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THESIS

SIMULATING EXPERIENCE IN AVIATION MAINTAINERS

by

Clifford E. Plass

September 2020

Thesis Advisor: Perry L. McDowell
Co-Advisor: Rudolph P. Darken

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13. ABSTRACT (maximum 200 words)

The intricacy and breadth of knowledge as well as logical and critical thinking required to effectively service and maintain the Marine Corps fleet of aviation assets cannot be fully realized through formal schooling. The operational tempo and readiness demands of the service cannot facilitate the full development of proficient maintainers prior to arrival in their units, leaving the majority of skill development to be achieved through on-the-job training. This is a slow process with numerous shortcomings that can be overcome through the introduction of experience simulation.

This thesis utilizes the Unity game engine to create a training program that simulates interaction with the A/S32A-45 mid-range towing tractor (MRTT). The prototype software explores the tasks associated with receiving tasking to troubleshoot a low power discrepancy. It follows one possible cause of the discrepancy through the steps required to diagnose and correct the issue.

The MRTT training program demonstrates the capability of the software to allow aviation maintainers to perform repetitions of troubleshooting and maintenance tasks that may not occur repetitiously in the conduct of the mission. The application could be expanded to cover all systems and discrepancies within the MRTT. The process could be applied to the fleet of aviation support equipment as well as aircraft systems in use.

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SIMULATING EXPERIENCE IN AVIATION MAINTAINERS

Clifford E. Plass
Captain, United States Marine Corps
BS, University of North Florida, 2011

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September 2020

Approved by: Perry L. McDowell
Advisor

Rudolph P. Darken
Co-Advisor

Gurminder Singh
Chair, Department of Computer Science

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LIST OF ACRONYMS AND ABBREVIATIONS

AR	Augmented reality
ASM	Advanced Skill Management
CDI	Collateral duty inspector
CLCon	Classroom and Laboratory Configurator
FY	Fiscal year
IOS	Instructor operator station
MAF	Maintenance action form
MAG	Marine Air Group
MAGTF	Marine air ground task force
MALS	Marine aviation logistics squadron
MCT	Marine combat training
MDTS	MRTS Data Tracking System
MOS	Military occupational specialty
MRTS	Multipurpose reconfigurable training system
MRTT	Mid-range towing tractor
NAMP	Naval Aviation Maintenance Programs
NAWCTSD	Naval Air Warfare Center Training Systems Division
OJT	On the job training
POI	Program of instruction
RRL	Ready relevant learning
SMS	Student management system
T&R	Training and readiness manual
VR	Virtual reality

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I. INTRODUCTION

The U.S. Marine Corps tactics rely heavily on the combined arms model. The Corps structure its forces into the Marine Air Ground Task Force (MAGTF) for the purpose of achieving this goal. The Corps utilizes aviation element in several ways to perform several aspects crucial to ability to carry out tactical and operational warfare.

Marines on the ground engage with hostile forces via direct fire weapon systems. With the assistance of air support and artillery, they then deliver indirect fires on any hostile force that seeks cover from the direct fires. The Marines use attack aircraft, both fixed and rotary wing, to provide indirect fires in support of ground elements.

A primary tenet of the Marine Corps, maneuver warfare, relies heavily on the ability to move more quickly than the opposition. Marines need to be able to rapidly locate themselves at the critical position in order to impose their will, and commonly do this using rotary and tilt-rotor aircraft to perform vertical envelopment (i.e., use of air assets to transport forces to where they can best attack the enemy).

A third contribution of USMC air capabilities is delivering logistical support any place, any time. Without timely and consistent resupply of food, ammunition, fuel and casualty evacuation, Marines cannot continue to operate for long periods in a wartime environment.

This heavy demand on USMC aviation assets means that the readiness of Marine Corps aviation capabilities is difficult to maintain. With some platforms demonstrating ratios of maintenance man-hours to flight hours as high as 24 to 1, this creates a significant need for efficiency among the maintenance crews.

These factors all emphasize the importance of the Marines’ fleet of aircraft. The nature and criticality of their mission leads pilots to be some of the most well-trained personnel in the Corps. They make heavy use of simulation to augment necessary cockpit time to ensure that their skills are honed to perfection. However, military aircraft have notoriously high ratios of maintenance man-hours to flight hours.

The operational tempo of the flying squadron and the ratio of maintenance man hours to flight hours results in a significant workload placed on the Marines that maintain the aircraft and support equipment. Yet there is no simulation to augment the training of the maintainers.

The maintainers attend schools with programs of instruction (POI) that can last in excess of a year. The POI introduces the maintainer to the Naval Aviation Maintenance Programs (NAMP), the theory of operations and systems of the piece of equipment or aircraft to which they will be assigned and introduces them to maintenance and troubleshooting procedures.

While pilots can gain proficiency through repetition in the simulator in addition to flights in the aircraft, the maintainer can only learn through hands-on experience. It can take several years after graduating from school for these maintainers to become proficient enough to be tasked directly with troubleshooting a discrepancy in a time critical environment such as the Marine Corps aviation squadron.

This learning curve becomes problematic as the preponderance of personnel assigned to a squadron are in their first tour of duty and are of the rank lance corporal (E-3) and below, which means that most of the squadron does not have the experience required to attain proficiency. The proficiency starts to develop as their first tour is coming to an end. The fiscal year (FY) 20 enlisted retention goals are to retain only 24 percent of all first term Marines (Ottignon, 2019). This would lead to less than one in four of the maintainers that just started to become proficient remain in the Corps to further develop their skills. Of these remaining Marines, most will be transferred to various necessary billets outside of maintenance, such as drill instructor, recruiter, instructors, leaving only a few to continue to gain proficiency in their primary MOS. This postpones their technical development until they return to the squadron in their third tour. The Marine Corps has made regular attempts to mitigate this loss of personnel through “kicker” programs designed to entice Marines to reenlist for an additional tour. Presently, for the fiscal year 21 reenlistment period, qualified aviation maintenance personnel can receive a $20,000 bonus for 48-month commitments (Rocco, 2020).

Most Marines in their third tour are placed in managerial or quality assurance positions and these Marines are so few that they cannot absorb the workload of the squadron, which must fall on the first tour inexperienced Marines. Development of troubleshooting and maintenance skills through on the job training (OJT) has drawbacks that lead to the slow acquisition of proficiency:

During a typical workday, the squadron will start by screening workloads and attending maintenance meetings to set priorities of tasking for the day. This is typically conducted at 0800 and lasts between 30 minutes and an hour. The squadron's maintenance meeting is conducted where the work centers receive their tasking from maintenance control. At this point the work center supervisor will need to conduct another meeting to task personnel within the work center. This makes the time between 0900 and 0930 before the maintainers have been tasked. They must then each access the computer and place their maintenance action forms (MAFs) in work to document their work, meaning they have initiated the worker and time tracking documentation coinciding with maintaining equipment. They gather their required equipment and inventory their tools which must be done before and after each task to ensure they are not ingested by the aircraft engines. Typically, work does not begin until 0930 or 1000. This allows one to two hours of work before lunch. Another inventory of tools is required before work can recommence. Once a diagnosis is reached, the maintainer must break to order the appropriate parts and wait for their delivery. All these processes can be streamlined through task separation and tasking but cannot be removed.

There are common discrepancies that occur on each piece of equipment. These are seen regularly during daily operation and can be easily identified and learned through OJT. When less common discrepancies occur, they must be creatively troubleshot through time intensive research and testing, which is improved by the amount of troubleshooting the Marine has previously performed. Most squadrons have a small handful of truly experienced maintainers, one of whom may have seen the discrepancy before and can speed up troubleshooting.

Once a discrepancy has been troubleshot, the actual correction of the discrepancy is time consuming. While there is much proficiency to be gained through the actual removal and replacement of parts, many maintainers can follow these procedures with minimal previous experience. The identification of parts that need repair or replacement is the more challenging proficiency to be trained.

To address these difficulties, the use of simulation could provide the maintenance personnel a means to rapidly experience and explore numerous repetitions of a wide variety of potential discrepancies that they may experience in the future.

We believe that a game-based troubleshooting trainer could provide a maintainer with years of experience in significantly reduced time. The overall proficiency of the maintenance department could significantly improve by developing the skills of its most numerous, yet most inexperienced personnel.

A. OBJECTIVE

The objective of this research is to provide maintainers training software that will accommodate exploring the systems under their area of responsibility without causing harm to the end item or aircraft. Using the software will allow the maintainer to build critical experience in troubleshooting and maintaining equipment.

B. RESEARCH QUESTIONS

1. Can modeling software be used to simulate real-world experience in maintaining aviation related equipment?

2. Can using a simulation improve the performance of aviation maintenance personnel?

3. Can the readiness of aviation assets be improved by the addition of simulation training to the maintenance work force?

C. METHODOLOGY

The research will make use of a prototype first person shooter style simulation that emulates a realistic scenario where a maintainer would need to troubleshoot a loss of power discrepancy on an MRTT. This will take the form of a pilot study due to the restrictions of COVID-19.

Participants will be asked to answer a small questionnaire designed to appraise their comfort level pertaining to troubleshooting mechanical systems and gaming in general. They will then play through the scenario depicted in the prototype. An office in Watkins hall will be made available for participants to make use of the researcher's computer, but participants will be afforded the opportunity to participate without physical interaction by downloading the game on their own computer.

After playing the game, they will be given another short questionnaire designed to gather data pertaining to any changes in their comfort level that might indicate learning has occurred. A final, open ended, question will seek feedback pertaining to improvements that could be made to the system.

The feedback will be used to evaluate the value of the study's premise as seen by objective participants as well as test the ability to generate a quality game-based training system that can be made readily available to maintainers in the fleet.

D. THESIS OUTLINE

Chapter II contains background information pertaining to the existing training methods in place for aviation maintainers, the requirements associated with achieving qualifications in aviation maintenance, an analysis of the use of simulation as a teaching tool, and a discussion of other simulation-based training software.

Chapter III discusses the merits of different methods of implementing training software. It compares VR, AR, MRTS and Unity as potential tools for this system. Finally, it discusses the implementation used for the prototype system created in this thesis.

Chapter IV provides a detailed overview of the original planned experiment as well as the actual implemented experiment, providing reasoning for the implemented course of action.

Chapter V details the data that was gathered during the conduct of the experiment. Each hypothesis is evaluated and tested and feedback from the participants is presented.

Chapter VI is the final chapter and concludes the results and conduct of the experiment.

II. BACKGROUND STUDY

A. 6073 MILITARY OCCUPATIONAL SPECIALTY (MOS) SCHOOL CURRICULUM

After initial introductory infantry training, Marines with the MOS of 6073, who work on aviation support equipment, begin their technical training by first attending the Aviation Support Equipment “A” school in Pensacola, Florida. This lasts approximately four months and is the Marines’ introduction to the NAMP. This school can be compared to the Marine Combat Training School (MCT), which imparts a basic functional knowledge of infantry tactics in all Marines but falls significantly short of the training necessary to attain the infantry MOS.

At “A” school the student learns the basics of concepts such as foreign object damage (FOD), hydraulic contamination control, tool control, maintenance documentation etc. Upon graduation, the Marines are basic aviation maintainers without a specialization. The maintainers with the 6073 MOS are then sent to a follow-on “C” school to learn their specialty.

During their approximate four months in “C” school, the students will be introduced to the wide variety of equipment for which they are responsible; one of these is the mid-range towing tractor (MRTT) which is one of the simplest and more readily implemented aviation assets. This list could vary based depending on the Marine Aviation Logistics Squadron (MALS) to which they are ultimately assigned, and the type of aviation assets they support. The 6073 will need to learn a variety of systems including, but not limited to, aircraft jacking systems, aviation engine slings, various cranes, tow tractors, weapons loaders, mobile electric power plants, demineralization carts, and aircraft starting units. These tasks require high- level functional knowledge of gasoline, diesel, and gas turbine engine systems, electrical systems, hydraulic, and pneumatic systems. This short school is the only formal training that the 6073 will receive, but it only covers the basics of these systems. Therefore, the maintainers will be required to learn the intricacies of their systems on the job.

In an effort to produce qualified maintainers to the fleet, the "C" school must touch briefly on these numerous systems. The course that covers the MRTT primarily focuses on introduction and familiarity with the unit and its embedded systems. The major takeaway that the maintainer is to receive is knowledge of where to look in the publication for information on each system. Each publication for support equipment uses a similar structure. There is a section that contains a general troubleshooting summary, which lists potential starting areas that a maintainer should evaluate when posed with a discrepancy. This provides the starting point from which the maintainer will need to use their own logic, reasoning and the assistance of a more experience maintainer to determine the cause. The publications also include wiring schematics and illustrated parts breakdowns for all systems. This is what the maintainer will use to order parts and provides, generally, an exploded view of the system. (Center for Naval Aviation Technical Training, 2016)

The relatively short length of this school forces them to attempt to teach general troubleshooting capabilities and resource acquisition and use these in the context of general overviews of individual equipment. The MRTT specific instruction entails five PowerPoint- aided periods of instruction: publications, safety, familiarization, systems, and the diesel engine. This instruction would take place over the course of a week or two and be the sum of the student's knowledge of this system. (Center for Naval Aviation Technical Training, 2016)

B. THEORY OF OPERATIONS

Most publications associated with intermediate maintenance of aviation support equipment will include a section called the "theory of operations." This section provides a description of the way that the systems work. A firm understanding of the theory of operations is critical to the capability to troubleshooting discrepancies. The complexity of the system as well as the quality of its written theory of operations can vary widely.

As an example, the NCPP-105 was a large gas turbine engine-based mobile start unit and electric power plant that was used to start larger aircraft engines and provide power for troubleshooting systems. While troubleshooting an issue where this unit will not start properly, the troubleshooting section will give a general area to begin looking. The theory of operations is what will allow the maintainer to understand that at various points during the startup process, the air pressure created by the starting engine will exceed system counter pressures on opposing sides of various pneumatic diaphragms, which close switches initiating the next segment of the start sequence. By walking through this detailed theory of operations while simultaneously measuring pressures, the troubleshooter can identify if certain processes are not taking place when they should. This is the only means of identifying a potential pinhole in these pneumatic diaphragms that could prevent the unit from starting. However, this level of detail within a theory of operations is the exception rather than the rule and this level of understanding and ingenuity is indicative of an experienced and creative maintainer and is not taught in school.

In the instance of the MRTT, the theory of operations is written at as a technical specification instead of a narrative of its operation. It is written for an audience that is assumed to have a thorough understanding of all the associated systems and provides fairly brief statements about the specifications of the system. For example, the fuel system section of the theory of operations is as follows, in its entirety: "The MRTT has a stainless-steel fuel tank located between the inner and outer frame rails on the passenger's side of the vehicle. The filler neck is 3 inches in diameter (internal) to allow filling from aircraft fuel trucks. The rigid lines for the MRTT's fuel system are made from stainless steel" (Naval Air Warfare Center, 2019, WP 003, p. 6) This does not provide meaningful information about the function of the system that the maintainer could use to troubleshoot the system.

C. TROUBLESHOOTING AND MAINTENANCE PROCEDURES OF THE MRTT

Aviation maintenance Marines are taught that the first step in troubleshooting any discrepancy is to look at the troubleshooting section of the publication. This section is a simple three column table. A number of potential discrepancies are listed, although this list is not all inclusive, they can provide the troubleshooter with a general area to begin looking. The next column lists a number of potential causes of the discrepancy. The final column lists the appropriate work package that provides more information about the system that could potentially be at fault.

Although there is some variance between publications and equipment, this section does not generally provide any instruction pertaining to how to determine which of the potential causes is likely or how to diagnose the particular discrepancy. Figure 1 shows the troubleshooting section page for the MRTT pertaining to a loss in pulling power. This is the discrepancy that was chosen for representation in the training software in this thesis. It is readily apparent that without extensive knowledge, this merely lists common causes of the discrepancy. While the list points the troubleshooter toward areas to look, it provides no means of determining which discrepancy is the cause or in what order they should be eliminated.

A task analysis could be used to create a sequence of steps to take in order to determine the cause of the discrepancy. Figure 2 was created from personal experience and accounts for time taken to test each discrepancy, likelihood of the discrepancy and cost to repair. While this analysis is not available in the provided publications, it is expected that the troubleshooter performs this sort of logical evaluation and steps when they are inspecting a system. This sort of analysis could be provided to fledgling troubleshooters in order to get them started, but would result in a slow, methodical analysis of the system. More appropriately, this construct could be used in simulation software as instruction to build experience among the personnel responsible. While an iterative process such as this may be required initially, a maintainer could recognize indicators of a discrepancy based on experience. That experience may be elusive through performing everyday tasks on the job but could be readily available through simulation.

NAVAIR 19-40-523 007 00

Malfunction	Probable Cause	Corrective Action	Refer to WP
Loss of power/reduction in pulling power.	Brakes binding.	Inspect all brake system components. Replace as required.	015 00
	Automatic transmission fluid level incorrect.	Check transmission fluid level.	012 00
	Fuel injection system out of adjustment or excessively worn.	Inspect fuel injection pump. Replace as required.	011 00
	Fuel filter/fuel pump internal strainer clogged.	Clean/replace fuel filter(s).	010 00
	Contaminated fuel.	Check fuel for contamination. If contaminated drain tank and fuel system. Refill with good quality fuel.	010 00
	Air intake restricted.	Check air filter service indicator. Inspect for damage. Replace filter cartridge or damaged component.	010 00
	Exhaust system restricted.	Check for crushed tail pipe, clogged muffler/spark arrestor. Replace as required.	010 00
	Fuel line leak.	Inspect for leaks. Replace line.	010 00
	U-joint failed on drive shaft.	Replace drive shaft or U-joints.	014 00
	Transmission failed.	Replace transmission.	012 00
	Transmission oil filter clogged.	Replace transmission oil filter. Check and refill transmission fluid to proper level.	012 00
	Transmission bands slipping.	Adjust bands.	012 00
	Transmission slips.	Replace transmission.	012 00
	Turbocharger failed.	Replace turbocharger.	010 00
	Low or uneven cylinder compression pressures.	Perform compression check, perform QEC if required.	010 00
Unable to maintain engine-operating temperature.	Cooling hose deteriorated.	Replace hose.	011 00
	Thermostat fails to close.	Replace engine oil thermostat.	011 00
	Oil cooler clogged.	Replace oil cooler.	011 00
Vehicle rides rough.	Front suspension component failed.	Check front suspension for failures. Replace failed component. Lubricate new components as needed.	013 00
	Low tire pressure, flat tire, damaged tire(s)/rim(s).	Check tire pressure, tire and rim condition for damage. Add air to tires or replace tire(s)/rim(s) as needed.	014 00
	Rear suspension component failed.	Check rear suspension for failures. Replace failed component. Lubricate new components as needed.	014 00

2

Figure 1. MRTT Troubleshooting Section. Source: Naval Air Warfare Center (2019).

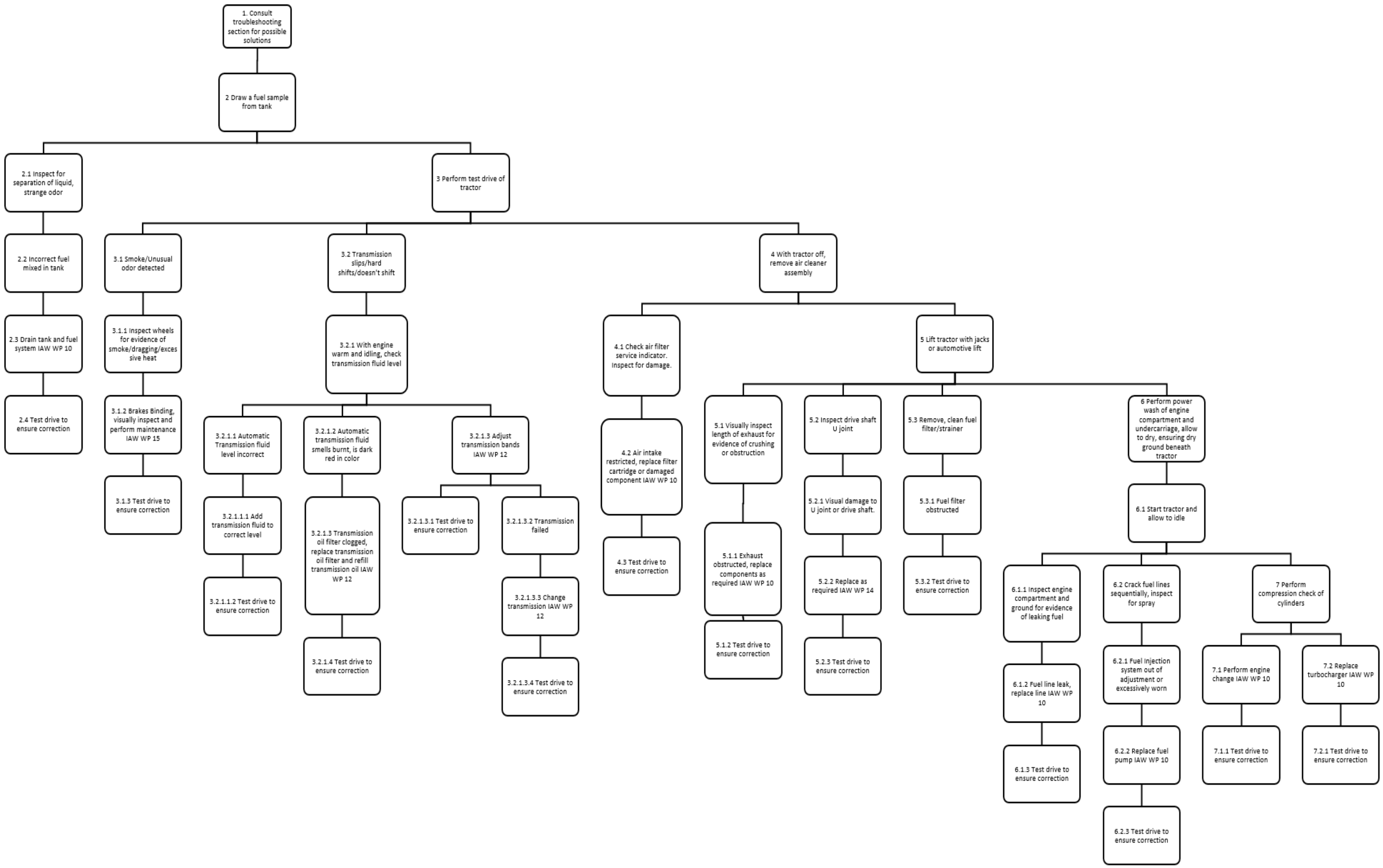

Figure 2. Troubleshooting task analysis

D. 6073 MOS TRAINING AND READINESS MANUAL.

1. Achieving Task Signoff

A maintainer's knowledge is tracked and documented through the Advance Skills Management system (ASM). This is an electronic training jacket that is used to document appropriate training and readiness task completion and levels of qualification for use in Marine Corps aviation. Figure 3 shows an example of level 2 and 3 documentation for training in the 6073 MOS. This training and readiness documentation records each iteration of task performance by a maintainer.

While many of these tasks can be reasonably assumed to be understood and within the capability of the maintainer to perform, it is not reasonable to expect that these tasks are actually encountered by each maintainer during the course of their daily operations. To direct your attention to the very first task "remove the oil pressure gauge." This task seems trivial and is listed as a required task to have been performed by any maintainer before reaching a level 4000 qualification. However, as with most systems, an oil pressure gauge is a reliable piece of hardware and will likely never require replacement in the lifetime of the MRTT. This leaves the question of how to achieve this task.

Training Action

ASM online

Description	Signer Authority	Auto	Status	Due Date	Progress
6073 A/S32A-45 AIRCRAFT TOW TRACTOR (GPMK) 2000-3000 SSSP (B) (front/back matter)		No	ASSIGNED on 15-Jul-2019		0 of 31 (0.0%)
A/S32A-45 Aircraft Tow Tractor System 2000 Basic Level Tasks		No			
GPMK-2000-23CE220. OJT: Remove the oil pressure gauge*	6073 CDI/CDQAR/WCS	Yes	ACTIVE		
GPMK-2001-23CE220. OJT: Install the oil pressure gauge*	6073 CDI/CDQAR/WCS	Yes	ACTIVE		
GPMK-2002-23CE230. OJT: Remove the oil temperature gauge*	6073 CDI/CDQAR/WCS	Yes	ACTIVE		
GPMK-2003-23CE230. OJT: Install the oil temperature gauge*	6073 CDI/CDQAR/WCS	Yes	ACTIVE		
GPMK-2004-23CE240. OJT: Remove the voltmeter gauge*	6073 CDI/CDQAR/WCS	Yes	ACTIVE		
GPMK-2005-23CE240. OJT: Install the voltmeter gauge*	6073 CDI/CDQAR/WCS	Yes	ACTIVE		
GPMK-2006. OJT: Remove the air filter assembly*	6073 CDI/CDQAR/WCS	No	ACTIVE		
GPMK-2007. OJT: Install the air filter assembly*	6073 CDI/CDQAR/WCS	No	ACTIVE		
GPMK-2008-23CE610. OJT: Service the engine BF4M2011*	6073 CDI/CDQAR/WCS	Yes	ACTIVE		
GPMK-2009-23CE710. OJT: Service the transmission C6*	6073 CDI/CDQAR/WCS	Yes	ACTIVE		
GPMK-2010. OJT: Service the front steer axle*	6073 CDI/CDQAR/WCS	No	ACTIVE		
GPMK-2011. OJT: Remove the tire/wheel assembly*	6073 CDI/CDQAR/WCS	No	ACTIVE		
GPMK-2012. OJT: Install the tire/wheel assembly*	6073 CDI/CDQAR/WCS	No	ACTIVE		
GPMK-2013. OJT: Remove the drop box*	6073 CDI/CDQAR/WCS	No	ACTIVE		
GPMK-2014. OJT: Install the drop box*	6073 CDI/CDQAR/WCS	No	ACTIVE		
GPMK-2015-23CE740. OJT: Service the rear drive axle shaft*	6073 CDI/CDQAR/WCS	No	ACTIVE		
GPMK-2016-23CE750. OJT: Service the rear drive axle*	6073 CDI/CDQAR/WCS	Yes	ACTIVE		
GPMK-2017. OJT: Remove the rear shock absorber*	6073 CDI/CDQAR/WCS	No	ACTIVE		

Figure 3. T&R 2000–3000 level ASM. Source: COMNAVAIRFOR (2019).

It would seem that the maintainer would then, logically, never achieve this particular sign off since the task would never be performed. However, in order for the maintainer to progress in their career, they need to achieve all level 2000 and 3000 level tasks. Additionally, every task or maintenance action performed in Marine Corps aviation must be inspected by a Collateral Duty Inspector (CDI). In order to qualify to become a CDI, the maintainer must possess at least a level 4000 qualification on the piece of equipment in question (Forces, 2017).

Following this logic, it would seem that no maintainer would be capable of becoming a CDI and therefor no work could be performed as no one would be qualified to inspect it. This is obviously not the case, so the solution to this problem takes many forms. The first, which is typically the case, the worker in question convinces the supervisor through demonstrated understanding of the systems that they are more than capable of performing this trivial task. This may work well in the example of replacing a gauge but may not carry over so well when discussing something more complicated but equally rare such as removing and replacing the engine.

Secondly, this task could be performed on equipment that does not actually require the work. It is possible for workers to achieve experience by performing tasks on equipment that is not currently in use, or that is not functional for other reasons. This causes problems with serviceability as damage could occur rendering otherwise functional systems inoperable, requiring additional spending and manpower to repair. It also takes away from mission essential manpower and possibly equipment.

A third option would be to change the T&R to reflect the expected tasks actually encountered by maintainers. This would be difficult to predict as every maintainer has different experiences. One maintainer could experience the same discrepancy ten times, while another never encounters it. This is evident in scenarios where a safety concern is found. Sometimes potential equipment malfunctions are identified, and technical directives are issued to replace or repair systems. This would require implementation and potential replacement of systems that would never again need work preventing future maintainers from gaining this hands-on experience, but the expectation of their expertise remains.

In illustration of the intention of this thesis, the fourth option is to simulate the task. A maintainer could perform the task in a simulated environment, demonstrating their knowledge of the system in question while preserving the integrity both of the equipment as well as the training and readiness system.

2. Troubleshooting in the Training and Readiness Manual

As depicted in Figure 3, the T&R lists several remove and replace tasks necessary to advance in qualification. What is conspicuously missing is troubleshooting. This is arguably the more challenging task associated with the repair of any discrepancy. The illustrated parts breakdown and the work packages in the publication frequently explain the tasks required to perform removal and replacement of deficient parts. The level of explanation and quality varies between publications and systems but is generally achievable by an appropriately experienced maintainer regardless of system knowledge.

That is not to say that the task of replacing a component is trivial but replacing components does not require the knowledge of why that component is being replaced. Yet this is the most important knowledge to earn through experience. The T&R assumes that troubleshooting occurs to identify the necessity of replacing the listed components, but as stated earlier, these components do not necessarily fail, so this assumption is not justifiable. How does one identify that the oil pressure gauge needs to be replaced? It could be something as trivial as the glass cover being cracked or as significant as the operator not realizing a loss of oil pressure because the gauge did not work causing engine failure.

E. SIMULATION AS A TEACHING STRATEGY

Numerous studies have explored the ways that knowledge is attained. David Kolb's experiential learning theory discusses a cycle of gaining experience then capturing that experience as knowledge. His theory has been criticized for not addressing the effect that experience without reflection can have on the quality of learning. There is also debate regarding learning styles. People can show preference for a particular medium of instruction, but this does not prohibit them from learning by other means (Cherry, 2020). That is not to say that experience alone can fully replace formal instruction, but that instruction alone cannot make a truly effective professional. This case is accepted within aviation maintenance as evidenced by the implementation of the T&R means of documenting experience. A paper in the *International Conference on University Teaching and Innovation, CIDUI 2014, 2–4 July 2014, Tarragona, Spain*, entitled "Learning through experience and teaching strategies outside the classroom at design university studies," explored the different dynamic and tension that is experienced by the student when removed from the classroom and placed in a non-academic context to learn through action. The resulting memory of the experience becomes more greatly ingrained in the mind than a lecture is capable of imparting (Costa, 2014).

Simulation can bolster experiential learning at a savings of time, assets, mission readiness and cost. That time is a critical asset in military aviation is an obvious statement. Timely availability of military aviation is key to both logistics and more direct effects on enemy forces. Timely performance of maintenance on these aviation assets is equally integral in ensuring they are available. Finally, to perform timely maintenance actions, we need a highly skilled force which becomes so in a timely manner. As discussed in the introduction, the time required to develop these skills and experience through on the job training takes years. This is due to the occurrence of various discrepancies, the time required to correct them as well as the distribution of the workload. Through simulation, a maintainer can practice performing a task or troubleshooting action without the elements that frustrate the actual task when performed. For example, many components of systems are installed in tightly restricted spaces. To gain a better understanding of the system, it may be beneficial for the maintainer to see the entirety of the system and how it interconnects with the rest of the unit. This can be achieved in seconds through simulation; however, it is completely impractical in physical reality. This is confounded by situations where, for example, it may be impossible to fit more than the open end of a combination wrench into the space occupied by a bolt affixing a part to be replaced. While there may be something to be learned by spending 30 minutes slowly turning the head of a single bolt one-eighth of a turn, then repositioning the wrench and repeating, it does not serve to improve knowledge of the system or troubleshooting skills.

As discussed previously, the availability of assets is key to the mission of military aviation. The use of functional assets for practice is not a feasible solution to gain experience among the maintenance workforce. This would decrease readiness as well as incur unnecessary cost. It seems intuitive that simulation is necessary, according to Caniglia (2019) three elements are necessary for its effective implementation.

1. Preparation

The simulation cannot stand alone as the basis of instruction. When used as an instructional aid as part of a traditional class, there are considerations that must be addressed. They must be tied to the course goals and must be properly facilitated. While Caniglia discusses numerous aspects to address proper implementation of the use of simulation as part of a curriculum, these cannot all be achieved when the simulation is made available as a reference tool after the class.

According to Caniglia, preparation varies with the type and complexity of the simulation. Most simulation creators suggest that simulations are best when:

- Simulations are tied to the course goals.
- Facilitators read ALL the supporting material for the simulation.
- Facilitators do a trial run or participate in the simulation before assigning the simulation to students, when possible.
- Facilitators make sure that university facilities support the simulation when facilities are needed.
- Instructors integrate instructional simulations with other pedagogies such as cooperative learning.
- Instructors should anticipate ways the simulation can go wrong and include this in their pre-simulation discussion with the class. (Caniglia, 2019)

The course goals in the instance of the aviation maintainers simulation would tie to the areas outlined in the T&R manual and the troubleshooting section of the maintenance instruction manual. Scenarios would be built to reflect various discrepancies and their causes to allow the student to think through and experience the process for identifying the problem areas. The parts can be changed in an expedient manner in order to save time that would be required on equipment and allow the student to visualize what would be required and have a rounded overview of the system that would not otherwise be visible.

Facilitators would not be present for the general use of the simulation as it is more of a study tool than something to be proctored during a class. However, for the purpose of achieving completion of tasks for documentation in the T&R, the role of facilitator could be accomplished by the work center supervisor responsible for signing the completion of these tasks. In this scenario, the supervisor would need to understand the simulation and be comfortable with its operation. Additional development of the software and approval of its use would be vital to this implementation.

Primarily, this simulation is designed to be a tool for use by maintainers who have already completed the traditional introductory classroom instruction.

2. Active Student Participation

> Effective learning comes through simulations when students are actively engaged.
>
> Students should predict and explain the outcome they expect the simulation to generate.
>
> Every effort should be made to make it difficult for students to become passive during the simulation. Every student must assume a role that they may or may not know before the simulation. Often it is not known until the simulation. (Caniglia, 2019)

This is an area that will be critical to achieving the purpose of the simulation. The ability to simply click on items in the simulation to remove and disassemble is part of what makes it appealing. This capability provides for a deeper understanding of the interoperability and function of systems. It provides for the ability to confidently dissect systems without concern for asset readiness or of damaging the system. However, it also affords the possibility of simply clicking on items to falsely achieve the simulation's logical goal without understanding how that goal was achieved.

3. Post-simulation Debriefs

> Post-simulation discussion with students leads to deeper learning. The instructor should:
>
> Provide sufficient time for students to reflect on and discuss what they learned from the simulation.
>
> Prepare question to ask during the debrief to ensure students see alignment between the simulation and the course goals. (Caniglia, 2019)

Post-simulation debriefs will be a critical step in the use of this simulation to achieve T&R qualifications. Simply clicking through items in the simulation can bring valuable understanding about the intricacies of the systems but can also be performed with no understanding of their operation or reasoning. This aspect will need to be closely monitored by the supervisor in order to ensure understanding of the task being performed.

F. MULTIPURPOSE RECONFIGURABLE TRAINING SYSTEM 3D

The Multipurpose Reconfigurable Training System (MRTS 3D) is intended to help bridge the gap in instruction. "'The long-term vision is to offer all Navy training in the Ready Relevant Learning (RRL) model, which will become the new norm, backed by repeatable processes, new standards and proven results. We are looking at how a Sailor learns, what they need to learn, when they need to learn it, and the best way to deliver the learning content," said Eric Pfefferkorn, the program manager for RRL at NAWCTSD in Orlando, Florida" (Church, 2018).

This system is being developed with the intention to use it to simulate equipment and facilities where the students emulate shipboard procedures and manuals while interacting with touch screens. It is intended to be expandable and customizable for use with training on any necessary system. Specifically, a desired effect is that this system can be used to refresh knowledge among more seasoned Sailors years after any formal education in the MOS may have taken place.

The MRTS system has been incorporated in the MOS school curriculum in a limited fashion. This system follows much more closely with the guidelines detailed in the previous section. MRTS utilizes several standalone machines to create a networked virtual environment for classroom use of simulation and has been implemented to emulate the mobile electric power plant.

The IOS forms the interface between the instructor and the students. From the IOS, the instructor can:

4. Set up training scenarios. This allows the instructor to create specific discrepancies for the students to troubleshoot in accordance with the curriculum.

5. The instructor can monitor the status of the students both individually and as a group.

6. Student performance can be input into the MRTS Data Tracking System (MDTS) for evaluation and future review.

7. The instructor can override student controls in order to demonstrate certain scenarios for the students.

8. The IOS allows for configuring a classroom layout within their operation station via the Classroom and Laboratory Configurator (CLCon).

9. Instructors can interconnect with other instructor terminals and monitor the performance of the network.

The CLCon is used to set up and document the configuration of the classroom, allowing the instructor to view seating arrangements, view and change student terminal configurations and view classroom statistics.

The student side terminals house the simulation subsystems where the overall simulation resides. It provides mechanisms for state tracking and integrates the simulation with other objects. The SMS provides the interface between the students and the instructor and allows the students to:

1. View all installed MRTS applications.

2. Initiate and begin a lesson plan for a chosen application.

3. View student data such as name, rank, course, assigned groups.

4. Interact with the instructor and other students using chat functions.

The MRTS system utilizes a central repository of objects for use in various systems. This is not dissimilar to a tool room that would be used in a MALS work-center. It contains the tools that would be required for the use or maintenance in any system and can be retrieved on demand for use. This allows the MRTS to expand with growing demand for implementation on various pieces of support equipment as any common objects can be reused in other configurations of the system. A common configuration of hardware and software without the optional implementation of a specialized pod is depicted in Figure 4.

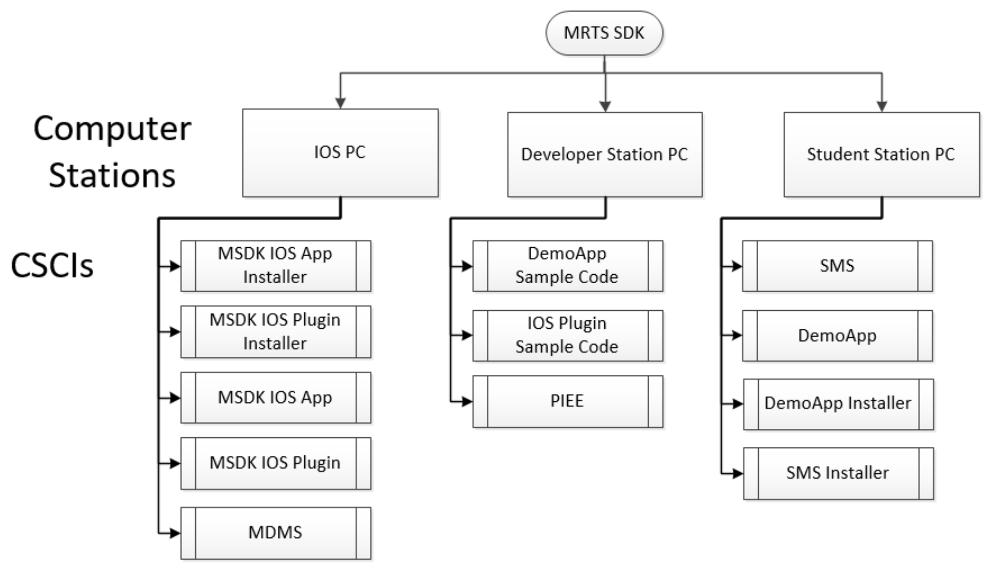

Figure 4. Classroom/Laboratory Hardware Configuration Item (HWCI)

MRTS is still in development in support of Naval training commands and is proposed to be customizable to expand beyond the mobile electric power plant for implementation as the Navy sees fit. This system will require multiple additional purchases of hardware to support its implementation. It will require a facility with a dedicated laboratory for its use and will require full support through either dedicated staff or contracted technical support entities. While these requirements may be justifiable in trade off for the capabilities gained, the plausibility of implementation outside of the structured setting of the schoolhouse is not realistic. This system is undoubtedly a multiplier for the quality of instruction for the maintainer’s introductory pipeline, but will be inaccessible for future reference once they arrive at their unit in the fleet Marine Corps.

MRTS could be used as a framework to develop a system to provide standalone scenarios to serve as refresher training or continuing OJT. Much of the base build has already been created to facilitate this sort of capability. Presently it has been built to simulate the mobile electric power plant as well as submarine specific applications. These would need to be modified in structure to accommodate the minimal hardware capability and portability proposed in this thesis. While the MRTS may provide a viable platform for future expansion of this program, at present it requires networking of custom-built consoles and servers that are beyond the scope of this thesis.

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III. TRAINING SYSTEM SOFTWARE

A. USE OF SIMULATION

1. Improve Aviation Readiness through Sets and Repetition

Aviation maintenance schools provide the theoretical indoctrination for maintainers. However, it is infeasible for the schools to mass produce experience. This is necessarily left to be built on the job. The only way to truly become proficient at a task is to perform it.

In military operations, it is stated that no plan survives first contact with the enemy. This does not discourage the generation of the plan. It is necessary to develop a plan to develop a set of heuristics in the combatant. The plan can be equated to experience. Planning generates a knowledge base for the way things should work. Knowing the plan inside and out allows the executors to adapt to events that cause deviation and correct the situation.

This is what experience produces with the maintainer. Through years of interacting with an aviation asset, the maintainer develops a clear understanding of the way the system should operate that extends beyond what can be learned through classroom instruction. Furthermore, the in-depth study and analysis of discrepant systems more deeply imbeds the understanding of the operation of that system. By experiencing many variations of trouble within a systems function, the maintainer develops a body of knowledge that they can draw on to affect troubleshooting with increased efficiency.

A maintainer troubleshooting a novel discrepancy for the first time may have the knowledge base to eventually discover and correct the issue. However, the time spent to achieve the result and the number of incorrect diagnosis' achieved before the final corrective action is reached can vary. As depicted in Figure 1, there are 15 probable causes listed in the troubleshooting section associated with the single loss of pulling power discrepancy. An inexperienced troubleshooter could spend hours or days attempting to determine means of eliminating potential discrepancies or reaching incorrect conclusions. When we then also consider the time taken to order and receive parts as well as perform the required maintenance to change the parts, reassemble and inspect the system, any incorrect diagnosis costs days and hundreds or thousands of dollars.

The operational tempo of Marine Corps squadrons cannot afford this sort of lag in maintenance. When time is essential, the troubleshooting of discrepant, mission critical assets are left to the most experienced maintainers to get the job done as quickly and accurately as possible. This causes further detriment to the capability of the new maintainer to gain experience by troubleshooting the system delaying achievement of experience vital to the future success and readiness of aviation.

The building of experience in a maintenance department is necessary to develop a functional squadron capable of meeting the needs of the nation. Yet it is this very need that acts to prevent the development of experience in maintainers. A training minded squadron could, in theory, sacrifice readiness while in CONUS to allow their maintainers to practice and develop necessary skills to increase capabilities and readiness while deployed. Yet, this is not feasible. In the dwell time between deployments, aviation squadrons fly just as much as during deployments to ensure that the pilots receive their required repetitions of flight mission sets.

2. Simulation Can Provide Quality Experiences

While nothing can truly replace physical experience, the aviation community has leaned heavily on simulation for the training of their pilots. Due to the inherent risk in their training, pilots are required to perform tasks in simulation before performing them in an aircraft. Simulation is used to bridge the gap between academic rigor and actual performance of the task in a physical aircraft. Simulation is used extensively to train missions that cannot reasonably be replicated. They are used to train night operations when a squadron may be constrained by city ordinances not to fly at night or to train combat scenarios not replicable physically. Building experience through simulation is not a new concept to aviation but is not used in practice for the maintainers.

A simulation can be used to allow the maintainer to build experience without cost to the readiness of the squadron. A three-dimensional (3D), detailed model of the aviation asset can be used to allow the maintainer to explore, troubleshoot and disassemble systems, building experience base in ways that cannot be performed on the actual asset. Most modern systems are designed using computer models prior to physical build. These models can be recreated for older systems or acquired from the designer for the more modern systems. Using these detailed scale models in simulation allows for the accurate replication of a system for exploration by a maintainer.

Porting the models into a simulation allows a maintainer to break down, disassemble and analyze a system in ways that are not practical or possible on an actual aviation asset. The simulation can implement discrepancies in a system to train maintainers in a highly accurate and realistic way. This would allow for the inexperienced maintainer to methodically study the system and discrepancies building an experience base without the constraints of time and money associated with squadron readiness. In simulation, troubleshooting a discrepancy can be conducted at the leisure of the trainee. If the diagnosis is incorrect, there is no time or monetary cost to the readiness of the squadron, the trainee can simply move on to continue troubleshooting. Learning through exploration and mistakes may not be the most efficient means, but many believe that it is the most effective, enduring means of learning.

Simulation in this manner can afford the maintainer access to a breakdown of systems not achievable in physical reality. As with most modern machines, aviation assets composite many systems within a single frame. Taking for example, the relatively simple MRTT used in this experiment. The fuel system is spread throughout the tractor and is accessible through various locations. The filters can be accessed through the open engine compartment from the top. The drain port on the fuel tank is accessed from under the tractor and the fill cap is on the exterior on the top of the tractor. The fuel pump and injectors are accessed in a different location and all parts interwoven among other systems and the tractor frame. Even in this simple example, it is difficult to understand and visualize the interconnectivity of the various parts of the system and how they interact when looking at the complete tractor. Simulation can allow the maintainer to view, manipulate and interact with only the fuel system by removing the surrounding tractor and systems affording a holistic view of the system in question.

A problem sometimes discovered that impacts readiness is that sometimes parts fail that are not anticipated by the system creators. For these discrepancies, there is not a detailed troubleshooting procedure that identifies the source, nor is there an abundance of parts in the supply system to deal with this new failure. These discrepancies surface as equipment ages and frequently cause the publication of technical directives to educate the fleet or to require system modifications. These novel discrepancies lead to scenarios where subject expertise does not exist. Simulation software can be readily modified, and patches distributed to train maintainers to deal with these situations expeditiously, overcoming the necessary learning curve through simulating experience.

3. Effectively Using Time for Simulation Can Improve Proficiency, Readiness, and Morale of the Force

When readiness lags squadrons often must take undesirable measures to regain mission capability. Readiness is not permitted to dip below a certain threshold, determined by the command culture, and when this threshold is not met it is necessary to decrease allotted liberty periods for the maintainers. To minimize the amount of lost liberty it is frequently the case where only the most effective and experienced maintainers are employed in the critical tasks necessary to regain the requisite readiness levels.

This frequently results in the employment of less experienced personnel in the performance of tasks unrelated to readiness. While designated personnel work diligently to correct discrepancies, the unexperienced attempt to shadow the actions and learn through the demonstration or are tasked with tending to the cleanliness of the spaces. While spaces do need to be tended, performing such tasks during designated liberty periods due to inadequate proficiency to improve squadron readiness is detrimental to moral.

Simulation can be used not only to train the maintainers to avoid this situation but can be a more productive use of this time. An effective simulator does not have to be a large piece of stand-alone equipment. It can be implemented as a simple executable application to be installed on every computer available in the workspaces. While the more experienced maintainers perform mission critical maintenance on the aviation assets, the less experienced can make use of the simulator to train and experience relevant troubleshooting and maintenance scenarios.

Broad availability of simulation will provide systemic improvement to the employment of time afforded for technical training. The importance of technical training is widely accepted and mandated within Marine aviation. Squadrons are required to set aside allocations of time for the purpose of training. Due to the available assets, this time is typically allocated to the accomplishment of required annual training or discussion of policies and procedures. While these training events are necessary, they do not necessarily contribute to the experience or effectiveness of the maintainers. If the simulator were available in each work center, this time could be used to either conduct individual progression, or it could be used by a more experience maintainer to demonstrate and explain more complex systems and discrepancies to trainees.

Overall, the use of simulation would produce more effective maintenance departments capable of making greater use of a larger percentage of their personnel. This increased efficiency and effectiveness would directly contribute to increases in readiness rates, confidence of the maintenance department, confidence in pilots pertaining to the soundness of their machines and overall improvement of moral across the squadron.

B. TASK ANALYSIS

1. VR/AR vs. UNITY/MRTS

In flight, it is vital that a pilot know instinctively the position and function of every control at their disposal. This muscle memory is necessary to allow for the unconscious decisions made continuously to maintain safe flight during even the most distracting events. Virtual reality simulations completely immerse the trainee in the environment to recreate the situations that will be encountered in the action to be trained and are the most common in use for flight simulation. Virtual reality is the closest thing that software can presently bring to represent a physical scenario.

Augmented reality is a manner of overlaying software onto reality. In many cases, this technology is used to provide additional information pertaining to what is being seen by the wearer. Its application to training software is reasonably expected to be extensive but is not necessarily applicable to the training of aviation maintainers.

While virtual and augmented reality present the most up to date state of the art representations of training software, their capabilities are not completely necessary for the maintainer nor are they fiscally responsible. Within a squadron, pilots vie for time in a limited number of simulators, competing with each other as well as with the pilots within other supported squadrons within the Marine Air Group (MAG). In many cases, these flight simulator facilities can rival the cost of aircraft flight. Aircraft flight simulators can cost as much as 10 to 12 million dollars per copy (Tegler, 2011). This does not consider the cost of the facility that must be built to accommodate the simulators, the maintenance of the facility, maintenance of the simulators or support provided to both systems. Commonly, within a squadron, the pilot corps consists of 20+ pilots of varying degree of experience vying with each other and four or so other squadrons worth of pilots for use of these facilities. For comparison, a typical maintenance department of each of these squadrons may contain 180+ maintainers. A similar implementation of a simulator facility for use by these maintainers is not feasible for the necessary throughput.

While not as prominent, the effects associated with the current state of the MRTS program are similar. This program requires an increase in hardware infrastructure and a classroom environment to implement. MRTS is structured to facilitate demonstration or proctoring by an instructor. This system requires connectivity to a network, a server to host, an instructor terminal, a developer terminal and student terminals. While this capability adds considerably to the effectiveness of instruction in a school environment, to implement this in its current form in the fleet to support all maintenance personnel would require similar endeavors and fiscal demands as implementation of flight simulators. Although arguably the lack of virtual reality in simulation would be cost savings.

The Unity real-time 3D development platform provides the capability to create and operate interactive, real-time 3D content for publication on a wide range of devices (Unity.com, 2020). This tool can be used for free in the development of VR/AR and 3D games if profitability of the implemented game remains below a specific threshold. Specifics of use for fleet wide implementation are beyond the scope of this thesis, however, it can be used to turn the model of an aviation asset into a 3D game-based trainer that can be implemented with limited change to the hardware infrastructure in place across Naval Aviation. While this sort of implementation does not provide the immersive environment discussed as a capability of VR/AR, troubleshooting skills are a test of logical, methodical thought process and do not require muscle memory associated with the real-life implementations of flight.

A game-based 3D training software can readily be made portable to existing computers in use in every work center across the fleet without additional implementation of hardware or infrastructure. The act of training troubleshooting capabilities is in creating repetition in thought processes and study of systems which can be retained and navigated readily through a game-based trainer without the implementation of VR/AR.

C. SOURCE CODE.

The MRTT Unity 3D build makes use of several sources and programs to create a game like environment that emulates the experience of a maintainer. The game is organized into linked folders as follows.

1. Animations

Animations used in this build are the creation of the researcher using Unity's build in animation creation functionality. The creator can record the manipulation of objects in the scene. In conjunction with an animator finite state machine, the creator can set conditions and sequences which trigger the created animations.

2. Asset Store Packs

This folder contains a large list of pre-built 3D objects that are made available for Unity users by artists who chose to post them. Many of these assets are open source, and all of the assets used in this build are freely available. Used in this build are:

a. 8K Skybox Pack Free

This is used to create the sky in the scene.

b. Asset Store Originals

This pack contains many 3D models of office furniture and was used to create the interior of the office space in the build.

c. Basic Metal Texture Pack

This is a set of textures that was used in various implementations of roofing, columns and benches.

d. Concrete Textures Pack

This set of textures was used in creation of the terrain map that forms the ground of the build.

e. Gas Station

This is a set of 3D objects that belong in a gas station and was used to create the fueling area on the support equipment compound.

f. Props

This pack contains the fuel drain barrel that is used in the scene to drain the contaminated fuel.

g. Roof Textures

This set of textures was used in the roof elements of the build.

h. School

This is a set of 3D objects that supplemented the available objects found in the asset store originals to create the office space in the build.

i. Standard Assets

This is a group of objects and capabilities that Unity provides for use by developers. In game, the player controls a first- person view camera that navigates like a first-person shooter game. This asset is available through standard assets.

j. Tiling Material Pack Free

This is another group of textures and materials that was used to create brick like walls in the game.

k. TV

This was another 3D object that was acquired through the asset store and used in the office space.

3. Character

This is the folder that contains the data for the character acting as the desk sergeant within the work center. This asset was created and posted for use on Mixamo.com (Mixamo, 2020). The character was complete with an FBX object file, and texture. Also downloaded from Mixamo was the sitting animation that is applied to the character.

4. Materials

This folder contains the materials and textures used in the build.

5. ProBuilder Data

Unity provides an object system for creating simple objects. Several objects within the game were created by the researcher using this tool.

6. Scenes

This folder contains data pertaining to the scene used. In this instance, it only contains one scene but in expanded versions, many various scenarios could be built and contained within this folder.

7. Scripts

Unity makes use of C# to impose script behaviors in games. This folder contains a number of scripts written by the researcher and applied to various objects within the build. This is the basic means for implementing user interaction with objects, animations and requirements.

8. Splash

This folder contains the particle system information that used to create the effect of pouring fuel from the MRTT tank.

9. Terrain

This folder contains the data used to create the terrain. Unity allows the developer to lay a ground terrain area and manipulate the texture, elevation and navigation.

10. Tractor

This folder contains the model used for the MRTT. The MRTT model and incorporated fuel system was generated using illustrations and dimensions available in the maintenance instruction manual (Naval Air Warfare Center, 2019). The model was created by Ryan Lee, a technical artist at FutureTech and research associate with the MOVES institute at the Naval Postgraduate School.

D. DESCRIPTION OF FUNCTIONALITY.

The trainer emulates the experience of a typical aviation support equipment maintainer. The trainee starts outside of the work-center on the support equipment compound. The compound, although not an exact replica, loosely follows the layout of the compound found at MALS-14 in Cherry Point, North Carolina.

In the event that the student is not familiar with the w, a, s, d controls of a first-person shooter, upon beginning the scenario they are presented with a series of text images providing tutorial. These tutorial images are created using a combination Unity canvas functionality and C# scripts to determine when to prompt and when the prompt acknowledges that the direction has been followed.

Upon demonstration of basic movement capability, the trainee is directed to enter the work-center. The canvas is removed from the screen and the mouse pointer is locked to a reticle in the center of the screen. In order to enter, the door of the work-center must be navigated. This is the first interact able object in the build. An attached script detects when the mouse cursor moves over the door. The script accesses the shader attached to the door and changes its color to a shade of green to indicate to the user that this object can be interacted with. Upon click or moving the mouse away, the shader will be restored to its preexisting texture.

Clicking will change the state of a Boolean trigger and initiate the animation sequence to open the door. The door animation is set to a timer and will automatically close after enough time has passed to allow the trainee to pass through. Once inside, the trainee will need to address the desk sergeant. A canvas was placed in front of the desk sergeant to facilitate activation when a click is detected anywhere in the space surrounding the character, desk or computer terminal. Interaction will provoke the display of a canvas image of the workload.

A workload is used in an aviation maintenance department to list all assets on hand that have discrepancies to be worked. This includes various types of equipment, discrepancies and statuses such as awaiting parts and awaiting maintenance. In larger implementations, this could be used to list available scenarios to be chosen by the trainee. For the purposes and scope of this build, only one option is selectable. Upon clicking the proper type equipment and discrepancy, the desk sergeant will direct the trainee to access a worker terminal.

This process serves to emulate several aspects of a maintainer's job. They receive tasking from the desk sergeant but are responsible for the paperwork associated with the performance of their own task. The worker terminals are displayed in a row on the far side of the room. Interaction with the mouse will change the color of the monitor at the worker terminal and applies to any of the several terminals available. Upon clicking, the worker will be able navigate the maintenance action forms associated with their tasked discrepant piece of equipment. This feature can be further expounded to train the administrative tasks of the job; but, for this scope, it only permits the screening of the MAF and changing the job status to "in work".

For consistency with the reality of aviation maintenance, the trainee will not be permitted to access the interaction features of the MRTT until their MAF has been placed in work. Placing the MAF in work will initiate a timer and unlock interaction with the

MRTT. At this point the trainee will have options of how to proceed. At any point during play, the trainee can access the troubleshooting manual by pressing the “tab” key. This will bring up a canvas with menu options displayed. Among these options is the troubleshooting manual. This is the starting point for troubleshooting and is when the maintainer would develop a mental plan of action that should resemble Figure 2. The system is designed as an experience building exercise. As a maintainer would encounter within the fleet, this is where the tutorial stops. The maintainer must now utilize reasoning to determine the cause of the discrepancy.

Upon exiting the work-center, the maintainer can see the fueling area for the equipment. As is the case at many compounds, there are two identical fuel containers that can be used to fill equipment. The markings are simple, small indicators of MOGAS (minimum octane gasoline) and JP-5 (aviation equivalent of diesel) and they are directly next to one another. This could help indicate a possibility to the maintainer that someone has put the incorrect fuel type into the tractor. Entering the workspace where the MRTT is parked, the trainee will encounter a solitary tractor and toolbox, both of which change color upon mouse over to indicate they can be interacted with.

The hood of the MRTT can be opened by mouse click. The animation is triggered with Boolean input and exposes a texturized display of the interior of the engine compartment. Upon clicking anywhere in the engine compartment, a menu is displayed with all the component systems of the tractor. Again, this feature is in place to facilitate expansion of the training software. Only the fuel system has been implemented and is selected with mouse click.

Upon selection, the fuel system becomes a point of emphasis. The tractor will be removed from the scene and an animation will play moving just the fuel system up and forward in the scene to facilitate study and interaction. The fuel system is displayed in the same manner as the MIM’s illustrated parts breakdown. This allows the maintainer to draw connects in their mind between the picture in the publication and the actual system as it is installed in the tractor.

There are multiple components on the fuel system that allow for interaction. Embedded in the scenario are three static variables whose condition must be satisfied in order to successfully complete the scenario.

1. Fuel Contamination Identification

On the exposed fuel tank, there is a fuel line, a fuel return line and a drain petcock. The petcock can be interacted with, and when clicked on will ask the trainee whether they would like to drain the fuel tank or pull a sample. If the trainee does not plan ahead, a selection of pull a sample will trigger an animation to open the petcock. The animation is designed to replicate the action as it would take place on equipment and will initiate the flow of fuel by triggering a particle system. The particle system will be allowed to flow onto the ground as it would in reality. This should spark thought in the trainee that they will need a tool.

Clicking on the toolbox will bring up a menu listing organizing the implemented tools by type as they may be organized in a box available to a maintainer for this purpose. Selection of specialty tools will open another menu. The trainee should select the metal can to gather the sample. Clicking on this selection will place a can on the work bench next to the box. Interacting with the can will take the lid off and returning to the petcock and selecting pull sample will place the can under the flow of fuel and fill it.

Returning to the work bench with the now full can of fuel, the trainee will need to determine how to test the fuel for contamination. This task expects the trainee to have or be able to gain an understanding of the properties of diesel and gasoline. The flash point is the temperature at which a liquid will emit enough vapor that when exposed to an ignition source will ignite. The flash point of gasoline is estimated to be -43 degrees Celsius or -45 degrees Fahrenheit. The flash point of diesel can be as low as 38 degrees Celsius or 100 degrees Fahrenheit in automotive applications designed for winter use, but will range higher in aviation applications (The Editors of Encyclopaedia Britannica, 2012). This means that at ambient temperature below 100 degrees, a can of diesel fuel will not produce enough vapor to be ignited by an open flame; a can of diesel fuel with gasoline contamination, however, will ignite.

The trainee returns to the toolbox and retrieves the propane torch, which will appear on the work bench when clicked. Clicking on the torch will activate a particle system that emulates the ignition of the torch. Clicking again will prompt the trainee if they want to test the fuel sample. If yes is chosen, the animation that is triggered will demonstrate the proper means of conducting the test. The torch is lifted, canted downward and passed over the open sample canister and returned to the bench. If the sample is contaminated, another particle system will be triggered showing a small flame coming from the fuel sample. The trainee can now replace the lid on the can to extinguish the flame and turn off the torch.

At this point the discrepancy has been identified and the next steps are required to correct it.

2. Drain Fuel

The trainee returns to the fuel petcock and selects it. In the menu that opens, the trainee selects drain fuel. For this action, an animation will place a used oil drum and funnel beneath the tank, the petcock animation will open and the particle system for the fuel draining will activate. The animation will play for 10 seconds. In reality, a full fuel tank will take much longer than this to drain. The time allocation was used to convey that it will not be an instantaneous process, but not to waste time simulating the actual required time. After the fuel has been drained from the system, the static Boolean variable will be set marking this task as completed.

3. Change Fuel Filters

There are two fuel filters visible in the fuel system, both will need to be removed. Upon clicking on the intractable main filter, an animation will play demonstrating the appropriate means of removing the filter. The filter will move off to the side and another click will reassemble. This emulates the replacement of the filter with a new one and sets the static variable to designate task completion.

The second filter is the pre-filter and is located on top of the assembly housing the main filter. Clicking on this item will animate removal of hose clamps and the pre-filter, again demonstrating the proper maintenance procedure. Clicking again will reassemble and set the static variable.

4. Job Completion

Pressing the escape key at this point will replace the fuel system inside the tractor, bring the MRTT back into the scene and close the hood. The trainee needs to return to the worker terminal in the work-center and mark the MAF as “job complete.” In expanded implementations completing the corrective action section of the MAF can be required but is not within the scope of this thesis. If the trainee has properly completed all tasks, all variables will be reset, and a congratulations screen will appear concluding the scenario. If the tasks have not been completed, a screen will appear prompting the trainee to complete the required tasks.

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IV. DESIGN OF EXPERIMENT

A. OBJECTIVE

The objective of this research is to provide maintainers training software that will accommodate exploring the systems under their area of responsibility without causing harm to the end item or aircraft. Using the software will allow the maintainer to build critical experience in troubleshooting and maintaining equipment.

B. RESEARCH QUESTIONS

1. Can modeling software be used to simulate real-world experience in maintaining aviation related equipment?

2. Can using a simulation improve the performance of aviation maintenance personnel?

3. Can the readiness of aviation assets be improved by the addition of simulation training to the maintenance work force?

C. HYPOTHESES

- Hypothesis 1

H01: There is no difference in confidence in troubleshooting capabilities among participants after exposure to the training software, $conf_{post} - conf_{prior} = 0$

HA1: There is improvement in confidence in troubleshooting capabilities among participants after exposure to the training software, $conf_{post} - conf_{prior} > 0$

- Hypothesis 2

We evaluated hypothesis 2 using a 5-point scale, where 1 was strong preference to not use the simulation, 5 was a strong preference to use the simulation, and 3 indicated no preference between the two. Therefore, a median value greater than three would indicate that the participant felt the simulation was more effective than classroom instruction.

H02: There is no preference among participants for the simulation training compared to traditional classroom instruction, $\mu_{use} <= 3$

HA2: There is preference among participants for the simulation training compared to traditional classroom instruction, $\mu_{use} > 3$

- Hypothesis 3

H03: Participants would not choose to make use of the simulation in support of daily operations $\mu_{use} = 0$.

HA3: Participants would make use of the simulation in support of daily operations, $\mu_{use} \neq 0$

D. STUDY

1. Initial Plan

Prior to COVID-19, the study was intended for a population of 6073 maintainers in the fleet Marine Corps. The target was the support equipment compound at Marine Corps Air Station (MCAS) Miramar. This site was chosen since it houses two conjoined but separate MALS. One MALS would perform as the control group.

a. Control

An MRTT would be designated as having a loss of pulling power and rough running discrepancy. The participants would then, one at a time be asked to troubleshoot the tractor in the presence of the researcher. The researcher would record the chosen order of systems inspected and record the overall time. For the sake of the experiment and to preserve the assets for possible necessary use by a squadron, the MRTT would not actually be sabotaged.

The participants would eventually inspect the fuel for possible contamination. This decision would be reached in whatever order they chose. The other possible options explored before this decision would be recorded. Upon decision to pull a fuel sample from the MRTT, the researcher would provide the participant with a sample to be analyzed. The decision of means to test the sample for contamination and determination made by the participant would be recorded.

After determination that the diesel fuel had been contaminated with gasoline, the participant would show and describe on the MRTT the procedure used to correct the problem to include draining the fuel from the system, replacing the fuel filter and pre-filter. Upon completion, the time would stop.

b. Study Group

The study group would be provided with the training software prior to conducting the same test described above. This would be done several weeks prior to the performance of the test to simulate the planned scenario where the software is available for use by the fleet, but discrepancies occur according to typical daily operations.

In the simulation, the participant will be exposed to an MRTT that displays the same discrepancy. The software will allow the participant to simulate the troubleshooting steps, test the sample, drain the tank, and replace the filters. The simulation will not allow the participant to claim job completion until all conditions for repair of the discrepancy are met. The participants will then be subject to the same test as the control group.

2. Revised Experiment

Participants were solicited from the Naval Postgraduate School computer science and modeling and simulation cohorts via email. The email gave a cursory explanation of the researcher’s experience and the nature of the study.

The participants were provided a standardized consent form that will be kept on file for 10 years following the conduct of the study.

a. Pre-study Questionnaire

The planned experiment utilized a target population that had already been exposed to the traditional instruction program associated with 6073 MOS. These participants would have varying levels of experience that would have been naturally distributed across the control and study group. However, with the modified participant population, it was necessary to assess the preexisting knowledge base of each individual participant in order to identify possible changes in comfort or knowledge after the conduct of the study. The pre-study questionnaire had questions about their level of confidence and proficiency in conducting repairs as well as about their level of familiarity with first person shooter style games. The entire survey can be found in Appendix A.

b. Task Performance

The participant was provided with two options for navigating the training software. A room was provided for use of a computer on the NPS campus, or if the participant was uncomfortable with performing the study in person, they were provided a link to the software and conducted the study while in a Teams meeting with the researcher.

The participant was greeted with a welcome screen and guided through a tutorial that introduces them to basic first-person shooter type game controls. The tutorial brought them into a work center that emulates the experience of a generic support equipment compound. They greet the desk sergeant (the manager in charge of assigning tasks to workers) and select the MRTT with the implemented scenario. He then directs them to a worker computer terminal where they are required to perform the administrative task of initiating work. The timer begins and displays on the screen.

The participant navigates to the tow tractor outside the work center and begins to interact. The participant is expected to open the troubleshooting section of the publication and determine that the most likely cause of the discrepancy is the fuel system. They open the hood of the tractor and select the fuel system, prompting the deactivation of the tractor from the simulation and presentation of the fuel system components.

The participant will then retrieve a fuel sample can from the toolbox provided and collect a fuel sample from the tank. These instructions are not provided to the participant as the nature of the software is to allow for discovery learning to ensure the greatest retention of the lesson. Upon retrieval of the sample, the participant tests the sample by passing a propane torch over the fuel which will only ignite if the diesel has been contaminated with gasoline.

The participant places the lid on the sample to extinguish the flame, drains the contaminated fuel from the tank, identifies and replaces the fuel filter and pre-filter, then presses the escape key to bring the rest of the tractor back into the simulation. The participant then returns to the worker terminal to complete the task. The time taken is recorded.

During the conduct of the training, the researcher provides direction as necessary to bridge the gap in knowledge inherent in the population. The software is designed with a trained mechanic in mind, therefore does not contain instruction on what tasks to perform.

c. Post-study Questionnaire

Upon completion of the study, we could not perform on unit testing of knowledge retention. A post-study questionnaire served to determine the level of insight that the participant believed they acquired about the situation presented. Many of the questions correlate to the pre-study questionnaire to assess changes in the users' beliefs. The entire survey can be found in Appendix B .

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V. DATA ANALYSIS

A. RESTRICTIONS

Initial plans for experimentation and data collection were to run experiments to analyze the effects of the training software on a group of aircraft maintainers. Due to the effects of the pandemic on operations, the experiment could not be conducted as planned due to travel restrictions put in place, so experimentation was limited to students at NPS.

As an alternative, students in the computer science and MOVES curricula were targeted. This would generate a pool of participants that while not necessarily subject matter experts in aviation maintenance, could provide valuable feedback on the training software usability.

Additionally, in order for Marines to participate in the study, or for the study to investigate the effects of the training on Marine Corps systems, additional reviews were necessary by the U.S. Marine Corps Institutional Review Board (IRB). Due to the time constraints involved, Marines were eliminated from the pool of participants. The NPS IRB approved a research protocol that the team followed.

To accommodate participant comfort levels and comply with the intent of mitigation measures to minimize potential exposure to COVID, many participants chose to conduct the experiment remotely. Microsoft Teams software was used to share the participant's screen with the researcher to facilitate navigation of the training software.

B. HYPOTHESIS TESTING

1. Hypothesis 1

H01: There is no difference in confidence in troubleshooting capabilities among participants after exposure to the training software, $conf_{post} - conf_{prior} = 0$

HA1: There is improvement in confidence in troubleshooting capabilities among participants after exposure to the training software, $conf_{post} - conf_{prior} > 0$

The frequency of the differences in participants' responses between the first question in each of the pre and post study questionnaires is shown in Figure 5. The mean difference in responses was 0.23 $\pm$ 0.32 with a standard deviation of 1.17. Because the confidence interval includes 0, we failed to reject the null hypothesis that there is no difference in the participant's confidence in their ability to troubleshoot this discrepancy.

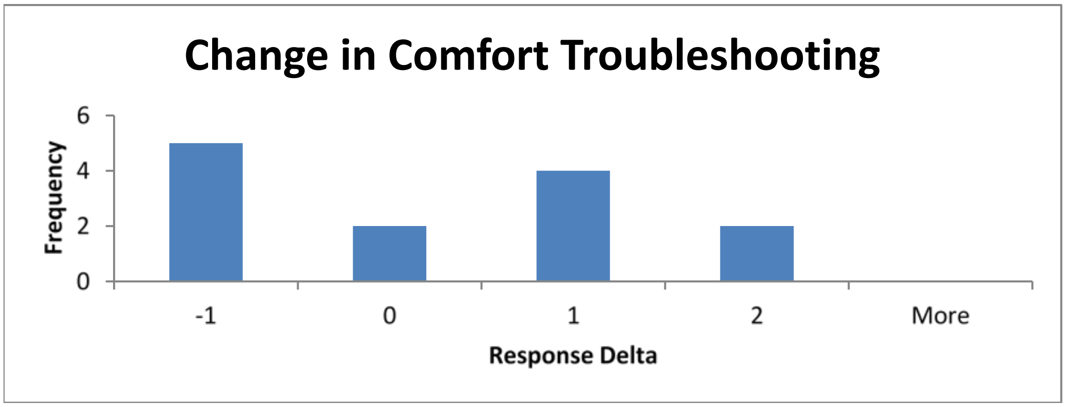

Figure 5. Change in comfort level

This would appear to indicate that the participants did not find the simulation useful to build comfort. However, the responses of 5 of the 13 participants indicate a decrease in comfort troubleshooting this discrepancy. This indicates to the researcher that it is more likely that the verbiage used in the questions did not properly convey the meaning, rather than a decrease in confidence after completing the study. Removal of negative responses yields a mean difference of 1 $\pm$ 0.27 and reduces the standard deviation to 0.76. Unfortunately, this is merely an interesting fact, and we cannot use it to reject our null hypothesis.

2. Hypothesis 2

H02: There is no preference among participants for the simulation training compared to traditional classroom instruction, $\mu_{use} <= 3$

HA2: There is preference among participants for the simulation training compared to traditional classroom instruction, $\mu_{use} > 3$

The frequency of the participants' responses to the second question in the post-study questionnaire is shown in Figure 6. In the answers to the question, a value of 1 indicates a complete preference for classroom instruction and a 5 indicates a preference to discard classroom instruction and replace it with this method, while a 3 indicates no preference. The mean response to this question was 3.08 $\pm$ 0.24 with a standard deviation of 0.86. Given that three lies within the confidence interval of the median value, we are unable to reject the null hypothesis that there is no preference.

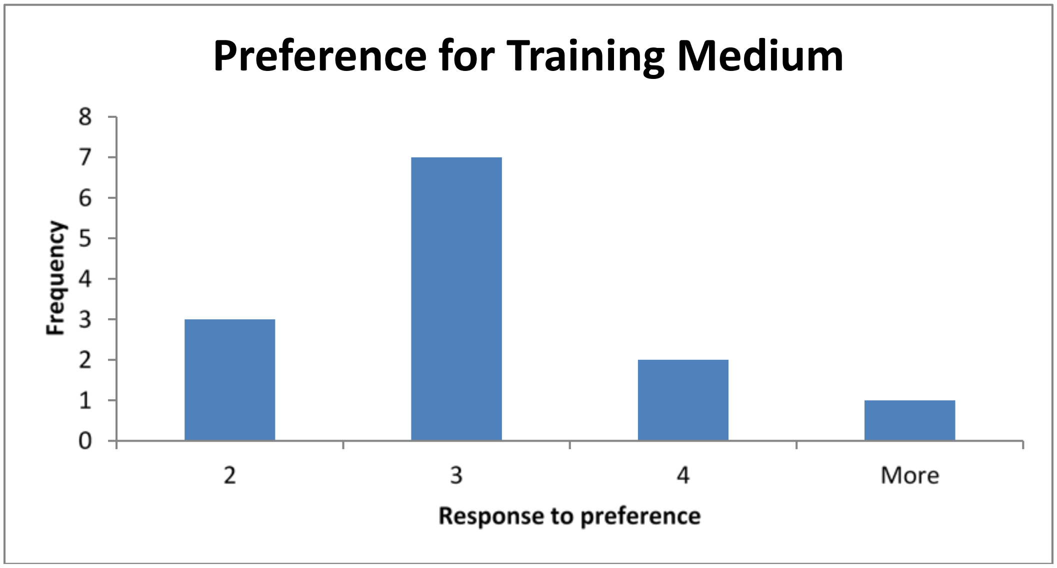

Figure 6. Preference for training medium

As is evident from Figure 6 the response to the question indicates that most participants believed that this method of instruction should be used equally alongside formal instruction. No participants indicated that formal instruction should be used alone, without the aid of this software.

While the data was not able to discard the null hypothesis, it should be noted that 10 of the 13 participants thought it at least as valuable as classroom instruction. In future development and testing, the phrasing of the questions to evaluate this hypothesis should be reconsidered.

3. Hypothesis 3

H03: Participants would not choose to make use of the simulation in support of daily operations $\mu_{use} = 0$.

HA3: Participants would make use of the simulation in support of daily operations, $\mu_{use} \neq 0$

The frequency of the participants' responses to the third question in the post-study questionnaire is shown in Figure 7. Question 3 of the post study questionnaire asks the participants to put themselves in the shoes of a novice maintainer and indicate whether they would use the training sim. The response indicates how frequently they would make use of the proposed system if they had unfettered access. The null hypothesis is rejected. The mean response was 3.69 $\pm$ 0.24 with a standard deviation of 0.85. This indicates that while some participants would make more use of the tool than others, all participants believed that they would use the tool if it was made available.

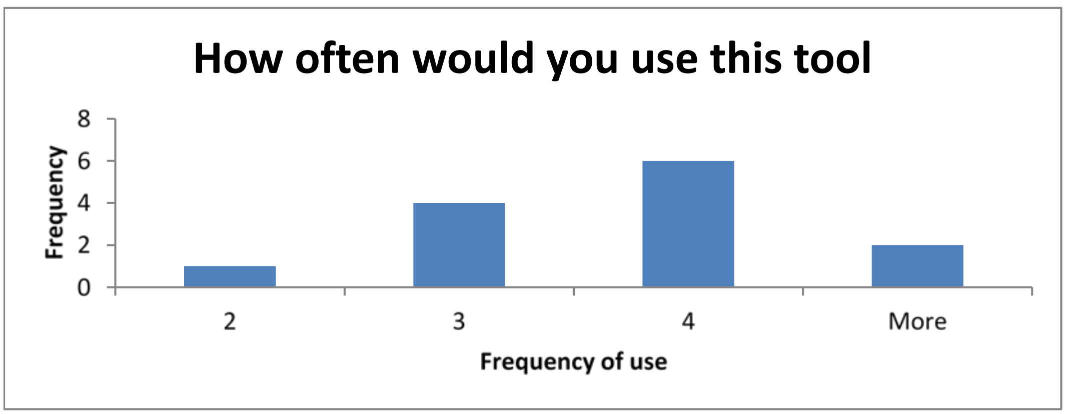

Figure 7. How frequently would the participant use the tool

C. PARTICIPANT FEEDBACK

Responses to additional questions and feedback comments were overall positive for the implementation and expansion of the system.

1. Areas for Improvement

Some discrepancies in the software were discovered immediately upon initiating testing. Foremost was the menu overlay system. When opened, the menus did not disable interaction with the scene in the background. In some instances, this would result in the opening of multiple overlapping menus and would take away from the smooth playability and immersion of the game. This was most disruptive upon completion of the task. At any point in the game, the participant could open a menu, navigate to the main menu and exit the program cleanly. However, once the MAF has been completed, the menu navigation falters and the user is forced to terminate the program manually.

While the build of the system was easily downloaded and played on the participants' computers without significant problems, differences in the resolution of each computer display would lead to the menus and onscreen texts to display differently, sometimes making it difficult to read.

Future implementations should include more help features in the system. The software is designed to force the user to think in order to identify causes of discrepancies and means of implementing troubleshooting techniques. However, it is also designed to train the maintainer in those techniques and procedures. Hint functionality should be implemented to assist the user when they reach a dead end.

Some participants thought that there should be barriers in place to prevent the user from navigating to areas that are not relevant to the task being trained. When built, the scene was designed to resemble the configuration of an actual support equipment compound. This was to allow for the placement of many pieces of equipment around the compound to facilitate implementation and expansion of the system. However, it could also be narrowed to avoid confusion and have only one piece of equipment active in the scene at a time in the maintenance area.

2. Positive Impressions

Among the participants that claimed little or no experience with gaming, there was some requirement for adaptation to the navigation. However, they all became familiar with the controls quickly and found them intuitive.

Participants liked the ability to reference the maintenance manual in game, however the need to close the reference again before continuing with the process was not ideal. Multiple participants wanted the implementation of some variant of heads up display in the system.

None of the participants involved in the study were previously familiar with the MRTT or the NAMP. However, the participants drew parallels to their areas of expertise and saw the value of implementing this in their career fields. The participants thought the premise of the training system was a great way to develop skills and mentioned that such a system would be greatly beneficial in augmenting instruction in areas such as motorcycle maintenance, weapon system maintenance, roofing and solar panel installation.

Participants added that this was a great pre-learning tool that provides space where the learner could navigate and learn comfortably at their own pace and ultimately come to the end result of learning a task completely new to them. It could also be used as an assessment tool to test existing knowledge and gain efficiencies.

VI. CONCLUSION

A. RESULTS

1. Hypothesis 1

Conduct of the pilot study and data analysis was not able to reject the null hypothesis that there was no difference in user confidence in troubleshooting abilities, $conf_{post} - conf_{prior} = 0$. The mean difference in responses was 0.23 $\pm$ 0.32 with a standard deviation of 1.17.

The researcher does not believe that this is indicative of a failure to instill confidence, but more likely poorly phrased questions. While an insignificant demonstration of increased comfort might be reasonable due to minimal exposure to a minimally implemented prototype, the data indicated in 5 of 13 participants a decrease in comfort in participant troubleshooting capabilities.

2. Hypothesis 2

Again, the conduct of the pilot study was not able to reject the null hypothesis that there is no preference for the prototype training software over classroom instruction $\mu_{use} <= 3$. The mean response to this question was 3.08 $\pm$ 0.24 with a standard deviation of 0.86, where preference for the simulation relates to a 5 and preference for classroom instruction relates to a 1.

The inability to reject this null hypothesis does not indicate rejection of the system. The response indicates that the participants believed strongly that instruction should be a balance of traditional classroom instruction and the software tool.

3. Hypothesis 3

The pilot study rejected the null hypothesis that participants would not choose to make use of the simulation in support of daily operations $\mu_{use} = 0$. The mean response was 3.69 $\pm$ 0.24 with a standard deviation of 0.85. This demonstrates that the study participants would choose to make use of this tool if it were at their disposal.

B. DISCUSSION

Aviation maintenance is a complex and technical profession. Using present training methods, years of on the job training and experience are required to become proficient as a maintainer on any specific platform.

The operational tempo and constant circulation and recruitment of personnel in the military services requires the rapid training of new personnel to staff maintenance divisions. This is performed through formal schooling that can take as many as two years of the service member's five-year contract to produce a minimally capable, basically trained maintainer. Once this maintainer joins their maintenance department, years of on the job training are required to hone those skills and make the maintainer a capable troubleshooter.

The nature of apparent discrepancies encountered during the maintainer's tenure at a squadron does not necessarily yield a well-rounded knowledge base. The acquisition of this knowledge is further impeded by the need to support operations and readiness, frequently leading to the employment of only the most experience and technically proficient maintainers for troubleshooting and more challenging maintenance procedures.

Aviation readiness could be significantly improved if all maintainers within a maintenance department had access to the experience and knowledge of the more seasoned maintainers. While the inexperienced maintainers do have access to more experienced personnel during OJT, these personnel are usually employed in supporting operations and cannot instruct troubleshooting procedures for discrepancies that are not currently present on an aviation asset. If maintenance personnel could build experience through simulation, their overall effectiveness could be improved.

Military services operational tempo and budget do not allow for continuous proctored instruction in a classroom setting or the purchase of classroom-based training networks requiring significant hardware. The training simulation needs to be independently accessible by all maintainers, when they are ready to access it. This means that the system must be capable of running on a laptop that is already present in the work-center or be hosted online and be accessible by those laptops.

The MRTT, built in Unity, for this thesis achieves this goal. The simulation is built as an executable that can be played on a minimally capable laptop. It was successfully tested on fourteen machines, with varying levels of capability. The build was placed in a SharePoint folder. The researcher shared the link with the participants. A 200Mb download of a zipped folder did not prove problematic for any participants. After which a double click of the MRTT.exe file launched the program which was successfully executed by all computers without troubleshooting or modification.

The MRTT prototype build was based on a task analysis of the troubleshooting section of the maintenance instruction and demonstrated troubleshooting procedures for contamination of diesel fuel with gasoline as a cause of the reduced pulling power discrepancy. While the restrictions of the ongoing pandemic prevented the conduct of experimentation as intended, the researcher believes the results would have been positive and could be conducted conclusively in the future.

This build assumes the user has a background education in maintenance and troubleshooting procedures. This is demonstrated in the troubleshooting step to test the fuel for contamination. It is expected that the trainee has knowledge of flash point differences of diesel and gasoline to determine if contamination is present. Future implementations should include capabilities such as asking for hints when the maintainer does not know how to proceed. However, this is intended as an experience building system, the premise of which is that knowledge is retained better when the right answer is not simply provided.

C. FUTURE WORK

1. Additional Functionality

Further expansion of this program to encompass all discrepancies and systems could provide an indispensable tool to rapidly develop experience among the personnel responsible for maintaining the MRTT. This concept could be applied across all equipment in Naval aviation to provide a ready resource for all maintainers. While this prototype is effective, professional construction of the software could provide a more immersive, realistic appearance that would stimulate greater interest among the target audience.

The prototype design for this thesis explores only one possible cause of one discrepancy on one piece of equipment. While circumstances prevented the analysis of data collected to support its effectiveness, I believe that future experimentation would support implementation.

This prototype could be expanded to cover all possible root causes for the discrepancy. One of the faults of this implementation is that it is not possible for the trainee to make an incorrect decision or explore a path of troubleshooting that does not lead to the correct answer. Experience comes from learning through exploration and sometimes making mistakes. Expanding this scenario will lead to more retention of information.

Future implementation should include other discrepancies that occur in the system. If this concept were to be applied for use in training, it should include every possible cause of every possible discrepancy. This could initially follow a task analysis for every discrepancy listed in the troubleshooting section of the maintenance instruction manual. The troubleshooting section is written before the equipment undergoes extensive use. Maintenance data should be collected from the user over the lifetime to identify unplanned discrepancies and their root causes.

While this software used the MRTT as an example prototype due to its simplicity, it required more man-hours to implement the working model than would likely be necessary for builds on other, newer aviation assets. It has become a common procedure during the creation of aviation systems to use 3D models in their design. This was not available for this prototype but could be acquired from the manufacturer for use in later implementations.

2. Cloud Hosting

One of the main considerations in the construction of this prototype was minimal requirements to purchase hardware. The build was intended and is capable of running on a minimally capable laptop similar to that which would be available in a work-center in the fleet.

The Navy and Marine Corps already host learning solutions online for the distribution of training materials. This could be maintained in a cloud repository and either hosted for remote log in or download of individual applications to user terminals.

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APPENDIX A. PRE-STUDY QUESTIONNAIRE

The following questions are designed to assess your preexisting general technical knowledge as well as your experience with gaming. Your honest self-evaluation will allow the researcher to better analyze the effect of the training scenario.

Using the provided scale, 1 indicating that you are not comfortable changing a flat tire on your car, and 5 indicating that you are comfortable rebuilding the engine, what is your level of mechanical ability?

1	2	3	4	5

Using the provided scale, 1 indicating that you have never received official mechanical instruction of any kind, 5 indicating attendance at formal MOS or certificate producing school, how much classroom instruction have you received in mechanical system troubleshooting or maintenance?

1	2	3	4	5

Using the provided scale, 1 indicating that you have never attempted to perform any work on your own vehicle, 5 indicating several years of experience as a mechanic in a repair facility of some sort, how much experience do you possess in troubleshooting and maintaining mechanical systems?

1	2	3	4	5

Using the provided scale, regardless of instruction or experience, with 1 representing completely unlikely, and 5 meaning highly probable, given a problem with your personal vehicle how likely would you be to attempt to fix it yourself?

1	2	3	4	5

Using the previously described metric, having never before performed a task, how likely would you be to disassemble a system in your vehicle or other machine to correct a discrepancy?

1	2	3	4	5

Using the provided scale, 1 meaning that you have minimal experience with first person shooter games, 5 meaning that you frequently play, how much gaming experience do you have?

1	2	3	4	5

What is the MAXIMUM number of hours per week you have played first person shooter style video games in your life?

___________________ hours/week

APPENDIX B. POST-STUDY QUESTIONNAIRE

The following questions are designed to assess the effectiveness and quality of the training you just completed. Your honest self-evaluation will allow the researcher to better analyze the effect of the training scenario.

Using the provided scale, 1 indicating that you are no more comfortable now, 5 indicating that you would perform the work on your own vehicle, how comfortable would you be diagnosing and correcting a situation where diesel fuel is contaminated with gasoline?

1	2	3	4	5

Using the provided scale, 1 indicating that you would prefer formal classroom instruction without this program, 5 indicating that this sort of training should replace classroom instruction, what is your impression of this tool for developing troubleshooting and maintenance skills?

1	2	3	4	5

Using the provided scale, 1 indicating never, 5 indicating every day, if you were a new maintainer and had access to this tool (provided it was expanded to cover many discrepancies) would you use this to gain experience in troubleshooting and maintaining systems in your area of responsibility?

1	2	3	4	5

Using the provided scale, regardless of instruction or experience, with 1 representing completely unlikely, and 5 meaning highly probable, given a problem with your personal vehicle and access to a tool such as this built for your vehicle, how likely would you be to attempt to fix it yourself?

1	2	3	4	5

Using the previously described metric, having never before performed a task, provided a tool like this, how likely would you be to disassemble a system in your vehicle or other machine to correct a discrepancy in the simulation?

1	2	3	4	5

Using the provided scale, 1 meaning that you found the gameplay difficult and unintuitive, 5 meaning that the controls and objective were clear and intuitive, provide feedback on the function of the trainer.

1	2	3	4	5

When using this program, how did you correct the discrepancy? 1 relates to reading the troubleshooting manual and methodically understanding the discrepancy and repair and diagnosis. 5 relates to opening the program and freely clicking on everything to find out what it does.

1	2	3	4	5

Additional comments for the research team:

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