Improve Aircraft Maintenance Sortie Production Rates with Extended Reality and Artificial Intelligence Assistance in Maintenance Processes

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ABSTRACT

The average age of United States Air Force (USAF) aircraft is 29 years, and this aging fleet requires skilled maintenance personnel to perform constant care to generate airpower. The Air Force employed the use of virtual and augmented reality technology to aid in developing aircraft maintenance personnel as well as to supplement established training methods. The application of augmented and virtual realities has reduced the time needed for classroom instruction during maintenance initial skills training without sacrificing the quality of education. The next step is to develop a system and processes that use extended reality assisted with artificial intelligence for use on the flight line. Various industries have developed extended reality capabilities that can be used by the Air Force to provide access to technical orders in a hands-free medium. Extended reality will also open opportunities for multimedia walkthrough instructions that include video teleconference support within a headset. Artificial intelligence has the potential to assist a maintainer through extended reality by providing predictive maintenance instruction while informing quality assurance processes in near real time. Artificial intelligence could recognize tasks at hand to help recall instructions and record accomplished tasks. Theoretical applications like this could free the cognitive load of individuals by automating the need to record information and recall reference material.

The scale of equipment needed to accomplish this AI assisted vision is not developed yet but several industry efforts with further development could enhance aircraft maintenance operations. This paper will compare current augmented reality technologies being employed by the USAF, those in development in complementary industries, and look for solutions that improve sortie production rates as well as their first-pass quality work. This cost benefit analysis will be measuring the time saved on process due to use of extended reality assisted with artificial intelligence versus already established procedures.

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Introduction

Immersive digital environments in social interactions and classrooms have driven conversations on how Virtual Reality (VR), Augmented Reality (AR), and Extended Reality (XR) technologies can provide data rich environments at a cost-effective scale. For example, an individual that lives in North America can tour historic castles in Europe in a 360° view via a virtual reality headset without the need to spend time and money traveling. A student studying about complex aircraft engines can learn the procedures on how to replace a jet engine turbine blade without touching an aircraft engine. Application of this technology beyond classroom instruction and novel experiences has proven to increase efficiency in various manufacturing applications to include aircraft maintenance operations. With the average age of U.S. Air Force (USAF) aircraft being 29 years old and some specific fleets of aircraft averaging 50 years old, the need to increase efficiencies in maintenance operations is paramount to generate combat airpower (Tirpak, 2021). It has already been proven that VR technology increases efficiencies in an academic environment and in theory, XR technologies assisted with future developments in Artificial Intelligence (AI) could reduce time needed for complex and routine tasks while providing a safer work environment (Cohen, 2021).

The term extended reality encompasses interactions with real and virtual environments covered under AR, and VR. AR uses a combination of computer-generated objects superimposed on the real world that adapt to the perspective of the user (Doolani, et al., 2020). VR is fully digital, mostly using special headset or glasses where all images are images or graphics produced by a computer (Doolani, et al., 2020).

Research Question

This research reviews the current use of digital training technologies focused on Virtual Reality (VR), Augmented Reality (AR), and Extended Reality (XR) capabilities that can be related to aircraft maintenance operations. Looking at U.S. Air Force (USAF) aircraft maintenance will be the primary focus but also exploring other related manufacturing industry applications of VR and AR. This paper addresses the following questions. Q1: How is the USAF currently using AR and VR to advance training and operations? Q2: How is AR, VR, and XR being used in commercial industries? Q3: In theory, how can the USAF develop a common XR technology paired with artificial intelligence for aircraft maintenance operations?

CURRENT USES OF EXTENDED REALITY IN AIRCRAFT MAINTENANCE

The use of AR in education settings has expanded despite some of the challenges in integrating AR content into traditional learning methods slowed by the high cost of proprietary equipment and programing (Lee, 2012). The Air Education and Training Command (AETC) within the USAF has invested in VR and AR technology to advance multiple efforts to include Undergraduate Pilot Training (UPT) 2.5 and Technical Training Next with Technical Training Transformation (T3) for training maintenance personnel. These technologies have been seen as perfect mediums that tailor training to individuals while aiding in overcoming the high cost of operating aircraft and scheduling constraints that can delay training. Training delays early on in a USAF member's career can affect deployment readiness for the USAF. Immersive technology modernizes and supplements established learning methods of class lectures and textbooks and provides a medium that can adapt to individuals needs and deliver content at the right place and at the right time (Lee, 2012).

USAF Maintenance Training

The USAF Crew Chief Fundamentals course teaches how to maintain landing gear, engines, swapping tires, performing inspections, and launching and recovering aircraft. This is a very technical course that requires students to digest large amounts of content typically delivered in lecture, written, and on-the-job training formats. Under the Technical Training Transformation initiatives, this program uses adaptive immersive learning technology to deliver tailored training content that places the students at the center of the learning experience. In some cases, use of VR to teach the new crew chiefs has resulted in a 46% reduction in course completion time compared to traditional methods (HTX Labs, 2021). Visualizing the relationship of where things are situated allows for faster retention of information. VR allows for more content to be self-paced while the teaching environment tracks progress and provides reports to students and instructors. With many of the crew chief students being technically adept with experience with video games or other digital interfaces, much of this training can be seen as a game. This has helped motivate some students to engage in the content and applies principles of gamification.

Member, Operations, Training, Analytic, Reporting

Within AETC, a common virtual platform named Member, Operations, Training, Analytic, Reporting (MOTAR) has been selected to fulfill the requirement to track force development within the digital space (Cunningham, 2021). MOTAR is an open architecture system that compiles all XR content for AETC training programs allowing for talent management tracking of individuals throughout their careers in the USAF. MOTAR will also communicate with legacy training systems to allow for an easy transition to this modern training platform.

Maintenance Operations and Training Augmented Reality was the original name of the system when the project was a USAF Spark Tank submission in 2018 under the Tennessee Air National Guard 164 Airlift Wing. The main premise of the system to consolidate AR/VR applications in one standardized interface, has not changed. The original design was showcased with a Microsoft HoloLens being used to aid in maintenance operations, enhanced animated step-by-step instructions, visible safety warnings, and access to collaborative interaction with supervisors and planners (Williams, 2018). MOTAR has always been a hardware agnostic medium allowing commercial-off-the-shelf hardware to be used on the system. This approach will enable a relatively smooth transition to future hardware advancements.

A common challenge for most commercial-off-the-shelf products is the Department of Defense cyber security protocols. Authority to connect equipment to a government network must undergo scrutiny and meet various information impact levels. Most of the training content would be hosted on unclassified networks meeting what is known as Impact Level 4 (IL4). This allows their system to handle Controlled Unclassified Information (CUI) that is still protected by limiting access to US persons with a security background check and non-disclosure agreements (DISA, 2017). Bureaucratic processes to grant authority to operate and connect commercial systems can create a delay in introducing new systems to MOTAR. This same hindrance also helps to safeguard against malicious intrusion into government systems.

Gamification

Gamification is the process of using game-related elements to nongame contexts (Basten, 2017). For example, in the crew chief training program, an individual tasked to change a tire needs to remove a safety wire and safety glasses are required for this task. If the student attempts to remove the safety wire before donning the appropriate safety equipment the screen will turn red, letting the student know that they have injured their eye in the virtual world (McCullough-Hudson, 2021). This immediate notification provides feedback to the student who failed a portion of the task and keeps them alert of their progress (Basten, 2017). Table 1 shows additional game elements that are applied in several disciplines to include immersive learning.

Table 1. Common Game Elements (Basten, 2017)

Game Element	Definition
Feedback	Immediate notification that keep users constantly aware of progress or failures
Goals	Activity goals that are adapted as challenges for the user
Badges	Optional rewards and goals outside the scope of a service's core activities
Point System	Reward for completing actions (that is, a numeric value that's added to the total points)
Leaderboard	Tracking and displaying desired actions to drive desired behavior through competition
User Levels	Indication of the user's proficiency in the overall gaming experience over time

Performance Analytics

Learning with a digital medium can provide instructors with a snapshot of a student's performance by tracking defined markers that contribute to digital training records for Airmen, allowing instructors to efficiently monitor students' progress (McCullough Hudson, 2021). In VR training near real time feedback can be provided to students and teachers to help focus on long term improvements. Beyond visualizing results of testing, a VR system can track additional performance metrics defined by the instructor to indicate progress or areas of concern. With the example of a student virtually cutting safety wire prior to donning safety glasses, the system can log this into categories of checklist discipline or safety procedures that can be highlighted to an instructor for correction and additional training. The digital system can assist students by providing additional training suggestions to help correct deficiencies leading to a tailored training experience. Most importantly, the instructor can now focus their time providing individualized training, ensuring students are comprehending and reducing student attrition through failure.

As more data about a student's performance is documented, a student's success can be predicted and therefore, allows for teachers to take proper measures to elevate the learning experience for the student (Rafique, et al., 2021). If the tracking system has documented history of a student struggling with safety procedures, it could predict the individual's success on upcoming safety related tasks, improve future course outcomes by providing opportunities to boost retention, and improve the overall quality of teaching (Rafique, et al., 2021). These metrics could be tracked to the point that prior academic outcomes could predict the success of an individual in a complex task, allowing for leaders or managers to select the most efficient person to complete a time critical task (Rafique, et al., 2021).

When applied outside of an academic environment, tracked metrics to predict future execution could be seen as intrusive or a demoralizing way to determine an individual's ability to perform a job they are qualified to accomplish. Like electronic monitoring and surveillance tracking, an individual's capabilities must be protected for privacy and to keep good morale within the workforce (Basten, 2017). The proper balance between efficiency and respect must be achieved allowing for continual improvement by providing feedback and determining an appropriate plan for improvement.

MOTAR provides robust performance analytics to act as a talent management system, keeping individuals aggressively modern by following Airmen from the beginning of their career, all the way to retirement (Thurber, 2021). Under the supervision of AETC Detachment 23, MOTAR is being advertised as a learning management system to other major commands within the USAF to help consolidate the various systems with overlapping lines of effort (Hudson, 2022).

7th Bomb Wing B-1 use of AR in Maintenance Processes

At Dyess AFB, TX the 7th Bomb Wing started to use a mixed reality product by ThirdEye Gen that is being developed to aid in multiple applications. For flightline maintenance support the glasses can be used as an alternative to large manuals that are typically viewed on laptop computers, tablets, or printed text. The technical orders can be recalled via voice command and instruction of processes can be displayed on the wearer's field of view showing the PDF or images of the task at hand (ThirdEye, 2021). Additionally, these glasses can enable remote support applications where others can view what the glasses are seeing to help or approve of processes on the flight line (Kanowitz, 2020).

Commercial Use of AR in Manufacturing and Aircraft Maintenance Related Fields

In 2013, Boeing started to develop a system called Boeing Augmented Reality Kit (BARK) for use in Airplane Manufacturing. This system uses the Microsoft HoloLens device with software called Papyrus that Boeing had developed and loads on the devices in the factory. Within Papyrus, digital models of aircraft assembly processes have been converted from the original computer-aided design content to allow for three-dimensional (3D) overlays to guide individuals through manufacturing processes. To properly align the 3D models over the physical environment, spatial registration is typically accomplished with pre-positioned reference points known as multi-markers. As a user moves throughout the project, they are advised to stare at a marker to re-calibrate the special references to account for any drift in overlay accuracy. As this system guides individuals through their assigned jobs, it also logs the progress that has been made to track progress more accurately on the assembly line. Boeing's use of BARK within its manufacturing processes has seen a 60-70% reduction in manufacturing errors (Davies, 2018).

Figure 1. BARK Graphical User Interface (AWE, 2021)

The company Lockheed Martin is using AR goggles for its assembly of space systems for NASA. They claim assembly personnel can make decisions more quickly and have been able to reduce an 8-hour activity down to 45 minutes (Langston, 2020). This is the result of a decrease in manufacturing errors and in some cases, Lockheed Martin has experienced zero re-work requests on tasks in which workers were assisted by the AR headsets (Langston, 2020). The supporting technology can recognize objects in the real world without the need for static reference points or barcode scanning and overlay relevant assistance without the need to engage with design experts on a regular basis. The company also reports significant time savings by reducing break time needed to review manuals on an external source. It was determined that before the use of AR, half of their time was spent turning wrenches and they were able to reduce the amount of time spent processing overhead data by about 90 percent (Langston, 2020).

Figure 2. Lockheed use of AR (Microsoft, 2020)

To help the DOD transition its legacy system to an XR solution, the Defense Advanced Research Projects Agency (DARPA) has issued a $5.8 million contract to build an AI system capable of scanning instruction manuals and converting their data into instructions for AR systems (Strout, 2021). This contract has been awarded to a subsidiary of Xerox named PARC. The second part of their system will take scanned information and create an AR guidance to deliver task information in a personalized way based on the user's skills (Strout, 2021).

Innovative training solutions pursued by the USAF like MOTAR will help reduce the time and resources needed in developing human capital for the USAF. Lockheed Martin and Boeing have proven XR and AR systems that reduce cost and time needed in their manufacturing processes. By combining these innovative solutions, more robust USAF aircraft maintenance processes can be developed to reduce the time and cost of generating aircraft.

COST BENEFIT ANALYSIS

Cost

Assigning a cost to operating an aircraft can all add up. The cost is mainly based on the time it takes to maintain an individual unit, the fuel needed to fly and other external factors like paying for use of airspace and the ground defined as a range under that airspace. Annually, the Office of the Under Secretary of Defense issues a list of the reimbursement rates associated with the fixed wing and rotary wing within the Department of Defense. The reimbursement rate does not factor in the cost of using airspace or a range but is related to aircraft operating cost and can be used to understand how much it will cost to operate that aircraft for training or a tasked mission. For example, in 2021 the defined reimbursable rate per hour for an A-10C - $7,779, any RC-135 - $19,044, and E-4B $92,948 (McAndrew, 2020). With such a large operating cost it is important that each flying hour allotted to aircraft be used efficiently and those flying are expected to exhaust all options to make sure their time flying is optimized. Undefined in this reimbursement rate is the cost of training an individual. Each time a scheduled flight is canceled, there is a large impact to the loss of flying training and deteriorating proficiency of aircrew that is not defined in monetary value. With a flight of attack pilots operating the A-10C, if one of the four planes in the flight cancels for maintenance-related factors, there is an immediate effect on that one pilot's opportunity for training and additional reduction in training efficiency for the other three pilots. For an RC-135V/W the loss of one scheduled flight affects the crew of 17-30 people all with unique training requirements.

Saving time in maintenance processes to generate available aircraft allows for additional scheduled flights that can maximize training. This value is not always directly associated with a dollar cost but can impact the loss in training for aircrew. The DOD spends billions of dollars annually to sustain aircraft to ensure they are available to simultaneously support today's military operations and maintain the proficiency to meet future defense requirements (GAO, 2020). Maintenance challenges are often tied to aging airframes that require greater investments of time and resources to complete critical tasks such as phase inspections and engine maintenance. An XR system can help prepare individuals performing the less common phase inspection tasks by providing a medium that allows access to the aircraft in a digital medium so that they are better prepared for the hands-on time with the equipment allowing the opportunity for a greater success rate in performing their tasks.

In addition to the impact on training and readiness, another non-monetary cost associated with using a digital medium comes in the form of cyber vulnerability. Wireless systems in an information-contested environment are susceptible to attack and can be compromised by being fed false information or completely disabled (Johnson, 2022). These threats are present during competition, crisis, and conflict and highlight a major downside to using an XR system in maintenance operations. The fundamental skills of maintenance personnel should be developed so that they are not reliant on technology (Johnson, 2022).

Large tech companies like Microsoft, Meta, and Apple have started to invest in VR and AR technology over the past decade. Where AR interacts with a user's surroundings by overlaying digital content, many companies see a greater market potential when compared to VR (Tilley, 2021). VR provides a very controlled environment for engineers to work with leading to lower cost and the time needed to develop content and hardware. Where AR needs to adapt to the surroundings it is introduced to and dynamically adapted to the users' interactions with objects that are not controlled by the programmers. One of the indicators to show the challenges of developing wearable VR equipment can be seen in the number of units sold. It was assessed that in 2021, only 325,000 AR headsets were sold with one of the more popular units being Microsoft HoloLens costing $3,500 (Tilley, 2021). Compared to the 9.4 million VR headset sold in 2021 with the

Figure 3. US Army AR (Novet, 2021)

Oculus Quest 2 by Meta selling for $299 (Ubrani, Mainelli, & Reith, 2021). With the forecasted AR industry growth potential, tech companies are planning to release their own smart glasses (Tilley, 2021). This competition will drive down the cost of units while developing a better product that can be used in aircraft maintenance.

Developing a purpose-built system that would specifically assist with aircraft maintenance operations would be costly. In 2018, the US Army developed the concept for use of XR capability and awarded a 10 year $21.88 billion a contract to Microsoft to build over 120,000 custom HoloLens headsets (Novet, 2021). If all the background cost is spread across the units sold these custom headsets could cost over $182,000 each.

The USAF is moving forward with using VR in areas where it works well now. The current strengths of VR are in training and education where an instructor can control and tailor content to the students, the Air Force is applying this technology in pilot training, maintenance training and many other initial skills courses.

Benefit

The USAF has seen a 46% reduction in training course completion time compared to traditional methods for some of their initial skills training (HTX Labs, 2021). This is in part to the efficiencies gained by using a virtual system that can adapt to the environment needed for an educational setting. It also ensures that students are prepared for precious hands-on time with actual aircraft so that training does not need to be re-accomplished. These benefits are already being realized and AETC will continue to develop the technology. This makes it more logical for similar capability to be used outside of the classroom as a cost savings measure.

Boeing's use of the BARK system saw a 60-70% reduction in manufacturing errors within its manufacturing processes (Davies, 2018). In the Lockheed Martin XR example, time spent dealing with manufacturing processes and overhead data improved by 90% (Langston, 2020). If aircraft maintenance in the USAF can find similar efficiency, they can spend more of the scheduled work hours generating aircraft to fly. Many of those efficiencies for Lockheed Martin were seen in their verification processes where technicians spent less time putting down their tools, walking back and forth to a computer or printed technical order to help guide them through processes (Langston, 2020). They were able to use simple voice commands with their XR headset to display video of detailed instructions or to log work completed for a faster quality assurance process. Less time would be spent on revising tasks if the USAF uses an XR system to assist in recording tasks that have been accomplished. It would also be able to notify a user that they have not accomplished a task in accordance with the technical orders. This would also inform the quality assurance process and ensure that the work is accomplished on the first attempt with the hope of seeing similar success to Boeing and Lockheed Martin programs with a 60-90% improvements in their processes.

As new weapons systems are procured, industry will design and manufacture using digital mediums that will allow for a more seamless transition of the extended reality content to the USAF.

THEORETICAL APPLICATION OF ARTIFICAL INTELLIGENCE WITH EXTENDED REALITY

Artificial Intelligence

The goal of AI integrated with XR should be to develop a system that can supplement human intelligence and continue to adapt as more information is introduced to it. This opens opportunities to streamline processes and more efficiently use a person's time. Development of systems like MOTAR within the USAF and Papyrus with Boeing can serve as powerful databases documenting many actions that can be analyzed to find efficiencies or recommendations on improvements. In the case of an educational system like MOTAR, allowing AI to perform analytical work on a student's performance would inform students and instructors of recommended ways forward. In near real time, AI could engage with a student in the form of gamification by providing feedback and goals to help students achieve their desired learning objectives. AI would need to always be monitoring a student's level of engagement and provide new challenges mitigating a decrease in gamification's positive effects (Basten, 2017).

Flight Line Operations

Developing a system like MOTAR for use outside the learning environment would need to stay out of the way of the user as if it was never there. Within the USAF it is important that maintenance personnel become proficient in their core competencies and not become reliant on technology. The physical equipment needs to be developed so that it is as simple as wearing safety goggles and the AI needs to assist in documenting work completed and intervene only when an unsafe situation is identified. To enable this, a system like Boeing's Papyrus does not rely on content to be specifically programmed for use in an AR environment but it is able to load the 3D overlays from engineering documents to help speed up fielding technology and reduce cost. DARPAs effort to build an AI system capable of scanning instruction manuals and converting data into instructions for AR systems will also accelerate fielding AI assisted options. AI needs to assist in tasks that are routine, and the value of human decision making is limited and require little use of their ethical faculties (Brose, 2020). Transmitting information from one system to another, sifting through oceans of data to classify the relevant information.

AI needs to use uploaded content to perform auto task recognition assisting in knowing when a project has been accomplished. A common task where AI assist could help is after every flight a prescribed amount of engine oil is to be added. AI could recognize the can of oil, how much has been poured from each can and document the accomplished task all while reporting the near real time status back to digital logbooks for aircraft status reporting and supply inventory. AI would be used to transmit information from one system to another and sift through vast amounts of data to classify the relevant information highlighting progress or concerns to supervisors so that a human's time is best spent in making decisions (Brose, 2020).

Creating reliance on a digital medium for military operations introduce several concerns. Cyber vulnerabilities of a digitally connected system are expected to be exploited and will most likely be denied, degraded, or destroyed by an adversary during conflict. If maintenance personnel create a reliance on a digital system to access reference material or to guide them through tasks it will be difficult to generate aircraft for combat operations during conflict. It is important that core competencies are developed to help mitigate cyber security concerns that could limit use of XR and AI. Safety around the flight line and other heavy equipment operations is another concern. A extended reality system has the capability to provided critical alerts and warnings to help keep individuals safe. This technology should be used at scale to assist when someone is in danger, but if XR is used to constantly overlay information this can become distracting and lead to mishaps. AI should assist in preventing dangerous situations by constantly monitor activity and providing visual and audio alerts only when needed. This would allow for fewer distractions while still preventing dangerous situations.

An AI system that is constantly monitoring and reporting information and provides real time corrective feedback to act as a quality assurance mechanism to ensure work is properly accomplished on the first pass. Like the manufacturing practices of Lockheed Martin, who is using AR goggles for its assembly of space systems for NASA, where they were able to see a 90 percent reduction in time spent processing overhead data, or Boeing's BARK seeing a 60-70% reduction in manufacturing errors, the USAF could see similar improvements in their processes. Privacy does become a concern when the system is constantly monitoring and reporting on an individual's actions (Langston, 2020). Data can be collected for both the activity performed and the user performing it can be used for process improvements and to tailor individuals training but to avoid a feeling of heavy-handed organizational control and lack of trust, data should be used only in a combined form with like data to prevent singling out people in public while still allowing for corrective action in private (Basten, 2017). With mass amounts of data being tracked on individuals, the overall AI system can identify deficiencies in the knowledge of the workforce and recommend to supervisors' areas for improvement that can be developed for remedial training.

Necessary Equipment

For this vision to become reality for the USAF it will need a XR headset that is lightweight and scaled down in size from the current industry equipment. There are concerns for eye strain and neck strain with extended use of XR systems as they are fielded today. Industry is investing a lot of money into further development of the commercial systems that will fit into everyday practices. The USAF should work with current efforts in industry to develop a system that has the feel and appearance of safety glasses but has the connectivity of a robust XR system like HoloLens. At first this system will require an internet or data connection to access AI assisted content, but as further investment is made in hybrid server technology wearable devices can be connected for episodic periods and run disconnected

with just the right amount of information and AI needed for the task at hand until it can once again be connected to the established network.

Current USAF efforts with software like MOTAR allow for a consistent record of an individual's training and experience levels to build out the information AI would need to assist in developing individuals. This same system would then be used to sift through vast amounts of data so that a human's time is best spent in making ethical decisions.

Agile Combat Employment Example

The USAF is developing doctrine and operating concepts for methods to dynamically establish operating locations to help project Airpower in a time of conflict, this is known as Agile Combat Employment (ACE). Established air bases are seen as static vulnerabilities that are expected to be targeted in conflict. Additionally, fiscal and political constraints have limited the establishment of new permanent air bases needed to employ air operations beyond US borders. (LeMay Center for Doctrine, 2021). An enabling principle to ACE will be individuals that perform tasks outside of their core specialty known as Multi-Capable Airmen. These individuals will be trained as a team and each team member will have diverse skills and can operate in an expeditionary environment to accomplish mission objectives together (LeMay Center for Doctrine, 2021). Deploying a team of multi-capable Airmen with XR capabilities would allow for enhanced on-the-job training enabling team members to train each other on their own expertise. It is critical that Airmen become proficient in their core competencies of their assigned specialty so that they are not reliant on a digital medium to perform their job. In ACE, XR with AI would best be used to train individuals on new skills and assist by logging information of tasks accomplished as well as finding efficiencies in processes.

To enable this concept, the XR system for ACE should have the capability to operate as an independent system that is disconnected from a network and work with intermittent connectivity. It needs to be able to sync data when connected to a trusted source. A local hybrid server would enable this for when the ACE location is disconnected from the broader network. It will also need to be hardened against cyber vulnerabilities. Without an independent system, Airmen using this technology would be limited when adversary nations disrupt internet connections or exploit the connected device. These prescribed system requirements highlight the necessity for Airmen to be proficient in their core competency and not reliant on technology to execute their tasks.

USAF Doctrine Note on ACE prescribes that the sustainment mechanism to enable distributed operations will need to be a "push" system rather than a "pull" system that delivers goods just in time for use. A digital connected XR system enabled with AI that can recognize and track supply levels would be ideal for a "pull" system, assisting logistic process by predictively requesting supplies when needed, but still can air in a "push" application by informing supply chains of supply status. If data connections are intermittent or throttled the system would report packets of appropriate data to make sure higher headquarters is aware of airfield and maintenance status.

Air Combat Command recently mandated their bases to use Command and Control Incident Management Emergency Response Application (C2IMERA) as a system to report status and send command and control messages to a base (Blumenstein, 2021). C2IMERA will have a practical application in ACE and would be a perfect network medium for content logged by XR headset with AI to report base status of forces. C2IMERA already has established connections to base Maintenance Operations Centers for reporting aircraft status. The next advance step is for an AI enabled XR headset worn by a maintainer to log work accomplished and report near-real-time updates to an estimated time for completion of a process, providing an installation commander the most recent updated status of forces.

CONCLUSION

After reviewing the AR, VR, and XR systems being used in commercial industry now gives hope that similar productivity can be seen in the USAF. The Extended Reality system needed to improve USAF aircraft maintenance efficiencies has not been created yet, but when it is developed and paired with AI, there is great potential for a safer and more productive work environment. This future will be enabled by the rapidly expanding virtual industry that large technology companies are supporting. With multiple commercial companies investing in virtual environments and equipment it is expected that the cost of operating in virtual worlds will decrease. Just as the proliferation of the personal computer in the late 1990s introduced computers in every office and many classrooms, the same economy of scale will reduce the cost of XR technology. The USAF should not invest in developing a proprietary military grade

system but should encourage innovation in continuing to use current commercial systems for training. Investing now will help to fuel the development of a lightweight system that can be integrated into daily routine. Additionally, as hardware becomes more integrated into a person's everyday life, the more natural it will be integrated into a work environment.

For the USAF to use commercial grade XR beyond an educational setting, the equipment needs to be scaled down in size to mitigate the plight of cumbersome equipment interfering with aircraft maintenance operations. Distractions caused by bulky headsets could quickly lead to unsafe situations in an environment already filled with dangerous equipment. The burden of wearing XR will be eased when the industry develops a wearable technology that has the look and feel of safety glasses. This future equipment needs to be paired with an AI system that facilitates human machine teaming by alleviating a maintainer from the task of documenting work complete. The first step is to develop an AI system that can automatically recognize equipment and associated tasks. From this simple automation, AI assistance can be expanded to record tasks that have been accomplished, allowing for a reduction in time spent accomplishing necessary paperwork as well as data inputs. This same AI system can increase efficiency by recognizing if a task has been accomplished correctly or not. This future concept needs an AI that can provide immediate corrective action, reducing the time spent on individual tasks. Like the success Boeing has seen with its AR efforts, the USAF could see a 60-70 percent reduction in the need to repeat tasks with the application of AI. Additional efficiencies would be seen in an automatic documentation that informs quality assurance processes to ensure task are correctly done allowing for more valuable time to be spent teaching individuals.

New technologies bring about change to established processes. Many of the established processes in the USAF have been forged by lessons learned from loss of large sums of taxpayer's money, life, or limb and because of this adoption of new tools should be carefully reviewed and vetted. This due diligence does not excuse cost overruns and product delivery delays that can deter procurement of aircraft maintenance XR equipment. The USAF needs to continue to invest in XR technology and develop AI that will increase efficiencies in generating combat airpower.

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