow for self-instruction. An AR system could allow for a high level of workmanship and high work productivity at an early stage of a AMTs career. The system has the capability of allowing novice technicians to retrieve information equivalent to an expert in the field." (Haritos & Macchiarella, 2005, p. 4)

This benefit cannot be understated due to the high expectations set on novice AMTs to be productive in a very short timeframe. Pressure to be efficient has been found to increase stress and decrease job performance among novice technicians further diminishes their ability to learn in an ideal environment (Ormrod, 1999).

AR application has been studied in numerous industries with positive results. These include architectural construction (Webster, Feiner, MacIntyre & Massie, 1996), and surgical medicine where it was observed that the mixed reality setting provided by AR aided in subsequent skill application in the real world (Kalawsky, Stedmon, Hill & Cook, 2000). The only question that remains is how to incorporate AR into the AMTs workflow. AR can be utilized as optical see-through technology (HMD), or as a video-based system that displays a mixed reality world (Majoros & Neumann, 2001). HMDs can be cumbersome and complicated to set up (Figure 2.9); this study will focus on a video-based tablet system utilizing the Aurasma application (Figure 2.10) to access CAD part data.

Figure 2.9 Example of a Mobile Augmented Reality System with Head Mounted Display at ERAU. Haritos & Macchiarella (2005a).

Figure 2.10 Example of a Mobile Augmented Reality System Using Aurasma Video-Based Overlay. Augmented Planet.com (2012). *http://www.augmentedplanet.com/wp-*

2.8 Conclusion

In conclusion, the aviation maintenance industry is a billion dollar business, and much of that is due costs incurred from human error. By improving job task cards, decision, skill based and perceptual errors can be reduced. Job task card standards can better capitalize upon the spatial recognition abilities of technicians by embracing advancements in mobile, digitalized part visuals over their current engineering drawings, which push workers to use more of their experiential and tactile knowledge. Novice AMTs struggle with meeting the pressures of a complex industry and training that cannot efficiently bring them to the level of expertize necessary in the industry (Haritos & Macchiarella, 2005b). Dynamic 3D models are simply more robust and easier to interpret than their static counterparts. Furthermore, training with 3D models can lead to improved spatial recognition skills that have the potential to allow mechanics the ability to complete their tasks efficiently and effectively the first time through. With this knowledge, task cards have an imperative to adapt to a 3D friendly medium such as a portable laptop computer or tablet. At the moment, tablets seem to be considered more toy than tool so training would be required to implement a work-like mentality to tablet use (Levinson, 2013).

Augmented reality might be the solution that bridges the gap between novelty to high functioning tool. Long on the minds of science fiction authors, AR has come to fulfillment in many outlets; most notably mobile applications. Smartphones and tablets may now harness the power of AR, opening the door to a variety of promising work purposes especially in this field of MRO. If properly trained on a tablet equipped with an

AR application for easy visual information consumption, novice technicians could experience an immediate increase in productivity and competence in their tasks comparable to that of experts (Haritos & Macchiarella, 2005b). This process would yield fewer errors, and ultimately a dramatic drop in the billions lost each year – not to mention the improved safety of the aviation industry. Compound this with the mobility of tablets and geographic features infused within its system that could open a 3D job task card by simply pointing the tablet at the part in question and then communicate real time back to the hangar the status of repair being done and the benefits are limitless.

Figure 2.11 Advertisement for Google Glass. Google (2013).
http://www.google.com/glass/start/what-it-does/

Looking forward beyond tablets, a new technology presents an idyllic solution to this problem. That solution is the technology associated with Google Glass (see Figure 2.11). Google Glass is a hands free, voice controlled, Internet capable augmented reality headpiece that gives its user real time information straight to their eyes (Google, 2013).

Though this technology is not yet released to the public, it will be soon and one can imagine applications created within the following years. Imagine a technician being directed directly to the part in question, opening up the 3D simulated job task card just by looking at the part, and then being able to view is repair step by step with highlighted augmented reality.

3 METHODOLOGY

3.1 Research Type

To obtain quantitative results of the effectiveness of the tool as well as the qualitative input about the tool from the novice participants randomly assigned to the experimental group, this study used mixed methods.

3.2 Research Question

Can an augmented reality delivered 3D work instruction replicate on the job training, elevating novice aviation maintenance technicians to perform at an expert level within the constraints of efficiency and human error?

3.3 Hypothesis

$H_0 : \mu_{Control} = \mu_{Experimental} = \mu_{Expert}$.

H_a : At least one mean is not statistically equal.

These hypotheses were applied to each dependent variable before the analysis of variance (ANOVA) test. The ANOVA test was is used to determine significant difference between the means of three or more independent groups (Laerd Statistics, 2014). Because this test compared three groups, it was a natural choice to determine if the means were significantly different. However, the ANOVA test is limited as it can only determine if significant difference exists, not which specific group(s) differ significantly with the other groups (Laerd Statistics, 2014). To establish which specific groups differed from each other a post hoc Scheffe's test was used. Scheffe's test is a flexible, conservative and robust post hoc test that can evaluate differences between groups of unequal sample sizes (Anderson, 2003). Because the sample sizes of the groups in this study differed, running the Scheffe's test was imperative to return significant results.

3.4 Variables

The variables for the study are outlined in table 3.1:

Table 3.1 Table Displaying the Study Variables and Their Categories

INDEPENDENT VARIABLES
Control Group
Experimental Group
Expert Group

DEPENDENT VARIABLES		
EFFICIENCY	EFFECTIVENESS	UNDERSTANDING
Time (seconds)	Errors Incurred	Visualization Questions
Checks to Instruction		Perceived Difficulty of Task
		Perceived Difficulty of Instruction

The independent variables in this study were the control group using a paper-based work instruction, the experimental group using the augmented reality delivered 3D instruction, and the expert group using the paper-based work instruction. The dependent variables generated by the groups were their efficiency, depicted by time on task and checks back to instruction; effectiveness, depicted by errors incurred; visual perception ability and understanding, depicted by the amount of visualization questions asked; and perceived difficulty of the technicians, depicted by responses to the posttest surveys. Possible confounding variables include: training with the application, time spent with the application, and bias towards or against current method. These confounding variables were presented for feedback from the participants for qualitative responses.

3.5 Sampling

Sampling for this experiment came from the AET students at Purdue University as well as the expert aviation maintenance technicians who work at the Purdue airport. There were 12 junior and senior level AET students at Purdue University during the semester this test occurred. All of those students participated in the testing. Three AMTs responded to the email requesting participation and participated in the study.

3.6 Population

The populations targeted by this experiment were novice aviation maintenance technicians with college experience and expert technicians.

3.7 Framework

In order to determine how much improvement the application affords novices, a control group using the paper-based instruction was implemented. The sample of 12 students (novices) was randomly divided into two samples of 6 – the control group and an experimental group using the AR application. In order to set the standard at which professional AMTs work that the experimental group could be compared to, the expert group used the paper-based instruction. The framework is diagramed in figure 3.1.

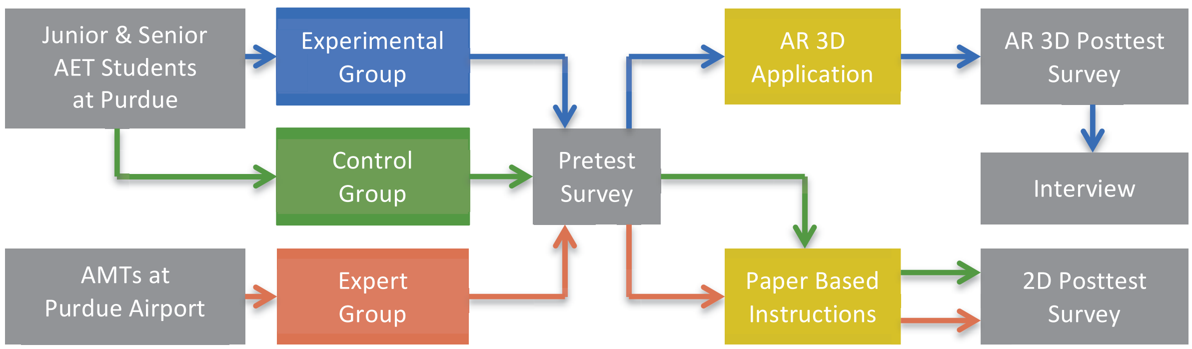


Figure 3.1 Flowchart Diagram of the Study

This framework was further validated by a follow up interview to triangulate experimental data that could not be measured by quantitative measurement based on their personal feelings on the application.

3.8 Units of Measurement

The units of measurement for this study were average time on task (measured in seconds), average number of errors, average number of checks back to instruction (tallied each time a participant looks back at the instruction, multiple steps can be reviewed in one 'check'), average visualization questions asked, and average score from the responses to the posttest survey asking participants their perceived difficulty of task and instruction (measured on a scale from 1 to 5)

3.9 Threats

The biggest threat facing this study was gaining enough subjects for testing, especially concerning the experts, as their schedules were very busy. Fortunately ANOVA is robust enough to handle small sample sizes. Sigma XL calculated a minimum sample size for robustness test for ANOVA using Skewness and Kurtosis. The results of their test are shown in figure 3.2:

Minimum Sample Size for Robust Hypothesis Testing		
Sample Data (user inputs):		
Hypothesis Test:		3 Sample One Way ANOVA
Alternative Hypothesis :	Ha	Not Equal To
Confidence Level:	100*(1-α)%	95%
Skewness:	Skew	1
Kurtosis:	Kurt	-0.48
Results:		
Minimum sample size for each sample/group:	n	3

Figure 3.2 Minimum Sample Size for Robust Hypothesis Testing. Sigma XL (n.d.). Retrieved from: http://www.sigmaxl.com/MinSampleSizeRobust.shtml

They found that the minimum sample size for ANOVA robustness is 3 (SigmaXL, n.d.). The sample sizes for the control and experimental groups in this study were 6. The expert group came in right at 3. ANOVA testing with small sample sizes is subject to weakened statistical power, however they are still significant (PROPHET StatGuide, n.d.).

It was also pertinent to simulate real world experience as much as possible, so it was be useful for the experimental group to have enough training to feel comfortable with the application. This limited confounding variables that could have led to misappropriated mistakes using the tool.

4 RESULTS

This chapter details the data results of the pre and post surveys as well as the test as observed by the researcher. Descriptive statistical analysis will be presented alongside impartial, fact driven summary of the procedures in question. For simplicity, the three testing groups will each be assigned titles to be used for the remainder of this discussion. Students randomly selected to be used in the study using a 2D paper based job task card will be known as the 'control' group, students assigned to use the augmented reality delivered 3D task card will be known as the 'experimental' group, and the AMT participants from Hangar 6 will be known as the 'expert' group.

4.1 Demographics

Altogether, fifteen participants performed the test. The control and experimental groups each consisted of six participants and the expert group accounted for three participants. Demographic data were gathered from the pretest survey.

4.1.1 Major and Experience

All twelve student participants in the control and experimental groups were AET majors at Purdue University with roughly 2-3 semesters of experience. Specifically, the control group averaged 2.17 semesters of class experience and 1.42 years of job experience via internships and summer jobs. The experimental group had similar, though slightly less, experience, averaging 2 semesters of class experience and 1.33 years of work experience. The expert group averaged 14.67 years of work experience with a max experience of 19 years. Only one student had FAA certification (a member of the experimental group), all three experts had their FAA certification and classified themselves as AMTs.

4.1.2 3D Interpretation Experience

Participants were also polled for previous experience with 3D instruction. Only one participant had previous experience and they belonged to the experimental group. Two had previous exposure to augmented reality applications, both Aurasma, one in each student group. All students had previous experience with CAD modeling and interpreting via CATIA; four students had also used Inventor, two Solidworks, two Pro E, one AutoCAD. Only one expert participant had used CAD software, they had experience with CATIA and Solidworks.

4.2 Results

The following charts, graphs and tables break down the quantifiable data gained from the trials. Each variable has also been given a description expressing why and how they were collected.

Table 4.1 Mean Results For Time (s), Errors, Checks, and Visualization Questions.

AVERAGE	TIME (s)	ERRORS	CHECKS	VIS Qs
Control	1133.68	3.50	13.33	1.50
Experimental	819.47	0.33	5.83	0.00
Expert	842.17	0.00	7.33	0.00

Table 4.2 Total Results For Time (s), Errors, Checks, and Visualization Questions

TRIALS	TIME (s)	ERRORS	CHECKS	VIS Qs
Control 1	1278.1	3	14	2
Control 2	822.7	4	16	1
Control 3	658.2	3	11	1
Control 4	1402.5	2	12	0
Control 5	1293.3	4	14	0
Control 6	1347.3	5	13	5
Experimental 1	760.7	0	5	0
Experimental 2	840.6	0	5	0
Experimental 3	507.8	2	7	0
Experimental 4	839.7	0	7	0
Experimental 5	926.4	0	6	0
Experimental 6	1041.6	0	5	0
Expert 1	1136	0	6	0
Expert 2	544.5	0	6	0
Expert 3	846	0	10	0

4.2.1 Time

Time was the key efficiency variable recorded for each trial. Times recorded for this test demand a degree of tolerance, as the trials were observational. Time began for each trial when all tools were accounted for, the participant was situated in the workstation, and the participant gave the verbal cue “Ready”. To reduce external variables during the test when the participant transitioned to the hangar, time was stopped after the participant had reached the step calling for transport of the water separator and was resumed when the participant was situated in the hanger and had given the verbal cue.

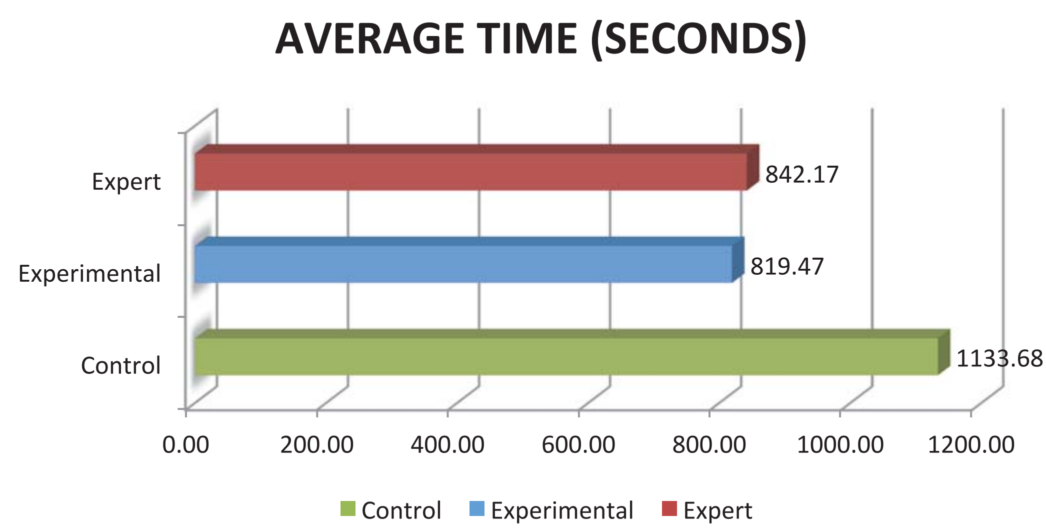


Figure 4.1 Bar Graph of Average Time on Task (Seconds)

Even though measures were made to reduce external variables from confounding time results, some of these must be discussed. The time expressed in these results indicates stop/start times given by each participant and accounts for the pace at which they chose to work. Unforeseen circumstances that might affect results include the state of the part as it began to see more and more work. Some nuts and bolts may have become more lubricated/easier to remove while others may have become more stubborn as they saw a heightened peak in use. These conditions could not have been adverted with the circumstances imposed.

The control group recorded the longest times with a high of 1402.5 seconds (23:22 minutes) and a low of 658.2 seconds (10:58 minutes), averaging 1133.68 seconds

(18:53 minutes). The experimental group averaged 819.47 seconds (13:39 minutes), recording a maximum of 1041.6 seconds (17:21 minutes) and a minimum of 507.8 seconds (8:27 minutes). The results of the expert group encountered trouble as the first expert recorded a time that may not be fully reflective of their ability. They chose to complete the task with the tools inherited from the previous student participant and commented several times that an expert would not use the tools they inherited. The first expert's time was much longer than those of the other two experts and should be considered. The expert group averaged 842.17 seconds (14:02 minutes) with the first participant included and averaged 695.30 seconds (11:35 minutes) without the first participant.

To compute the analysis of variance (ANOVA) test the times had to be converted to seconds. The following assumptions were made in order to use the ANOVA test: (i) all populations involved follow a normal distribution, (ii) all populations have the same variance (or standard deviation), and (iii) the samples were randomly selected and independent of one another. The null hypothesis and alternative hypothesis for the ANOVA measuring time were as follows:

$H_0 : \mu_{\text{Control Time}} = \mu_{\text{Experimental Time}} = \mu_{\text{Expert Time.}}$

H_a : At least one mean time is not statistically equal.

The results for the one-way ANOVA test are displayed in Table 4.3.

Table 4.3 ANOVA for Time (Seconds)

Analysis of Variance (One-Way) for Time (Seconds)

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*
CONTROL	6	6,802.1	1133.68	97404.63
EXPERIMENTAL	6	4,916.8	819.47	32444.72
EXPERT	3	2,526.5	842.17	87479.08

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	339553.78	2	169776.89	2.47186	0.12619	5.5163
Within Groups	824204.93	12	68683.74			
Total	1163758.71	14				

The test statistic from the ANOVA table (F) was 2.47186 and the critical value (F crit) was 5.5163. Because the observed value (F) was lower than the critical value (F crit) the test failed to reject the null hypothesis. The results are statistically similar. The p value for the test was 0.12619, which is also greater than the 95% confidence level.

4.2.2 Errors

In order In order to obtain quantifiable data for effectiveness, errors were assigned to the participants when they skipped a step, performed a step out of turn, performed any action outside of the instruction, or refused to perform a task.

The most common error among participants was confusing a hose for a line on the first step, “Remove all fittings and lines.” The key reason for this is the obvious ambiguity of the task prompt. Though the images for the section were clear, participants in the control group failed to attend to the images or were simply confused

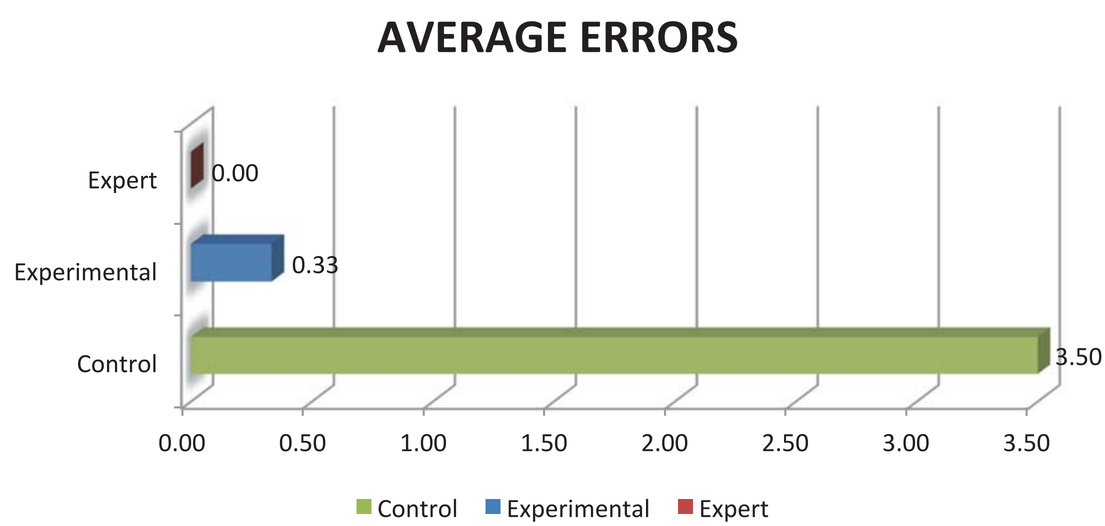


Figure 4.2 Bar Graph of Average Errors

by the visual cues. The experts either recognized the images or used their knowledge of what a fitting and line was. No experimental participant had an error on this section. Only one experimental participant recorded an error (2) and those errors were attributed to completing tasks out of turn. The maximum error count for the control group was 5 and the minimum was 2.

The same assumptions were made in order to use the ANOVA analysis. The null hypothesis and alternative hypothesis for the ANOVA measuring errors were as follows:

$H_0 : \mu_{\text{Control Errors}} = \mu_{\text{Experimental Errors}} = \mu_{\text{Expert Errors.}}$

H_a : At least one mean error count is not statistically equal.

The results for the one way ANOVA test are displayed in the following figure:

Table 4.4 ANOVA for Errors

Analysis of Variance (One-Way) for Errors

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*
CONTROL	6	21.	3.5	1.1
EXPERIMENTAL	6	2.	0.33333	0.66667
EXPERT	3	0.E+0	0.E+0	0.E+0

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	38.9	2	19.45	26.42264	0.00004	5.5163
Within Groups	8.83333	12	0.73611			
Total	47.73333	14				

The test statistic from the ANOVA table (F) was 26.42264 and the critical value (F crit) was 5.5163. Because the observed value (F) was higher than the critical value (F crit) the test rejected the null hypothesis. At least one of the mean errors is significantly different. The p-level for the test was 0.00004, which is also significantly lower than the 95% confidence level.

Because the null hypothesis was rejected, a Scheffe's test was conducted to compare error results. This test was run in SPSS and the results are displayed on the next page:

Table 4.5 Scheffe's Test for Errors

Multiple Comparisons

Dependent Variable: Errors
Scheffe

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Control	Experimental	3.16667*	.49535	.000	1.7858	4.5475
	Expert	3.50000*	.60668	.000	1.8088	5.1912
Experimental	Control	-3.16667*	.49535	.000	-4.5475	-1.7858
	Expert	.33333	.60668	.862	-1.3578	2.0245
Expert	Control	-3.50000*	.60668	.000	-5.1912	-1.8088
	Experimental	-.33333	.60668	.862	-2.0245	1.3578

*. The mean difference is significant at the 0.05 level.

Homogeneous Subsets

Errors

Scheffe[a,b]

Group	N	Subset for alpha = 0.05: 1	2
Expert	3	.0000	
Experimental	6	.3333	
Control	6		3.5000
Sig.		.846	1.000

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 4.500.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

The post hoc Scheffe's test analyzes each coupling of the data to determine statistical difference in the components (Anderson, 2003). Though none of the variables were considered statically equal to any other group, the control group was proven to be statistically different from the experimental and expert groups (.000).

4.2.3 Checks

Checks were tallied for each participant every time they referenced the instruction. Checks were not added for referencing multiple steps at once, but rather each uninterrupted check back to the instruction. The purpose of recording these checks is to evaluate the additional time/effort given to parsing ambiguous instruction, thus providing quantifiable data assessing each instruction method's ability to transfer visual cues to the technician. The more checks back to the instruction, the harder the instruction was to understand. Notably, the paper-based instruction consisted of 10 task prompts while the videos created for the augmented reality delivered instruction condensed these into 6 steps.

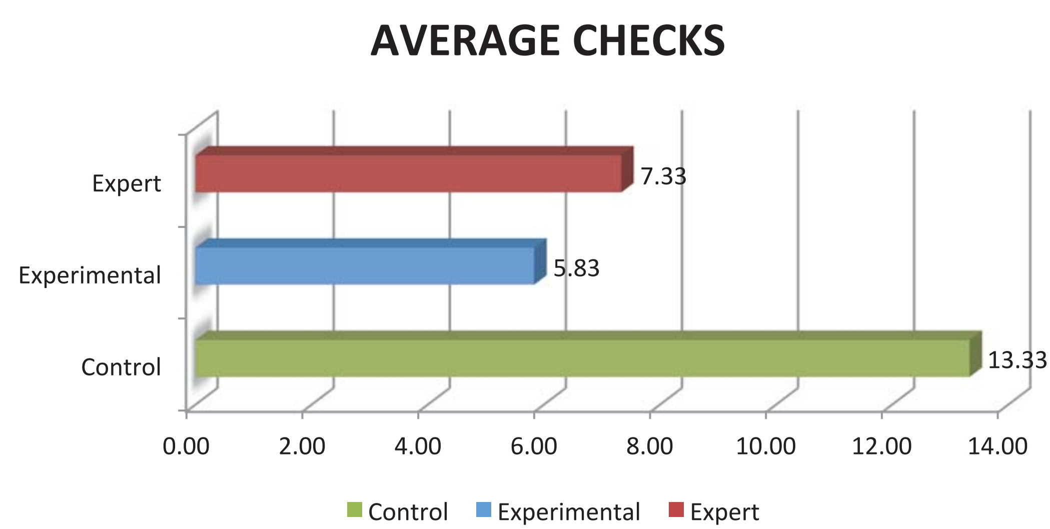


Figure 4.3 Bar Graph for Checks

With 10 steps to check the control group averaged 13.33 checks, indicating the students struggled to understand some of the steps upon first review. The highest check total for the control group was 16 and the low was 11. With the same instruction, experts managed to comprehend all steps with an average of 7.33 checks back to the instruction. The high for the expert group was 10 and the low was 6. This lower count suggests that the experts not only managed to understand the instruction, but also managed to foresee multiple steps at once. This can be accounted for by their years of experience and the efficiency that allows them. It should be noted here that none of the participants had previous experience with this task, so the material was equally fresh to all.

Experimental group participants only had six steps to attend to, averaging 5.83 checks per trial. Many of the experimental group participants viewed several steps at the within the same check, two of them double-checked their work. The high check count for the experimental group was 7 and the low was 5 checks.

As with the previous variable tests, the same assumptions were made in order to use the ANOVA analysis. The null hypothesis and alternative hypothesis for the ANOVA measuring errors were as follows:

H_0 : $\mu_{\text{Control Checks}} = \mu_{\text{Experimental Checks}} = \mu_{\text{Expert Checks.}}$

H_a : At least one mean instructional check count is not statistically equal.

The results for the one way ANOVA test are displayed in the following table:

Table 4.6 ANOVA for Instructional Checks

Analysis of Variance (One-Way) of Instructional Checks

Summary

Groups	Sample size	Sum	Mean	Variance
CONTROL	6	80.	13.33333	3.06667
EXPERIMENTAL	6	35.	5.83333	0.96667
EXPERT	3	22.	7.33333	5.33333

ANOVA

Source of Variation	SS	df	MS	F	p-level	F crit
Between Groups	180.9	2	90.45	35.20216	0.00001	5.5163
Within Groups	30.83333	12	2.56944			
Total	211.73333	14				

Based on the results from the ANOVA the null hypothesis can be rejected, at least one mean instructional check count is not statistically equal to the means of the other groups. The p-level of significance is far below the alpha of .05 and the F value is significantly higher than its corresponding F critical level. To further analyze the data, another post hoc Scheffe's test was run.

Table 4.7 Scheffe's test for Checks

Multiple Comparisons

Dependent Variable: Checks

Scheffe

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Control	Experimental	7.50000*	.92546	.000	4.9202	10.0798
	Expert	6.00000*	1.13346	.001	2.8404	9.1596
Experimental	Control	-7.50000*	.92546	.000	-10.0798	-4.9202
	Expert	-1.50000	1.13346	.442	-4.6596	1.6596
Expert	Control	-6.00000*	1.13346	.001	-9.1596	-2.8404
	Experimental	1.50000	1.13346	.442	-1.6596	4.6596

*. The mean difference is significant at the 0.05 level.

Homogeneous Subsets

Checks

Scheffe[a,b]

Group	N	Subset for alpha = 0.05	
		1	2
Experimental	6	5.8333	
Expert	3	7.3333	
Control	6		13.3333
Sig.		.402	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 4.500.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Based on Scheffe's test, the control group statistically checked the instructions more than both the experimental and expert groups, posting significance values of .000 and .001, respectfully. The experimental and expert groups are not statistically different or statistically equal, but fall within the same subset.

4.2.4 Visualization Questions

In addition to the checks tallied for each participant, visualization questions asked by the participants struggling to understand which part of the water separator they needed to work on were also tallied. This indicated a larger visualization breakdown between the participant and the instruction.

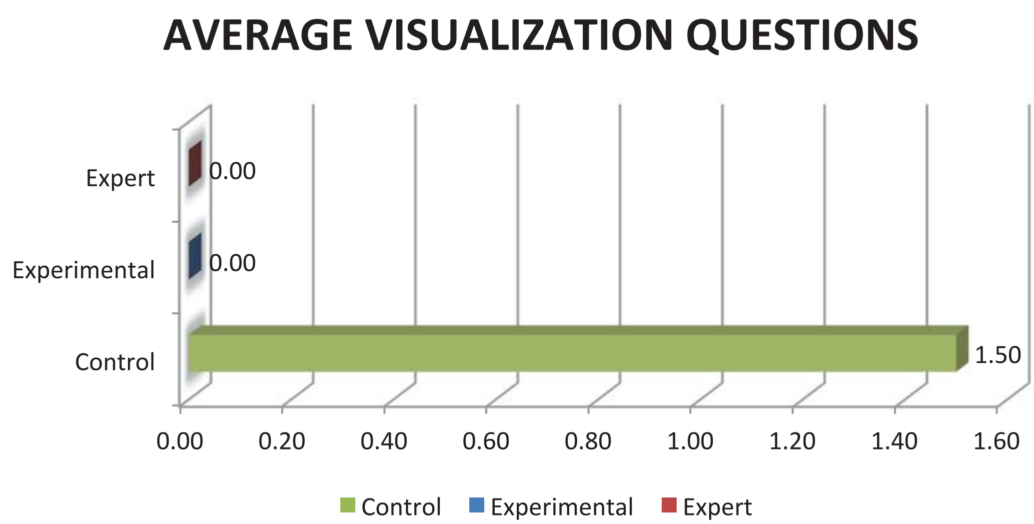


Figure 4.4 Bar Graph for Average Visualization Questions

The control group was the only group to ask questions pertaining to the visualization of the task. The maximum question count totaled 5, while two participants in the control group did not need any help with the visualization of the task. It is assumed that without these answers the participants would have recorded higher times and possibly committed more errors. As the control group recorded higher numbers on every measurable scale it is not assumed that answering these questions confounded any results.

The same assumptions of variance equality were made in order to use the ANOVA analysis for visualization questions. The null hypothesis and alternative hypothesis for the ANOVA measuring errors were as follows:

$H_0 : \mu_{Control\ VisQ} = \mu_{Experimental\ VisQ} = \mu_{Expert\ Vis\ Q.}$

H_a : At least one mean visualization question tally is not statistically equal.

The results for the one way ANOVA test are displayed in the following table:

Table 4.8 ANOVA for Visualization Questions

Analysis of Variance (One-Way) for Visualization Questions

Summary

Groups	Sample size	Sum	Mean	Variance
CONTROL	6	9.	1.5	3.5
EXPERIMENTAL	6	0.E+0	0.E+0	0.E+0
EXPERT	3	0.E+0	0.E+0	0.E+0

ANOVA

Source of Variation	SS	df	MS	F	p-level	F crit
Between Groups	8.1	2	4.05	2.77714	0.10204	5.5163
Within Groups	17.5	12	1.45833			
Total	25.6	14				

The one-way ANOVA for visualization questions has a p-level of 0.10204, which is above the desired range for statistical significance. Therefore, the results for visualization questions are not statistically significant.

4.2.5 Perceived Difficulty of Instruction

Table 4.9 Table of Results for Perceived Difficulty

TRIALS	DIFFICUTLY (TASK)	DIFFICULTY (INSTRUCTION)
Control 1	3	3
Control 2	2	3
Control 3	2	2
Control 4	3	4
Control 5	3	4
Control 6	3	4
Augmented 1	2	1
Augmented 2	2	2
Augmented 3	1	2
Augmented 4	1	1
Augmented 5	2	1
Augmented 6	2	1
Expert 1	2	3
Expert 2	2	2
Expert 3	2	3

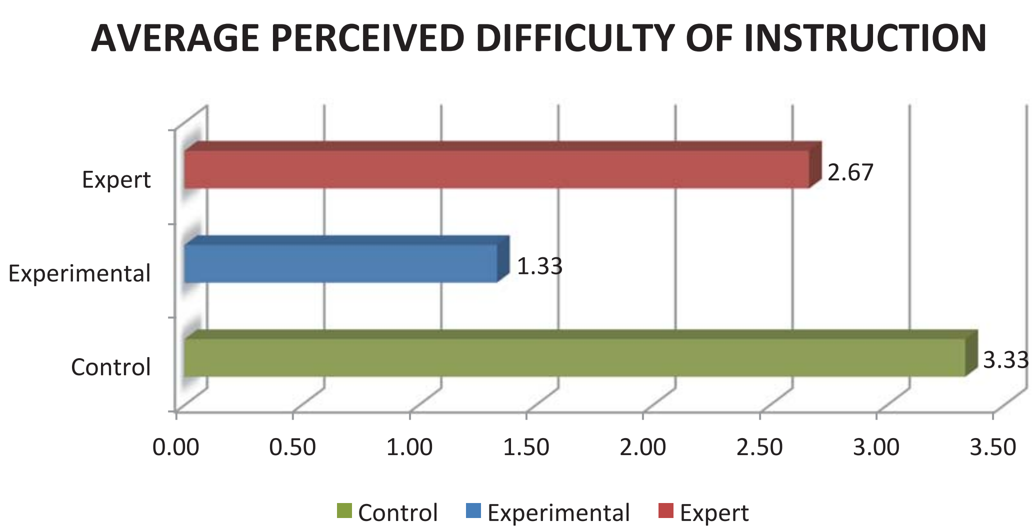


Figure 4.5 Bar Graph of Average Perceived Difficulty of Instruction

In the posttest survey, the participants were asked to denote a level of difficulty to the understandability of whichever instruction they were assigned to use. In order to obtain quantitative results a Likert Scale was used. Likert Scales allow for degrees of opinion and allow for data to be easily analyzed, however they also run the risk of being compromised due to social desirability (McLeod, 2008). To reduce social pressures, anonymity was given to the participants. Answers were also given on a scale from 1-7.

Experimental participants found the instruction to be the easiest to understand, averaging 1.33 out of 7. The maximum difficulty perceived was 2 out of 7 by two participants and the minimum of the group was 1 out of 7 matched by the remaining subjects in the experimental group. The expert group rendered the second lowest margin at 2.67 out of 7 with two participants citing a 3 out of 7 and one noting a 2 of 7-difficulty rating. The control group found their instruction to be the most difficult, averaging 3.33 of 7 with maximums of 4 echoed by three participants and one score of 2 out of 7.

All previous assumptions were made in order to utilize the one-way ANOVA for perceived difficulty of instruction. The null and alternative hypotheses are:

$\mu_{\text{Control Diff\_Inst}} = \mu_{\text{Experimental Diff\_Inst}} = \mu_{\text{Expert Diff\_Inst.}}$

H_a : At least one mean perceived difficulty is not statistically equal.

The results for the one way ANOVA test are displayed in the following table:

Table 4.10 ANOVA for Perceived Difficulty of Instruction

Analysis of Variance (One-Way) for Perceived Difficulty of Instruction

Summary

Groups	Sample size	Sum	Mean	Variance
CONTROL	6	20.	3.33333	0.66667
EXPERIMENTAL	6	8.	1.33333	0.26667
EXPERT	3	8.	2.66667	0.33333

ANOVA

Source of Variation	SS	df	MS	F	p-level	F crit
Between Groups	12.26667	2	6.13333	13.8	0.00077	5.5163
Within Groups	5.33333	12	0.44444			
Total	17.6	14				

With an F value considerably higher than the critical value and a p-level far below the desired alpha range, these results are significant and the null hypothesis refuted. At least one mean perceived difficulty of instruction is significantly different than the other groups. Further analysis is provided by Scheffe's test.

Table 4.11 Scheffe's Test for Difficulty of Instruction

Multiple Comparisons

Dependent Variable: DiffInst

Scheffe

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Control	Experimental	2.00000*	.38490	.001	.9271	3.0729
	Expert	.66667	.47140	.397	-.6474	1.9807
Experimental	Control	-2.00000*	.38490	.001	-3.0729	-.9271
	Expert	-1.33333*	.47140	.047	-2.6474	-.0193
Expert	Control	-.66667	.47140	.397	-1.9807	.6474
	Experimental	1.33333*	.47140	.047	.0193	2.6474

*. The mean difference is significant at the 0.05 level.

Homogeneous Subsets

DiffInst

Scheffe[a,b]

Group	N	Subset for alpha = 0.05: 1	2
Experimental	6	1.3333	
Expert	3		2.6667
Control	6		3.3333
Sig.		1.000	.357

Means for groups in homogeneous subsets are displayed.

Scheffe's test significantly validates a statistical difference between the experimental group and the control (.001) and expert (.047) groups. Therefore, experimental participants found the instructions to be significantly easier to understand than the other participants in the study. The control and expert groups are within the same subset but not statistically equal or unequal.

4.2.6 Perceived Difficulty of Task

Like the question relating to perceived difficulty of the instruction, participants were asked, “How difficult did you find the maintenance task to be?” Answers were to be given on a scale from 1-7.

Interestingly, the experimental group not only found the instruction to be easier to understand on average than the paper based solution used by the control and experimental groups, they also perceived the task itself to be easier to perform on average. Their aggrigate score was 1.67 out of 7 with two participants indicating that it was a 1/5 and the rest scoring a 2/7. All three experts perceived the task to be a 2 out of 7 in difficulty. The control group averaged 2.67 out of 7 with four participants scoring the task as a 3/7 and two participants denoting a 2/7 in difficulty.

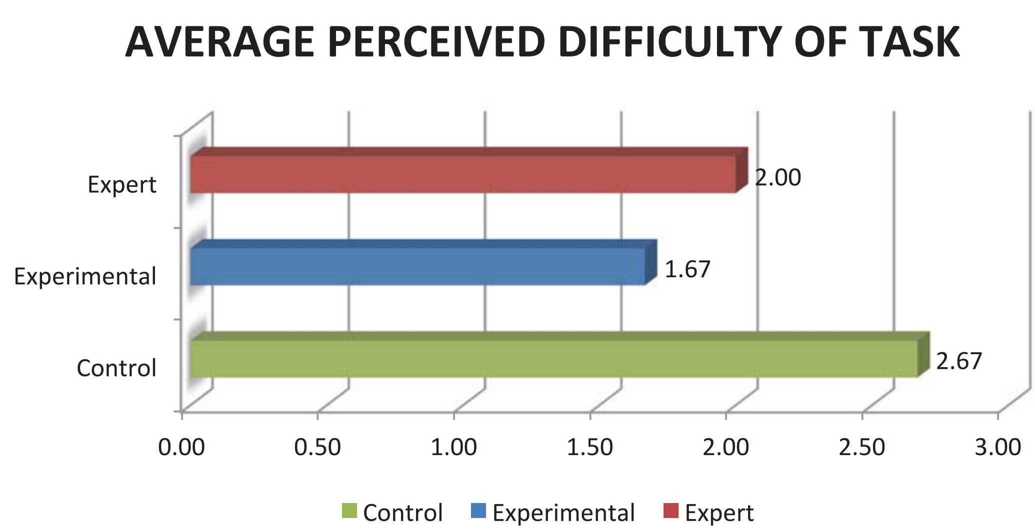


Figure 4.6 Bar Graph for Average Perceived Difficulty of Task

To utilize the one-way ANOVA for perceived difficulty of instruction, all previous assumptions were made. The null and alternative hypotheses are:

$H_0 : \mu_{Control\ Diff\_Task} = \mu_{Experimental\ Diff\_Tasl} = \mu_{Expert\ Diff\_Task}$.

H_a : At least one mean perceived difficulty is not statistically equal.

The results for the one way ANOVA test are displayed in the following table:

Table 4.12 ANOVA for Perceived Difficulty of Task

Analysis of Variance (One-Way) for Perceived Difficulty of Task

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*
CONTROL	6	16.	2.66667	0.26667
EXPERIMENTAL	6	10.	1.66667	0.26667
EXPERT	3	6.	2.	0.E+0

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	3.06667	2	1.53333	6.9	0.01012	5.5163
Within Groups	2.66667	12	0.22222			
Total	5.73333	14				

Based on the information given by the table, at least one group perceived the instruction to be easier or harder than the other two groups, rejecting the null hypothesis. The p-level was 0.01012, lower than the given alpha of 0.05 and the F value was higher than the critical value. Scheffe's test was run to determine which group differed.

Table 4.13 Scheffe's Test for Perceived Difficulty of Task

Multiple Comparisons

Dependent Variable: DiffTask

Scheffe

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Control	Experimental	1.00000*	.27217	.011	.2413	1.7587
	Expert	.66667	.33333	.178	-.2625	1.5959
Experimental	Control	-1.00000*	.27217	.011	-1.7587	-.2413
	Expert	-.33333	.33333	.619	-1.2625	.5959
Expert	Control	-.66667	.33333	.178	-1.5959	.2625
	Experimental	.33333	.33333	.619	-.5959	1.2625

*. The mean difference is significant at the 0.05 level.

Homogeneous Subsets

DiffTask

Scheffe[a,b]

Group	N	Subset for alpha = 0.05: 1	2
Experimental	6	1.6667	
Expert	3	2.0000	2.0000
Control	6		2.6667
Sig.		.584	.148

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 4.500.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Interestingly, Scheffe's test validated that only two groups significantly differed from each other. Based on the results of the test, on average the experimental group perceived the task to be easier than the control group. The results between the other couplings are inconclusive, though the expert group was closer to the experimental group (.584) than the control group (.148).

4.3 Problems

As a part of the posttest survey, each participant was prompted, “Did you have any problems completing the task? Explain.” The following is a summation of their responses broken down by test group.

4.3.1 Control Group Problems

Responses from the control group pertaining the problems encountered during the trial were split into three rough categories: problems with tools, problems with visualization and no problems encountered. The following pie chart visualizes this data.

Figure 4.7 Pie Chart for Control Group Problems

The lone participant who noted tools as a problem source was the first participant who decided at the beginning of the test to swap tools (time spent retrieving the new tools was not counted towards their time total). The three participants from the control group observing problems with visualization focused primarily on the pictures provided on the paper instruction being hard to understand. One participant noted that the pictures were too small while another stated, “I had to familiarize myself with the system before I could remove any of the lines or fittings. I also had some issues due to the lighting.” The test took place in the lower section of the hull and dim lighting played a role in every trial. Interestingly, one of the participants who cited they did not encounter any problems contrasted the participants who struggled with visualization claiming, “No (problems). Pictures were included in the job task card so I was able to follow easily.”

4.3.2 Experimental Group Problems

Problems listed by participants in the experimental group did not include visualization, but rather focused on the tools and the part with a vast majority (4/6) claiming that they did not encounter any problems. The participant citing trouble with the tools stated that they “weren’t the most adequate/efficient,” while the participant who had trouble with the part itself noted that, “putting the (o-) ring back on at the end was difficult.”

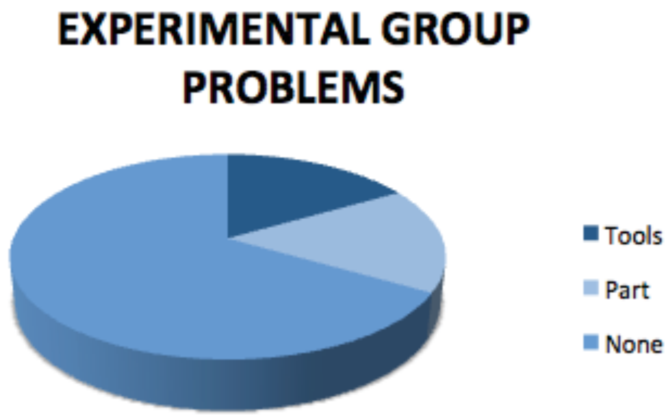


Figure 4.8 Pie Chart for Experimental Group Problems

4.3.3 Expert Group Problems

The experts were split on sources for problems. One did not encounter a problem, notably, this was the expert participant who recorded the lowest time. One expert ran into trouble with the part's level of airworthiness – stating, "SEP shifted during installation. Need to loosen clamp to align for drain lines." This is an example of how experts would normally report task problems and does not have direct influence on the test. Finally, the first expert to perform the trial reported that the tools given would not be used by an expert (this problem was discussed in section 4.2.1 relating to time on task.

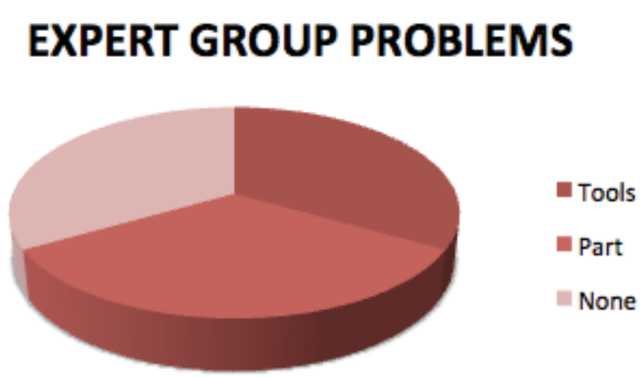


Figure 4.9 Pie Chart for Expert Group Problems

4.4 Augmented Reality Delivered 3D Instruction Posttest Interview Results

The following section analyzes responses to the posttest survey and interview given to participants in the experimental group surrounding their opinions of the augmented reality application and its place in the area of service learning. Sections are separated by question topic.

4.4.1 Mobility

In the posttest interview experimental participants were asked, “Did the application match the mobility the task required?” All six participants replied, ‘yes’ to this question.

4.4.2 Enough Information

In the posttest interview experimental participants were asked, “Do you believe the application delivered enough information to perform this task proficiently during your first time servicing it?” All but one participant stated that the application did provide enough information.

4.4.3 Augmented Reality Delivered 3D Instruction as a Method of Learning

In the posttest interview experimental participants were asked, “Did the application help you learn this service task?” Of the six participants who took the interview, four responded positively, one negatively, and one simply chose not to respond. The negative entry focused more on the simplicity of the task itself stating, “Not really, the job was pretty basic and nothing was new to me.” The positive responses highlighted the augmented reality and visualization features citing, “Yes, the AR makes the task easier to understand,” and “Yes, things that would be hard to convey using just the paper based instructions (were easier to understand).”

4.4.4 Augmented Reality Delivered 3D Instruction vs. Paper Based 2D Instruction

In the posttest survey experimental participants were asked to circle yes or no to the following question, “If you answered yes to question 2 (a question asking the participants if they had used a 2D paper format job task card to complete a maintenance task before this experiment), was the augmented reality incorporated job task card more effective at conveying maintenance task procedures than a paper based job task card?” All study participants had used a paper format to service a part prior to this test. Every experimental group participant responded ‘yes’ to this question. In a follow up question, participants were asked why they felt the way they did about the comparison. Every response was related to visualization benefits generated by the 3D visuals with two citing that they received added spatial awareness from the AR.

4.4.5 Augmented Reality Delivered 3D Instruction vs. On the Job Training

In the posttest interview experimental participants were asked, “On the job training is typically a large part of the learning process for novice aviation technicians, how well do you believe augmented reality delivered instructions could match or replace on the job training with an expert?”

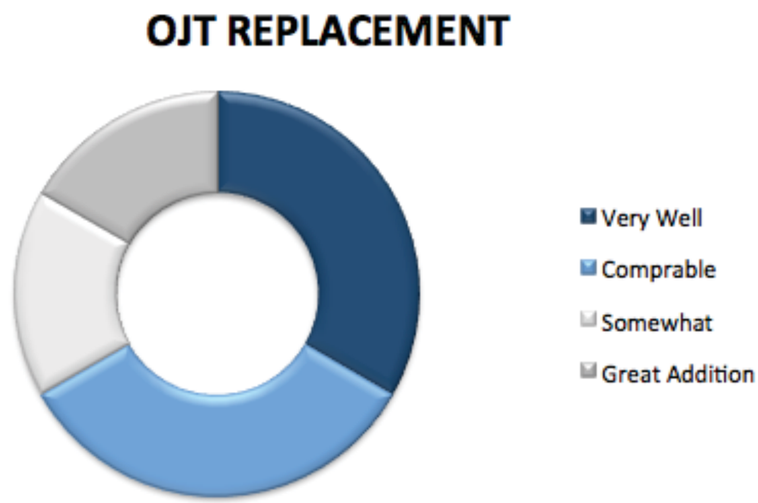


Figure 4.10 Donut Chart displaying opinions on if AR 3D Instructions could replace on the job training

Two of the six experimental participants stated that augmented reality delivered work instructions would replace OJT training “Very Well.” Two more said that the augmented reality work instructions were comparable. One of those probed the idea, “Is there a way to ask augmented reality a question? It could definitely replace training with an expert.” A separate experimental participant was in the ‘somewhat’ category, observing, “You miss out on the expert’s personal experience and tips.” The last participant suggested that the augmented reality application could be used alongside the expert, “They would be a great addition to an expert’s knowledge/training, especially for certain areas/tasks.”

4.4.6 Augmented Reality Delivered 3D vs. On the Job Training Preference

In the posttest interview experimental participants were asked, "Would you prefer using augmented reality delivered instructions to having on the job training with an expert?" Half of the experimental group responded that they would rather use the augmented reality delivered instructions with one adding, "(I) prefer less social and doing it myself." Two of the six experimental group participants indicated that they would like to use the AR application alongside an expert or in addition to an expert. One of the two asking for AR with an expert noted that they would like to have an expert their to answer questions while the other said, "Yes, I would like to see it alleviate the load on the expert or allow the student access to data beyond what the expert gives him/her." One last participant stated the choice was comparable.

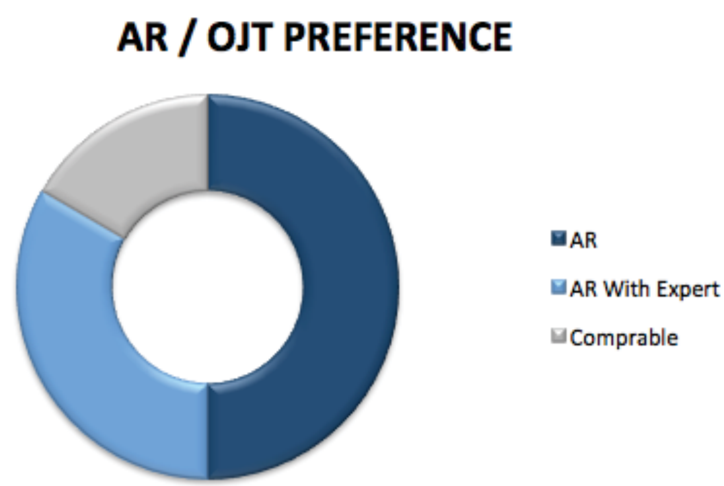


Figure 4.11 Donut Chart Showcasing Preferences on Augmented Reality vs. On the Job Training

4.4.7 Improving the Application

Finally, the experimental participants were asked, “How would you improve the application?” Responses varied. The most frequent point of concern was with the video playback feature used by Aurasma. Aurasma uses image triggers recognized through the mobile device’s viewfinder to identify which media to play. Once the media starts to play the user must keep the trigger in the viewfinder or the media will stop playing. Participants found this limiting; observing an area of improvement could be video control. “One issue is handling the device, couldn’t have the video play and work at the same time.” “Make it so you don't have to hold the tablet in one place the whole time to see the instructions. Even though the animation was short the tablet was in an awkward position at times.” In order to better instruct maintenance workers, a feature could be added to prompt the media and then continue to play even without connection to the trigger. “After scanning the card, be able to move away from it and still watch the video.”

Beyond video control the application could give added information to technicians. “A display of the tools needed for the task (would improve the application).” If the results of this test are any indication, adding the tool notification would have been helpful, as previously stated, 3 of the 15 participants noted not having the optimal tools to be a problem. Alongside a notification for tools, adding features that would better replicate the knowledge of an expert would further aid the augmented reality delivered 3D instruction’s ability to replace on the job training with an expert. “Should watch out for problem areas and give warnings." Helpful warnings could assist in reproducing an expert's experience with previous dealings with a certain task.

Finally, use the part itself as the trigger for instruction. "The only improvement I could suggest would be regarding the triggers, since they might be too large/unreliable in real world application." The research team worked to incorporate this feature, however Aurasma requires very specific triggers to prompt media to play in order to assure dependability. Capturing the part in different stages of repair was impractical, as the application could not process which trigger it was seeing. Ideally, the application would work at each stage of the maintenance, allowing the technician to move forward whenever they were lost. These improvements have the potential to propel this research forward and yield more significant results.

4.5 Chapter Summary

Chapter 4 broke down the results of the test and provided analysis of the data collected. Augmented reality delivered 3D work instruction was proven to elevate novice technicians to significantly reduce errors and checks back to instruction from their counterparts using paper-based instruction and put them in the same subset for experts using the paper-based instruction. Although not statistically significant, their time on task and visualization questions were brought much closer on average to experts while using the augmented reality delivered 3D work instruction than the paper based solution. Also, while using the AR delivered 3D work instruction novices perceived both the instruction and task to be easier to understand than experts and other novices using a paper based task card on a statistically significant level.

After using the AR 3D work instruction, all novices asked found their task to be preferable to using a paper-based task card, and half found they preferred it to on the job training while none preferred on the job training suggesting it was at least comparable and could be used alongside training with an expert. A third of novices asked after using an AR 3D application thought it could replace on the job training. Another third believed it was comparable, while the last two participants stated it was somewhat replaceable and could be a great addition to an expert's knowledge. Shortcomings for the test and future improvements for the application were also discussed. Giving all participants standard tools would have mitigated result ambiguity and decreased lurking variables. Furthermore, several advancements could be made to the application to better attend to user needs. Chapter 5 will use this analysis to look back on the thesis as a whole to summarize findings, draw conclusions, and suggest future work.

5 DISCUSSION

This chapter serves as a summation of the thesis as a whole, providing analysis, discussion and a conclusive statement. Sections will review key topics from chapter 2 with insight from the results of chapter 4. Implications of the findings will be examined within these sections, followed by a frank discussion of this study's limitations. Using the limitations, a section on future research will suggest recommendations. Finally, a conclusive statement will digest findings.

5.1 Preventing Human Error and Optimizing Efficiency By Improving Task Cards

Research in the scope and significance sections of chapter 1 provided shocking data about the consequences of human error within the aviation maintenance industry. 20% to 30% of in-flight engine shutdowns are caused by maintenance errors, and these can lead to roughly $675,000 in costs per shutdown (Rankin, et al., 2000). A byproduct of this study gave significant data pointing to the increased effectiveness of technicians using technologically advanced task cards. Novice technicians using augmented reality delivered 3D instruction committed significantly fewer errors than their peers using paper based cards.

Efficiency of service can also be improved with technology. Another meaningful finding from this research was that novice technicians gained better spatial awareness and understanding from the augmented reality delivered 3D job task card than the paper-based instruction, leading to less checks back to the instruction. The novices had statistically fewer checks back to the instruction when using the application. This is due in large part to the condensation of instruction present in the application (from 10 to 6). However, the control group averaged 133.3% checks per instruction task while the experimental group had just a 97.2% checks per instruction task average. This 36.1% reduction was potentially a large factor in their time on task total and implies better understandability, leading to an improved visualization schema and efficiency overall.

In addition, time on task was a key variable challenged by this study. Although the data was not statistically conclusive, the variance in mean time on task between the control and experimental groups is worth noting. The experimental group completed the task on average over five minutes faster than the their peers in the control group. The exact difference in time was 5:14.2 minutes, roughly 27.7% of the average time taken by the novices using the paper-based instruction. This translates to an improvement of 16.63 minutes on the hour. In an industry where time on task holds tremendous weight, utilizing technologically advanced instruction could drastically improve efficiency. Applying advanced visualization techniques to experts would give more substantial evidence towards this idea, but cannot be supported by our data.

Finally, improved task cards can result in decreased perception of difficulty. The statistically significant results for perceived difficulty of instruction generated by the experimental group are impressive enough, but a much more interesting finding was that the experimental group actually significantly perceived the task itself to be easier.

Alleviating perceived difficulty may also reduce technician frustration and stress. Improving the visualization technology of job task cards have been proven to increase efficiency while decreasing errors and perceived difficulty. These conclusions suggest a heightened push towards refining the technology of task cards across the industry.

5.2 Elevating Novice Technician Performance Without On the Job Training

Elevating novice technicians to an expert performance level through the use of an augmented reality delivered 3D instruction application was a primary focus of this thesis. Under that rubric, the results are largely positive. Service effectiveness was a key indication of success. When novice technicians were assigned to use the same instruction as the expert group they averaged statistically different results in errors and checks back to information. The novice technicians using the AR 3D application were not statistically different in these categories and averaged results very close to those of the expert sample. While the time on task data was not statistically significant, the experimental group was on average actually faster at completing the task than the expert group. They also averaged a difference of 22.7 seconds between of the experts compared to a difference of 5 minutes and 14.22 seconds between them and the control group. These results suggest that novice technicians using the augmented reality delivered 3D work instructions were in fact able to perform at the level of an expert without the aid of on the job training.

Furthermore, a large portion of the experimental group actually preferred the application to on the job training with none of the participants preferring on the job training. They also agreed that an augmented reality application delivering 3D work instruction could at the very least be a good addition to an expert's knowledge, if not completely replace on the job training. Though the sentiments of six novice aviation maintenance technician students cannot be applied to the whole industry, they at least suggest that this technology should be considered as a viable addition, and possible alternative, to on the job training.

Lastly, the conditions of the testing have not yet been discussed, though they contribute to the success of the study. The test was performed during a cold front and participants were exposed to harsh weather while working on the plane parked on the runway. Contributing to the poor conditions, the lighting in the aft cargo bay of the decommissioned Boeing 727 was modest and inconsistent – leading to bad visibility for the participants. Finally, the water separator itself was timeworn and rusted. This study was performed in an extreme 'real world' scenario, and the robustness of the results in this regard should be emphasized. Outside of ideal, lab-like conditions the application still allowed novice technicians to perform at an expert level and differ significantly with their peers using the paper standard. Moreover, the application itself was proven to meet the mobile demands placed on it and remain highly durable.

5.3 Study Limitations

While an attempt to eliminate lurking variables and precautions to ensure pure testing conditions were made, no study is perfect, and limitations are the unfortunate byproduct of human error and time constraints. The most prominent limitation to this study is sample size. Sample sizes of six and three are hard to statistically analyze for authoritative results. Regrettably, the study was constrained by the number of bodies available. Although the number of students in AET classes at Purdue University was maximized, the class sizes for the semester testing was completed only accounted for 12 students. A matched pairs study could have been completed, but the results would be convoluted, as each student would already have experience completing the task. Experts were gathered from technicians operating out of the Purdue airport. All available technicians were emailed twice, requesting participation, and only three responded. Even so, the study still falls within the realm of robustness with no sample size falling below 3 (Sigma XL, n.d.). Thus, even with a lower power of significance than initially desired, this study still yielded significant results.

The biggest threat to the testing results that should be discussed is the choice of tools used by participants. Though the paper based work instruction outlined which tools were needed (a 9/16th wrench and deep well socket ratchet set), most participants used the same tools as the participant before them (specifically an adjustable wrench and a normal socket ratchet set chosen by the very first participant). Some participants recognized the needs of the instruction and switched tools. The first expert participant was very vocal about the tools they inherited. Though they completed the task with the tools they inherited they stated that, “I could have finished the task in half the time with a 9/16th wrench and deep well socket.”

Accordingly, this expert trial recorded the highest time total of the expert group (18:55.8 minutes). The remaining two expert technicians completed the task with the prescribed tools and totaled times of 9:04.5 minutes and 14:06.0 minutes. It is not known if the first expert participant would have been able to match his claim of half the time, though it probably would have lowered his time total by a noticeable margin.

As it stands, the time indication includes a measure of preparedness of the participants. Their ability to read the instruction concerning tools needed or failure to adjust once the need to change tools became apparent cannot be separated from the data and must be included.

5.4 Future Recommendations

Based upon the limitations of this study, future research should apply this technique on a larger scale. A special focus on finding experts should be of paramount concern to further validate results. Having standardized tools is a key recommendation. Standardized tools could significantly cut down on lurking variables. Both of these suggestions would help fine-tune the results and analysis, but there is one other variable that could not be separated from the data and should be closely examined in future research.

Future research must validate the method of delivery of instruction. In this study, an augmented reality application delivered instruction very well, but its effect cannot be separated from that of the 3D CAD model used for visualization. An excellent idea for forthcoming studies would be to use the same 3D instruction with differing methods of delivery. This study utilized research suggesting that augmented reality would be a good way to present instruction, especially in efforts to replicate on the job training with an expert, but other methods of presentation may be more effective. For future work with augmented reality, the authors believe that enhancing trigger fidelity could greatly enhance the application. Having the ability to recognize stages of maintenance and automatically trigger instruction for the next step would be of great use for a struggling novice.

5.5 Conclusion Statement

This study's primary goal was to determine if an augmented reality delivered 3D work instruction could replicate on the job training and elevate novice aviation maintenance technicians to an expert level. The authors are satisfied with the results, finding statistically significant improvement within the novice population and novice averages very similar to those of experts. The data does not suggest that the novice sample using the augmented reality delivered 3D work instruction was statistically equal to the expert sample. However, their significant improvement when using the application brought them very close to an expert level and should have importance to the industry. On the job should probably never be replaced entirely, some knowledge comes only with experience, and simply cannot be replicated by visualization enhancements. Nonetheless, this data advocates for the benefits of technologically enhanced instructions. Adding an application like the one used in this study alongside an expert's input and guidance could greatly benefit novice technicians.

Secondarily, the results promote a move toward enhanced presentation techniques for all technicians. Utilizing advanced visualization technology can significantly lower perceived difficulty of both instruction and task. Furthermore, errors and time on task could be mitigated, reducing human error and increasing efficiency. All of these benefits contribute to potential reductions in costs and increased safety for the industry.

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APPENDICES

Appendix A Surveys

Pre-Questionnaire:

1. What is your major/job specialty?

Responses

Control 1: *AET*
Control 2: *AET*
Control 3: *AET*
Control 4: *AET*
Control 5: *AET*
Control 6: *AET*
Experimental 1: *AET*
Experimental 2: *AET*
Experimental 3*: AET*
Experimental 4: *AET*
Experimental 5: *AET*
Experimental 6: *AET*
Expert 1: *AMT*
Expert 2: *AMT/Inspector*
Expert 3: *AMT*

2. Do you have your FAA certification?

   a. Yes No

Responses

Control 1: *No*
Control 2: *No*
Control 3: *No*
Control 4: *No*
Control 5: *No*
Control 6: *No*
Experimental 1: *No*
Experimental 2: *No*
Experimental 3: *No*
Experimental 4: *No*
Experimental 5: *No*

Experimental 6: *Yes*
Expert 1: *Yes*
Expert 2: *Yes*
Expert 3: *Yes*

3. How many years/semesters of on the job experience do you have?

Responses

Control 1: *2 Semesters*
Control 2: *2 Years, 3 Semesters*
Control 3: *6 years, 2 Semesters*
Control 4: *Less than a year, 2 Semesters*
Control 5: *2 Semesters*
Control 6: *2 Semesters*
Experimental 1: *2 Years, 2 Semesters*
Experimental 2: *2 Semesters*
Experimental 3: *About a year, 2 Semesters*
Experimental 4: *2 Semesters*
Experimental 5: *Four and a half years, 2 Semesters*
Experimental 6: *6 months, 2 years*
Expert 1: *15 years*
Expert 2: *19 years*
Expert 3: *10 years*

4. Have you participated in any other experiments or job experiences involving 3D job task cards?

Responses

Control 1: *No*
Control 2: *No*
Control 3: *No*
Control 4: *No*
Control 5: *No*
Control 6: *No*
Experimental 1: *No*
Experimental 2: *No*
Experimental 3: *No*
Experimental 4: *No*

Experimental 5: *No*
Experimental 6: *Yes*
Expert 1: *No*
Expert 2: *No*
Expert 3: *No*

5. If yes did you prefer the 3D job task card to the standard paper format, and why?

Responses

Control 1: *N/A*
Control 2: *N/A*
Control 3: *N/A*
Control 4: *N/A*
Control 5: *N/A*
Control 6: *N/A*
Experimental 1: *N/A*
Experimental 2: *N/A*
Experimental 3: *N/A*
Experimental 4: *N/A*
Experimental 5: *N/A*
Experimental 6: *3D, the info*
Expert 1: *N/A*
Expert 2: *N/A*
Expert 3: *N/A*

6. Have you had any experience with 3D modeling programs? If so, which have you used?

   a. Yes No

   If Yes, which ones?

   1. NX
   2. CATIA
   3. Inventor
   4. Solidworks
   5. Pro E
   6. Solid Edge

7. Other(s)______________________

Responses

Control 1: *Yes, CATIA/Inventor*
Control 2: *Yes, CATIA/AutoCAD*
Control 3: *Yes, CATIA/Inventor*
Control 4: *Yes, CATIA*
Control 5: *Yes, CATIA/Solidworks/Pro E*
Control 6: *Yes, CATIA*
Experimental 1: *Yes, CATIA/Solidworks/Pro E*
Experimental 2: *Yes, CATIA*
Experimental 3: *Yes, CATIA/Inventor*
Experimental 4: *Yes, CATIA*
Experimental 5: *Yes, CATIA*
Experimental 6: *Yes, CATIA*
Expert 1: *No*
Expert 2: *No*
Expert 3: *Yes, CATIA/Solidworks*

7. Have you ever used any augmented reality applications, mobile or otherwise (Aurasma, Metaio, etc.)?

Responses

Control 1: *N/A*
Control 2: *Aurasma*
Control 3: *N/A*
Control 4: *N/A*
Control 5: *N/A*
Control 6: *N/A*
Experimental 1: *N/A*
Experimental 2: *N/A*
Experimental 3: *N/A*
Experimental 4: *N/A*
Experimental 5: *N/A*
Experimental 6: *Aurasma*
Expert 1: *N/A*
Expert 2: *N/A*
Expert 3: *N/A*

8. Have you ever been trained with on the job training by an expert technician?

Responses

Control 1: *Yes*
Control 2: *Yes*
Control 3: *Yes*
Control 4: *Yes*
Control 5: *No*
Control 6: *No*
Experimental 1: *Yes*
Experimental 2: *Yes*
Experimental 3: *Yes*
Experimental 4: *Yes*
Experimental 5: *Yes*
Experimental 6: *No*
Expert 1: *Yes*
Expert 2: *Yes*
Expert 3: *Yes*

9. If yes, please rank your learning experience with on the job training:

(Not Helpful)				(Very Helpful)
1	2	3	4	5

Responses

Control 1: *3*
Control 2: *4*
Control 3: *5*
Control 4: *4*
Control 5: *N/A*
Control 6: *N/A*
Experimental 1: *5*
Experimental 2: *4*
Experimental 3: *4*
Experimental 4: *4*
Experimental 5: *4*
Experimental 6: *5*
Expert 1: *5*

Expert 2: *5*
Expert 3: *5*

(STOP)

For participants using 2D instruction:

1. Have you performed this maintenance task before?

    a. Yes

    b. No

Responses

Control 1: *No*
Control 2: *No*
Control 3: *No*
Control 4: *No*
Control 5: *No*
Control 6: *No*
Expert 1: *No*
Expert 2: *No*
Expert 3: *No*

2. Have you ever used a 2D paper format job task card to complete a maintenance task before this experiment?

    a. Yes

    b. No

Responses

Control 1: *Yes*
Control 2: *Yes*
Control 3: *Yes*
Control 4: *Yes*
Control 5: *Yes*
Control 6: *Yes*
Expert 1: *Yes*
Expert 2: *Yes*
Expert 3: *Yes*

3. How difficult did you find the maintenance task to be?

1 2 3 4 5 6 7

Responses

Control 1: *3*
Control 2: *2*
Control 3: *2*
Control 4: *3*
Control 5: *3*
Control 6: *3*
Expert 1: *2*
Expert 2: *2*
Expert 3: *2*

4. Did you have any problems completing the task? Explain.

Responses

Control 1: *Only problem was the tools (Didn't have 9/16th wrench, need deep sockets for ratchet instead of shallow)*
Control 2: *Pictures too small.*
Control 3: *No.*
Control 4: *No. Pictures were included in job task card so I was able to follow easily*
Control 5: *I had to familiarize myself with the system first before I could remove any of the lines or fittings. I also had some issues due to the low lighting.*
Control 6: *Pictures hard to read.*
Expert 1: *I could have completed the task in half the time with the right tools.*
Expert 2: *No.*
Expert 3: *SEP shifted during installation. Need to loosen clamp to align for drain lines.*

5. How difficult was it to understand the 2D job task card?

1 2 3 4 5 6 7

Responses

Control 1: *3*
Control 2: *3*
Control 3: *2*

Control 4: *4*
Control 5: *4*
Control 6: *4*
Expert 1: *3*
Expert 2: *2*
Expert 3: *3*

(STOP)

For people using the augmented reality delivered 3D instruction:

1. Have you performed this maintenance task before?

    a. Yes
    b. No

Responses

Experimental 1: *No*
Experimental 2: *No*
Experimental 3: *No*
Experimental 4: *No*
Experimental 5: *No*
Experimental 6: *No*

2. Have you ever used a 2D paper format job task card to complete a maintenance task before this experiment?
    a. Yes
    b. No

Responses

Experimental 1: *Yes*
Experimental 2: *Yes*
Experimental 3: *Yes*
Experimental 4: *Yes*
Experimental 5: *Yes*
Experimental 6: *Yes*

3. How difficult did you find the maintenance task to be?

1 2 3 4 5 6 7

Responses

Experimental 1: *2*
Experimental 2: *2*
Experimental 3: *1*
Experimental 4: *1*
Experimental 5: *2*
Experimental 6: *2*

4. Did you have any problems completing the task? Explain.

Responses

Experimental 1: *Nope.*
Experimental 2: *No.*
Experimental 3: *No.*
Experimental 4: *No.*
Experimental 5: *Putting the ring back on at the end was difficult.*
Experimental 6: *Yes, tools weren't the most adequate/efficient.*

5. How difficult was it to use the augmented reality portion of the job task card?

1 2 3 4 5 6 7

Responses

Experimental 1: *1*
Experimental 2: *2*
Experimental 3: *2*
Experimental 4: *1*
Experimental 5: *1*
Experimental 6: *1*

6. If you answered yes to question 2, was the augmented reality incorporated job task card more effective at conveying maintenance task procedures than a paper based job task card?
    a. Yes
    b. No

Responses

Experimental 1: *Yes*
Experimental 2: *Yes*
Experimental 3: *Yes*
Experimental 4: *Yes*
Experimental 5: *Yes*
Experimental 6: *Yes*

7. From question 6, please describe why you feel this way.

Responses

Experimental 1: *It was easier for me to process through the steps when I saw the augmented reality task cards.*
Experimental 2: *Offers visual assistance with tasks.*
Experimental 3: *Shows exactly which part is being worked on so there's no confusion.*
Experimental 4: *It was easier to actually see the parts that needed to be removed, as opposed to reading someone's description of where they are located.*
Experimental 5: *Because you could see exactly what parts needed to be removed.*
Experimental 6: (*Did not answer).*

8. If you answered no to question 1, do you feel like you learned something from using the augmented reality?

Responses

Experimental 1: *Yes*
Experimental 2: *Yes*
Experimental 3: *Yes*
Experimental 4: *Yes*
Experimental 5: *Yes*
Experimental 6: *Yes*

(STOP)

Post Test Interview:

1. Do you believe the application delivered enough information to perform this task proficiently during your first time servicing it?

Responses

Experimental 1: *No.*
Experimental 2: *Yes.*
Experimental 3: *Yes.*
Experimental 4: *Yes.*
Experimental 5: *Yes.*
Experimental 6: *Yes.*

2. Did the application match the mobility the task required?

Responses

Experimental 1: *Yes.*
Experimental 2: *Yes.*
Experimental 3: *Yes.*
Experimental 4: *Yes.*
Experimental 5: *Yes.*
Experimental 6: *Yes.*

3. On the job training is typically a large part of the learning process for novice aviation technicians, how well do you believe augmented reality delivered instructions could match or replace on the job training with an expert?

Responses

Experimental 1: *Very well.*
Experimental 2: *Seems comparable to having an expert available.*
Experimental 3: *Somewhat, but you miss out on the expert's personal experience and tips.*
Experimental 4: *Is there a way to ask augmented reality a question? It could definitely replace training with an expert.*
Experimental 5: *Very well.*
Experimental 6: *They would be a great addition to an expert's knowledge/training, especially for certain areas/tasks.*

4. Have you been trained with on the job training before?

Responses

Experimental 1: *Yes.*
Experimental 2: *Yes.*
Experimental 3: *Yes.*
Experimental 4: *Yes.*
Experimental 5: *Yes.*
Experimental 6: *No.*

5. Would you prefer using augmented reality delivered instructions to having on the job training with an expert?

Responses

Experimental 1: *Augmented reality.*
Experimental 2: *Comprable.*
Experimental 3: *Augmented Reality, prefer less social and doing it myself.*
Experimental 4: *As long as an expert was still available to answer questions.*
Experimental 5: *Yes.*
Experimental 6: *Yes, I would like to see it alleviate the load on the expert of allow the student access to data beyond what the expert gives him/her.*

6. How well do you believe you could service this part again after using the application?

Responses

Experimental 1: *Very well.*
Experimental 2: *Yes.*
Experimental 3: *Very well.*
Experimental 4: *Yes.*
Experimental 5: *Very well.*
Experimental 6: *Very well.*

7. Did the application help you learn this service task?

Responses

Experimental 1: *Yes.*
Experimental 2: *Yes.*
Experimental 3: *Yes.*
Experimental 4: *Yes.*
Experimental 5: *Yes.*
Experimental 6: *Yes.*

8. How would you improve the application?

Responses

Experimental 1: *A display of the tools needed for the task.*
Experimental 2: *Video control, one issue is handling the device, couldn't have the video play and work at the same time.*
Experimental 3: *After scanning the card, be able to move away from it and still watch the video.*
Experimental 4: *Make it so you don't have to hold the tablet in one place and the whole time see the instructions. Even though the animation was short the tablet was in an awkward position at times.*
Experimental 5: *Should watch out for problem areas and give warnings.*
Experimental 6: *The only improvement I could suggest would be regarding the triggers, since they might be too large/unreliable in real world applications.*

(STOP)

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Appendix B Forms

APPLICATION NARRATIVE

A. PROPOSED RESEARCH RATIONALE

● Describe why you are conducting the study. Identify the research question being asked.

The aviation maintenance industry is a billion dollar business, and much of that is due to costs incurred from human error. By improving job task cards, decision, skill based and perceptual errors can be reduced. Job task card standards can better capitalize upon the spatial recognition abilities of technicians by embracing advancements in mobile, digitalized part visuals over their current engineering drawings, which push workers to use more of their experiential and tactile knowledge. Novice aviation maintenance technicians struggle with meeting the pressures of a complex industry and training that cannot efficiently bring them to the level of expertise necessary in the industry. On the job training is the current standard for novice technicians to learn new processes, however scheduling conflicts, the confinement of work zones and discrepancy between the advice of multiple expert technicians offer room for improvement within training. Research has shown that augmented reality can deliver instruction to replicate the benefits of on the job training without its costly draw backs. Furthermore, training with 3D models can lead to improved spatial recognition skills that have the potential to allow mechanics the ability to complete their tasks efficiently and effectively the first time through. This study will seek to ask the question.

• Can an augmented reality delivered, 3D job task card allow novice aviation maintenance technicians to perform at an expert level with little to no on the job training?

B. SPECIFIC PROCEDURES TO BE FOLLOWED

● Describe in a step-by-step manner what you will require subjects to do in this study.

The sample of students (novices) will be randomly divided into a control group and experimental group and preform procedure with the control group using the paper based solution and the experimental group using the AR application. Expert technicians will only be used as a standard by which the control and experimental groups are compared so they will only use the paper based solution. The study breaks down as follows:

- €The subjects will be given a pretest survey and then escorted to the area of the airplane the task relates to.
- €They will then utilize whichever work instructions they were given to perform

the maintenance task, being measured for time and errors committed.

• € When they finish they will complete a posttest survey and the experimental group will be given a follow up interview inquiring as to their personal feelings of the application.

● Identify all data you will collect.

• € There will be a Pretest survey, posttest survey for control group, and a posttest survey for experimental group. These are included in the attachments.

• € Interviews will take place after the testing in coordination with posttest surveys to ascertain subject's analysis of the usefulness of the augmented reality application, as well as their thoughts and feelings on using augmented reality in general.

• € During the test they will be observed by John Pourcho who will measure total time of the test as well as number of errors made.

C. SUBJECTS TO BE INCLUDED Describe:

● The inclusion criteria for the subject populations including gender, age ranges, ethnic background, health status and any other applicable information. Provide a rationale for targeting those populations. There will be no ethnic identifiable criteria used in selecting subject populations, the only criteria for the test subjects will be that they are a junior or senior majoring in aviation technology at Purdue University. We will be selecting from the junior/senior pool because they have the most experience and best represent the novice technician population.

● The exclusion criteria for subjects.Subjects will only be excluded if they are not juniors or seniors in aviation technology at Purdue University.

● Explain the rationale for the involvement of any special populations including prisoners N/A

● Provide the maximum number of subjects you seek approval to enroll from all of the subject populations you intend to use and justify the sample size. You will not be approved to enroll a number greater than this. If at a later time it becomes apparent you need to increase your sample size, you will need to submit a Revision Request. The maximum number of subjects we will be seeking from the novice population will be 40 as that maximizes the number of junior and seniors in aviation technology at Purdue University.

● For NIH funded protocols: If you do not include women, minorities and children in your subject pool, you must include a justification for their exclusion. The justification must meet the exclusionary criteria established by the NIH.

N/A

D. RECRUITMENT OF SUBJECTS AND OBTAINING INFORMED CONSENT

● Describe your recruitment process in a step-by-step manner. The IRB needs to know all the steps you will take to recruit subjects in order to ensure subjects are properly informed and are participating in a voluntary manner. An incomplete description will cause a delay in the approval of your protocol application.

Co-investigator John Pourcho will address students during time allotted during classes and invite them to participate in the study. He will use a PowerPoint slideshow showcasing the information outlined in Sections A and B of this report.

John Pourcho will also petition expert mechanics via email. After receiving the email of the head mechanic from consultant from co-investigator Professor Timothy Ropp, who works alongside the experts at the Purdue University Airport, John Pourcho will send the following transcript:

Hello,

My Name is John Pourcho and I'm a graduate student in the Computer Graphics department here at Purdue. I'm currently working on a thesis investigating augmented reality implementation within the aviation maintenance process, specifically job task cards. Professor Timothy Ropp is on my graduate committee and forwarded me your contact. I wanted to gauge what availability/interest the expert technicians working at the Purdue airport might have in early fall for testing. I appreciate any information you can provide!

Thanks for your time,
John Pourcho

E. PROCEDURES FOR PAYMENT OF SUBJECTS

● Describe any compensation that subjects will receive. Please note that Purdue University Business Services policies might affect how you can compensate subjects. Please contact your department's business office to ensure your compensation procedures are allowable by these policies.

The only compensation subjects will receive will be extra credit for participation. This extra credit will not exceed 3% and there will be an alternative method of obtaining the same amount if students to not wish to participate in the study. No monetary incentives will be provided.

F. CONFIDENTIALITY

● Describe what steps you will take to maintain the confidentiality of subjects. Ethnic identifiers such as ethnicity and gender will not be recorded. For age, education level and experience, these will be obtained via the pretest survey within explicitly marked 'Not Required' sections of the survey. No identifiable data will be collected (name, address, date of birth, telephone number, etc.) that could be connected with the age, education level and experience to tie participants to their identity.

● Describe how research records, data, specimens, etc. will be stored and for how long. The IRB generally recommends locked storage, such as a cabinet, for identifiable information. Please note, consent forms signed by subjects, parents and/or legally authorized representatives ARE considered research records. Consent forms, surveys and interview responses will be destroyed once recorded in a Microsoft Excel worksheet or Microsoft Word document to be then consolidated into data sheets for the thesis document. From there they will be stored on a secure server at Purdue University's PLM Center located in KNOY 373.

● Describe if the research records, data, specimens, etc. will be de-identified and/or destroyed at a certain time. If records, data, specimens, etc. will be de-identified, address if a code key will be maintained and when, if ever, it will be destroyed. Additionally, address if they may be used for future research purposes. Following the answer to the previous question, the data will be securely stored on a server requiring a code key (password) to view. These results could be used for future research.

G. POTENTIAL RISKS TO SUBJECTS

● There are always risks associated with research. If the research is minimal risk, which is no greater than every day activities, then please describe this fact.

Senior and junior level students in aviation technology at Purdue University commonly have labs that require them to work on the aircraft using job task cards. This test is very much in line with those labs and will not pose any additional risks to the process already set in place.

● Describe the risks to participants and steps that will be taken to minimize those risks. Risks can be physical, psychological, economic, social, legal, etc. Risks to aviation technicians generally include accidents in dealing with the aircraft in which a tool or part is dropped and potentially falls on the technician. Risks that may also affect the participants are the stress of completing the task effectively or stresses that result from other aspects of their lives (exams, homework, personal relationships). Although the stress added by outside influence cannot be controlled by this study, co-investigator John Pourcho will be observing each test and will be there to aid in any physical risks that may develop. Furthermore, participants will be assured that their results are anonymous and no pressure will be placed on them to complete the task in a timeframe, which should minimize the psychological risks the testing process may induce.

● Where appropriate, describe alternative procedures or treatments that might be advantageous to the participants. These tests follow normal maintenance procedure used by the airport and as such, there are already safety provisions set up to aid the technicians.

● Describe provisions for ensuring necessary medical or professional intervention in the event of adverse effects to participants or additional resources for participants. On top of the provisions created and overseen by the university and airport for technicians working on the aircraft, co-investigator will be there observing the participants prepared to call and address medical and safety professionals.

H. BENEFITS TO BE GAINED BY THE INDIVIDUAL AND/OR SOCIETY

● Describe the possible direct benefits to the subjects. If there are no direct benefits, please state this fact. Possible direct benefits of participating in the study include but are not limited to:

• € Added experience with aviation maintenance work

• € Experience with maintaining the part being used for the test (a water separator unit for the Boeing 727)

• € Exposure to new technology that could become a useful tool within the aviation maintenance field later in their careers

● Describe the possible benefits to society.

When errors are made in the aviation industry there are often significant consequences. These consequences range from costly flight delays and inefficiencies in maintenance work to possible injury and death of airline passengers. Studies have shown that one in every five airline accidents are due to maintenance error and 80% of those are related to preflight activities wherein the task cards are used. Other studies have shown that 20% to 30% of in-flight engine shutdowns are caused by maintenance errors, and these can lead to roughly $675,000 in costs per shutdown. Numbers like this depict the importance of minimizing maintenance errors and should be of paramount interest to the aviation industry.

Furthermore, the U.S. Government Accounting Office expect a large number of experts to retire in the coming years, leaving mentorship of the novice population to less experienced AMTs and negatively affecting novice AMT training. Novice AMTs could greatly benefit from a solution that counteract the problems associated with OJT training and provide them with concurrent information that would allow them to perform at an expert level earlier and more often.

I. INVESTIGATOR'S EVALUATION OF THE RISK-BENEFIT RATIO Given that there are little to no elevated risks placed on the subjects beyond what is already expected in their lab work in aviation maintenance, the safety processes already set in place by the university and airport for aviation maintenance work and the individual and societal benefits that could potentially stem from this research, there should be no doubt that the benefits outweigh the risks of this study.

J. WRITTEN INFORMED CONSENT FORM (to be attached to the Application Narrative)

● Submit a copy of the informed consent document in the form that it will be disseminated to subjects. The approved consent form will be stamped with the IRB's approval and returned to you for use.

Attached

● If recruiting subjects who do not speak English, submit both an English version as well as a version translated into the appropriate foreign language.

N/A

K. WAIVER OF INFORMED CONSENT OR SIGNED CONSENT

If requesting either a waiver of consent or a waiver of signed consent, please address the following:

N/A 1. For a Waiver of Consent Request, address the following:

a. Does the research pose greater than minimal risk to subjects (greater than everyday activities)? b. Will the waiver adversely affect subjects' rights and welfare? Please justify?

c. Why would the research be impracticable without the waiver?

d. How will pertinent information be reported to subjects, if appropriate, at a later date?

N/A 2. For a Waiver of Signed Consent, address the following:

a. Does the research pose greater than minimal risk to subjects (greater than everyday activities)?

b. Does a breech of confidentiality constitute the principal risk to subjects?

c. Would the signed consent form be the only record linking the subject and the research?

d. Does the research include any activities that would require signed consent in a non-research context?

e. Will you provide the subjects with a written statement about the research (an information sheet that contains all the elements of the consent form but without the signature lines)?

N/A

L. INTERNATIONAL RESEARCH

When conducting international research investigators must provide additional information to assist the IRB in making an appropriate risk/benefit analysis. Please consult the bullet points below when addressing this section of the application.

N/A

• Research projects must be approved by the local equivalent of an IRB before Purdue's IRB can grant approval to the protocol. If there is not equivalent board or group, investigators must rely on local or cultural experts or community leaders to provide approval and affirm the research procedures are appropriate for that culture. The Purdue IRB requires documentation to be submitted of this "local approval" before granting approval of the protocol. Additionally, please provide information about the IRB equivalent and provide contact information for the local entity. The body or individual providing the local approval should be identified in the application narrative as well as information as to that body's or individual's expertise.

• In the application narrative describe the experience and/or other qualifications the investigators have related to conducting the research with the local community/culture. Describe if the investigators have the knowledge or expertise of the local or state or national laws that may impact the research. The investigators must understand community/cultural attitudes to appreciate the local laws, regulations or norms to ensure the research is conducted in accordance with U.S. regulations as well as local requirements.

• For more information on specific requirements of different countries and territories, investigators can consult the Office for Human Research Protections International Compilation of Human Research Protections (http://www.hhs.gov/ohrp/international/). This is only one resource and it may not be an appropriate resource for your individual project.

M.

In the application narrative describe how the investigators will have culturally appropriate access to the community. If the investigators were invited into the community to conduct the research, please submit documentation of the collaboration.In the application narrative explain the investigators' ability to speak, read or write the language of potential participants. Describe the primary language spoken in the community. Explain provisions for culturally appropriate recruitment and consent accommodations translated materials or translators.

Attention should be given to local customs as well as local cultural and religious norms when writing consent documents or proposing alternative consent procedures. This information should be provided in the application narrative, and as appropriate, provide justification if requesting the IRB to waive some or all requirements of written consent.In the application narrative describe how investigators will communicate with the IRB while you are conducting the research in the event the project requires changes or there are reportable events. Also, if the researcher is a student, describe how the student will communicate with the principal investigator during the conduct of the research and how the principal investigator will oversee the research.If this research is federally funded by the United States, additional documentation and inter- institutional agreements may be required. Contact the IRB Administrator for assistance.Submit copies of consent documents and any other materials that will be provided to subjects (e.g., study instruments, advertisements, etc.) in both English and translated to any other applicable languages.

SUPPORTING DOCUMENTS (to be attached to the Application Narrative) Recruitment advertisements, flyers and letters.N/A Survey instruments, questionnaires, tests, debriefing information, etc. Attached

If the research is a collaboration with another institution, the institution's IRB or ethical board approval for the research.

N/A

If the research accesses the PSYC 120 Subject pool include the description to be posted on the web- based recruitment program (formerly Experimetrix).

N/A

Local review approval or affirmation of appropriateness for international research.

N/A

If the research will be conducted in schools, businesses or organizations, include a letter from an appropriate administrator or official permitting the conduct of the research.

N/A

Revised 10/10

Ref. # ____________

APPLICATION TO USE HUMAN RESEARCH SUBJECTS

Purdue University
Institutional Review Board

1. Project Title: Augmented Reality Application Utility for Aviation Maintenance Work Instruction
2. Full Review ☐ Expedited Review ☒
3. Anticipated Funding Source: No funding required, College of Technology overseeing project.
4. Principal Investigator *[See Policy on Eligibility to serve as a Principal Investigator for Research Involving Human Subjects]*:
   Dr. Nathan Hartman — Computer Graphics Technology, KNOY 373, 765-496-6104, 4949267, nhartman@purdue.edu
5. Co-investigators and key personnel *[See Education Policy for Conducting Human Subjects Research]*:
   John Pourcho, Graduate Student — Computer Graphics Technology, KNOY 373, 317-407-0716, jpourcho@purdue.edu
   Professor Timothy Ropp — Aeronautical Engineering Technology, NISW, 765-494-9957, tropp@purdue.edu
   Dr. Patrick Connolly — Computer Graphics Technology, KNOY 323, 765-494-9957, tropp@purdue.edu
6. Consultants *[See Education Policy for Conducting Human Subjects Research]*:
   N/A — N/A
7. The principal investigator agrees to carry out the proposed project as stated in the application and to promptly report to the Institutional Review Board any proposed changes and/or unanticipated problems involving risks to subjects or others participating in the approved project in accordance with the HRPP Guideline 207 Researcher Responsibilities, Purdue Research Foundation-Purdue University Statement of Principles and the Confidentiality Statement. The principal investigator has received a copy of the Federal-Wide Assurance (FWA) and has access to copies of 45 CFR 46 and the Belmont Report. The principal investigator agrees to inform the Institutional Review Board and complete all necessary reports should the principal investigator terminate University association.

   [signature] — 8/27/2014
   Principal Investigator Signature — Date
8. The Department Head (or authorized agent) has read and approved the application. S/he affirms that the use of human subjects in this project is relevant to answer the research question being asked and has scientific or scholarly merit. Additionally s/he agrees to maintain research records in accordance with the IRB's research records retention requirement should the principal investigator terminate association with the University.

   PE CONNOLLY — CGT
   Department Head *(printed)* — Department Name

   [signature] — 8/25/14
   Department Head Signature — Date

APPLICATION TO USE HUMAN RESEARCH SUBJECTS

9. This project will be conducted at the following location(s): (please indicate city & state)
   - ☒ Purdue West Lafayette Campus
   - ☐ Purdue Regional Campus (Specify): ______
   - ☐ Other (Specify): ______

10. If this project will involve potentially vulnerable subject populations, please check all that apply.
   - ☐ Minors under age 18
   - ☐ Pregnant Women
   - ☐ Fetus/fetal tissue
   - ☐ Prisoners Or Incarcerated Individuals
   - ☒ University Students (PSYC Dept. subject pool ___)
   - ☐ Elderly Persons
   - ☐ Economically/Educationally Disadvantaged Persons
   - ☐ Mentally/Emotionally/Developmentally Disabled Persons
   - ☐ Minority Groups and/or Non-English Speakers
   - ☐ Intervention(s) that include medical or psychological treatment

11. Indicate the anticipated maximum number of subjects to be enrolled in this protocol as justified by the hypothesis and study procedures: The maximum number of subjects enrolled in this protocol will be 30.

12. This project involves the use of an **Investigational New Drug** (IND) or an **Approved Drug For An Unapproved Use.**
   ☐ YES ☒ NO
   Drug name, IND number and company: ______

13. This project involves the use of an **Investigational Medical Device** or an **Approved Medical Device For An Unapproved Use.**
   ☐ YES ☒ NO
   Device name, IDE number and company: ______

14. The project involves the use of **Radiation or Radioisotopes**:
   ☐ YES ☒ NO

15. Does this project call for: (check-mark all that apply to this study)
   - ☐ Use of Voice, Video, Digital, or Image Recordings?
   - ☐ Subject Compensation? Please indicate the maximum payment amount to subjects. $_____
     Purdue's Human Subjects Payment Policy Participant Payment Disclosure Form
   - ☐ VO2 Max Exercise?
   - ☐ More Than Minimal Risk?
   - ☐ Waiver of Informed Consent?
   - ☐ Extra Costs To Subjects?
   - ☐ The Use of Blood? Total Amount of Blood _____ Over Time Period (days) _____
   - ☐ The Use of rDNA or Biohazardous materials?
   - ☐ The Use of Human Tissue or Cell Lines?
   - ☐ The Use of Other Fluids that Could Mask the Presence of Blood (Including Urine and Feces)?
   - ☐ The Use of Protected Health Information (Obtained from Healthcare Practitioners or Institutions)?
   - ☐ The Use of academic records?

16. Does investigator or key personnel have a potential financial or other conflict of interest in this study?
   ☐ YES ☒ NO

PURDUE UNIVERSITY

HUMAN RESEARCH PROTECTION PROGRAM
INSTITUTIONAL REVIEW BOARDS

To:

From:

Date:Committee Action: IRB Action Date IRB Protocol # Study Title Expiration Date

NATHAN HARTMAN KNOY 311

JEANNIE DICLEMENTI, Chair Social Science IRB

09/18/2014

Approval

09/17/20141408015085Augmented Reality Application Utility for Aviation Maintenance Work Instruction 09/16/2015

Following review by the Institutional Review Board (IRB), the above-referenced protocol has been approved. This approval permits you to recruit subjects up to the number indicated on the application form and to conduct the research as it is approved. The IRB-stamped and dated consent, assent, and/or information form(s) approved for this protocol are enclosed. Please make copies from these document(s) both for subjects to sign should they choose to enroll in your study and for subjects to keep for their records. Information forms should not be signed. Researchers should keep all consent/assent forms for a period no less than three (3) years following closure of the protocol.

Revisions/Amendments: If you wish to change any aspect of this study, please submit the requested changes to the IRB using the appropriate form. IRB approval must be obtained before implementing any changes unless the change is to remove an immediate hazard to subjects in which case the IRB should be immediately informed following the change.

Continuing Review: It is the Principal Investigator's responsibility to obtain continuing review and approval for this protocol prior tothe expiration date noted above. Please allow sufficient time for continued review and approval. No research activity of any sort may continue beyond the expiration date. Failure to receive approval for continuation before the expiration date will result in the approval's expiration on the expiration date. Data collected following the expiration date is unapproved research and cannot be used for research purposes including reporting or publishing as research data.

Unanticipated Problems/Adverse Events: Researchers must report unanticipated problems and/or adverse events to the IRB. If the problem/adverse event is serious, or is expected but occurs with unexpected severity or frequency, or the problem/even is unanticipated, it must be reported to the IRB within 48 hours of learning of the event and a written report submitted within five (5) business days. All other problems/events should be reported at the time of Continuing Review.

We wish you good luck with your work. Please retain copy of this letter for your records.

Ernest C. Young Hall, 10th Floor - 155 S. Grant St. - West Lafayette, IN 47907-2114 - (765) 494-5942 - Fax: (765) 494-9911

For IRB Use Only
APPROVED
SEP 17 2014
EXPIRES 9-16-15
PURDUE UNIVERSITY
INSTITUTIONAL REVIEW BOARD

RESEARCH PARTICIPANT CONSENT FORM

Augmented Reality Application Utility for Aviation Maintenance Work Instruction
Dr. Nathan Hartman
CGT
Purdue University

What is the purpose of this study?

This research study seeks to answer the question, 'Can augmented reality allow novice aviation maintenance technicians to perform at an expert level with little to no on the job training?' Your participation in this study with Purdue University will help experimentally answer that question and further determine if augmented reality delivered work instruction has a place in aviation maintenance. This project has been sponsored by the college of technology's computer graphics department and will plan to enroll the help of 20-30 participants.

What will I do if I choose to be in this study?

- Participants will be given a pretest survey and then escorted to the area of the airplane the task relates to.
- You will then utilize whichever work instructions they were given to perform the maintenance task, being measured for time and errors committed.
- When you finish you will complete a posttest survey and the experimental group will be given a follow up interview inquiring as to your personal feelings of the application. .
- There will be a Pretest survey, posttest survey for control group, and a posttest survey for experimental group. Surveys simply question previous experience and overall feelings to the research, there are no right answers.
- Interviews will take place after the testing in coordination with posttest surveys to ascertain subject's analysis of the usefulness of the augmented reality application, as well as your thoughts and feelings on using augmented reality in general.
- During the test you will be observed by John Pourcho who will measure total time of the test as well as number of errors made.

How long will I be in the study?

Total time invested will vary from subject to subject but should not exceed 30 minutes.

What are the possible risks or discomforts?

Senior and junior level students in aviation technology at Purdue University commonly have labs that require them to work on the aircraft using job task cards. This test is very much in line with those labs and will not pose any additional risks to the process already set in place.

Risks to aviation technicians generally include accidents in dealing with the aircraft in which a tool or part is dropped and potentially falls on the technician. Risks that may also affect the participants are the stress of completing the task effectively or stresses that result from other aspects of their lives (exams, homework, personal relationships). Although the stress added by outside influence cannot be controlled by this study, co-investigator John Pourcho will be observing each test and will be there to aid in any physical risks that may develop. Furthermore, participants will be assured that their results are anonymous and no pressure will be placed on them to complete the task in a timeframe, which should minimize the psychological risks the testing process may induce.

Are there any potential benefits?

This experiment has no direct reward for participating; there are no direct benefits to subjects. However, you may indirectly benefit from having experience with an emerging trend in aviation maintenance.

Possible indirect benefits of participating in the study include but are not limited to:

- Added experience with aviation maintenance work
- Experience with maintaining the part being used for the test (a water separator unit for the Boeing 727)
- Exposure to new technology that could become a useful tool within the aviation maintenance field later in their careers

Will information about me and my participation be kept confidential?

All participants will remain anonymous. No data or information obtained by the researchers will be connected to your performance in the experiment. Ethnic identifiers such as ethnicity and gender will not be recorded. For age, education level and experience, these will be obtained via the pretest survey within explicitly marked 'Not Required' sections of the survey. No identifiable data will be collected (name, address, date of birth, telephone number, etc.) that could be connected with the age, education level and experience to tie participants to their identity. The project's research records may be reviewed by the CGT department at Purdue as well as by other departments at Purdue University responsible for regulatory and research oversight.

What are my rights if I take part in this study?

Your participation in this study is voluntary. You may choose not to participate or, if you agree to participate, you can withdraw your participation at any time without penalty or loss of benefits to which you are otherwise entitled.

Who can I contact if I have questions about the study?

If you have questions, comments or concerns about this research project, you can talk to one of the researchers. Please contact:

Dr. Nathan Hartman — Computer Graphics Technology, KNOY 373, 765-496-6104, nhartman@purdue.edu

John Pourcho, Graduate Student — Computer Graphics Technology, KNOY 373,

317-407-0716, jpourcho@purdue.edu

If you have questions about your rights while taking part in the study or have concerns about the treatment of research participants, please call the Human Research Protection Program at (765) 494-5942, email (irb@purdue.edu)or write to:

Human Research Protection Program - Purdue University
Ernest C. Young Hall, Room 1032
155 S. Grant St.,
West Lafayette, IN 47907-2114

Documentation of Informed Consent

I have had the opportunity to read this consent form and have the research study explained. I have had the opportunity to ask questions about the research study, and my questions have been answered. I am prepared to participate in the research study described above. I will be offered a copy of this consent form after I sign it.

________________________________ ____________________
Participant's Signature Date

____
Participant's Name

________________________________ ____________________
Researcher's Signature Date

Appendix C Data

TRIALS	TIME (s)	ERRORS	CHECKS	VIS Qs
Control 1	1278.10	3	14	2
Control 2	822.70	4	16	1
Control 3	658.20	3	11	1
Control 4	1402.50	2	12	0
Control 5	1293.30	4	14	0
Control 6	1347.30	5	13	5
Experimental 1	760.70	0	5	0
Experimental 2	840.60	0	5	0
Experimental 3	507.80	2	7	0
Experimental 4	839.70	0	7	0
Experimental 5	926.40	0	6	0
Experimental 6	1041.60	0	5	0
Expert 1	1136.00	0	6	0
Expert 2	544.50	0	6	0
Expert 3	846.00	0	10	0

AVERAGE	TIME (s)	ERRORS	CHECKS	VIS Qs
Control	1133.68	3.50	13.33	1.50
Experimental	819.47	0.33	5.83	0.00
Expert	842.17	0.00	7.33	0.00

AVERAGE	DIFF	DIFF (APP)	YEARS EXP	SEM EXP
Control	2.67	3.33	1.42	2.17
Experimental	1.67	1.33	1.33	2.00
Expert	2.00	2.67	14.67	N/A