The Use of Virtual and Augmented Realities in Air Force Training

By

Mr. Joshua A. Booth

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Instructors: Col Tony Millican, Dr. Dennis Armstrong, and Dr. Tony Gould

Air Command and Staff College
Distance Learning
Maxwell AFB, AL

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Preface

The United States Air Force has a history of residing on the forefront of technology. This characteristic extends to the imagination of the Airmen who serve in the world's greatest air force. The 2015 USAF document, *Global Vigilance, Global Reach, Global Power for America,* states "The effectiveness of Air Force airpower comes directly from the power of Airmen. . .the Service's unmatched capabilities exist only and precisely because of the imagination, innovation, and dedication of its people."[1] Airmen are once again proving this statement with innovations in the arena of force development through the use of augmented, virtual and mixed reality (collectively referred to as extended reality or "XR") technologies. At this time, there have been no service-wide efforts to standardize the use of these technologies. Many innovative Airmen from the unit to command levels have initiated their own XR programs for developing others where resources are lacking for traditional training, or risks are too great to provide traditional training.

There are valid reasons for this novel approach to education and training. The quality of a first-hand experience is far greater at imbedding the skills of a trade in students than teaching theory and providing examples. The fighter pilot community has discovered a pilot who experiences their first encounter with enemy aircraft in simulation (either in flight simulators or in flying exercises such as red flag) is far better prepared for their first real engagement in battle.

Other occupations will benefit from a similar process. XR systems provide more flexibility, higher throughput, and are more robust than the currently used training simulators and mock-ups currently used to provide training. Virtual systems can provide individualized experiences to students, allowing students to proceed at their own pace and retry failed procedures multiple times without holding up the class. Schools could easily add scenarios to XR training modules to account for commonly noted missteps by students.

With the benefits of XR in education and training, the question is why it is not seeing more use across the military. There have been successes in industry (specifically medical surgical training and industrial training applications). The cost of XR technologies and the computers to run them have been rapidly falling with a corresponding increase in quality. Pockets of successful use of XR systems are beginning to bubble up across the military establishment. The question of what is holding back the widespread use of this potentially game-changing technology is the basis of the research in this paper.

Abstract

Recent advances in technology have brought the cost of extended reality (XR) systems down to a level where development of training programs in virtual environments is feasible. Studies have shown that learning experiences in virtual environments equate to experiencing the same tasks in real life. Civilian industries have begun using XR systems for training and development in everything from medical surgery to Wal-Mart cashiers. While these technologies are finding their way into corporate training efforts, their implementation in the Air Force seems infrequent and small-scale. Purchases of commercial systems by units have been useful, but limited. There are several examples of limited testing of XR and a few programs in development that never seem to reach an operational status. The widespread use of these systems is being hampered by several factors. There is a lack of coordinated effort at the enterprise level to develop and guide the use of XR systems. There is no established XR community to exchange ideas and lessons learned. There is no serious involvement from the cyber community in the use of XR systems. Finally, there is no secure network available to host the integration of multiple Air Force XR systems across the globe.

Section I. Introduction

The uses of virtual technologies in education are not new. For many years, schools have experimented with virtual worlds, much like the Air Force experiment with "MyBase" in Second Life®, in 2008.[2] These computer generated environments have attempted to capitalize on the customizability and interactivity of software to enhance learning. While educators and developers have attained success to varying degrees with these types of virtual worlds, another technology is poised to take virtual learning to a new level. Virtual reality (VR) and augmented reality (AR) have reached a technological maturity (and price point) that enable deployment in most learning environments.

A discussion on VR and AR technologies may get confusing due to the non-standard terms and definitions in the industry. As hardware and software developers create devices or content, they use naming conventions that make sense to their project or program. Sometimes, these conventions counter the use of the same terms used by another entity. Over time, the industry has solidified the meaning of some terms, but many other terms remain vague or undefined. An example is the term "mixed-reality," which still has different meanings in various areas of industry. The use of VR is a term generally accepted as defined by Jaron Lanier, the first person to coin the term. Mr. Lanier refers to VR as a system that replaces a user's reality with an artificial one. However, Jaron offers 52 definitions of VR in his latest book, *Dawn of the New Everything*.[3] For the purposes of this paper, the term "XR" (extended reality) will be used as an all-encompassing definition of alternate, augmented, and virtual realities that attempt to replace some or all of a user's perceived reality with a computer-generated artificial reality. In XR, the attempt is not to bring computer-generated content to a user (as is done on a monitor), but to bring a user *into* the computer-generated environment. The effect XR developers seek is known as "presence."[4]

The use of XR technologies generates excitement and novelty when users first encounter an experience that provides an exceptional sense of presence. The question for instructors and leadership becomes, "does the technology live up to the hype?" In his doctoral dissertation on the uses of VR in higher education, Dr. Tony Millican identified in his research "acquiring technology just for the cool factor"[5] as the largest concern of US Air Force Squadron Officer College leadership. Due to its nascent use in education, researchers and educators have yet to develop the best practices resulting in highest impacts to learning. Since much remains to be discovered about what is possible and how to implement XR, those interested in beginning XR programs must focus on the effects they are trying to achieve at the beginning of program development. The concentration is not on achieving what is possible with the technology (e.g. highest frame rates, best graphics, fidelity of haptic feedback, etc.), but on what is needed to conduct student learning in the most effective and efficient way possible. An effects-based approach to XR training program development will steer program development effectively with the highest return on investment.

Section II. Background and Significance

Some individuals envision futuristic ideals of XR technology exemplified in movies like *The Matrix* or *Minority Report*. They imagine virtual worlds that are indistinguishable from real life, or artificial graphics filling the room encompassing their whole field of vision. Other people think of the novelty use of sticking their phones in a plastic or cardboard case (such as Google Cardboard) to watch a 360 video or using the Ikea app to see an artificial coffee table appear in their living room through the camera on their phone. Still others think of the broken promises of Virtual Reality from the 1990's. Nintendo commercials touted the Virtual Boy would "transport game players into a virtual utopia."[6] In reality, the system was a small, monochrome display that did not track the user's movement. The lack of tracking, and its poor graphics and refresh rate, simply made users sick. Nintendo shut the product line down within a year of launch.[7] This and other similar failures in XR hype caused many to feel disillusioned about the prospects of this technology.

XR technology today lands somewhere in the middle. While the graphics have finally reached a level of quality that will give the user a sense of presence in an artificial environment, users will not mistake what they see for the real world. Most VR applications create a sensation of being inside a cartoon or CGI children's movie. Some applications still make users nauseous, but the industry has learned tricks to minimize simulator sickness.[8, 9] Haptic feedback is still relegated to pulses and vibrations from hand controllers for most common applications. The exception to this are the hyper-real specialty projects that require purpose-built facilities and heavy object tracking capabilities (e.g. The VOID™ entertainment company).[10] AR combines computer-generated graphics with a user's vision of reality. It is a more emerging technology that is just beginning to become useful, though in a somewhat limited capacity and at a higher cost. The field of vision is more limited than the displays in VR head mounted displays (HMD), and many AR HMDs cannot accommodate prescription glasses.

The reason for interest in XR technologies would be the cost and access to the technologies are finally to a point they are useful. In previous decades, the hardware (and computing systems powerful enough to run them) was only in the domain of universities and military research due to six-figure costs related to running these systems. Now, users may obtain all the hardware needed to create a convincing virtual environment for under $2,000.[11] Companies, such as Facebook©, Immersive VR Education©, Resolution Games©, and Microsoft©, are beginning to capitalize on this low price point, creating virtual experiences for gaming, meditation, electronic social gatherings, and training. Some industries, such as medical, have taken advantage of using the virtual environment for training.[12] Various units in the Air Force have begun using XR technologies, but it has not yet scaled up to become a norm. The looming questions involve determining the value of XR technologies in training and education. If valuable, program leaders need to determine how to implement XR in their field. Lastly, they need to determine what barriers there are to implementing XR solutions and how to overcome those barriers.

Current uses of technology in Air Force technical training

Air Force technical training is equivalent to civilian trade schools. The technologies used in the course are as varied as the career fields. In most courses, instructors teach a portion of instruction in a traditional classroom setting using projectors or large monitors displaying an educational presentation. The schools issue students military-developed note-takers and course materials. Standard quizzes and exams monitor trainee progression. For skills training in the technical career fields, schools use computerized training (e.g., computer based training modules), mock-ups (models used to represent the real mechanism being studied), training systems (real systems either decommissioned or previously set aside for training), and laboratories (computers, scientific or test instruments arranged to demonstrate principles).

Existing technology in the military schools are not bad. They are time-tested and of known value to the education of trainees. However, there are limitations with each technology used. For example, it is debatable whether even the best computer simulations on a computer monitor provide true experiential learning. Experiential learning is a learning process "whereby concepts are derived from and continuously modified by experience."[13] Realistic mock-ups could provide students with experience, but they tend to be few in number and limited in the tasks that can be trained on them. Training systems are similarly handicapped in that they are limited in number, and they tend to be difficult to maintain.

The computer generated training simulations on standard computer screens provide familiarization and enhance understanding of materials to students. An example would be the virtual aircraft maintenance-training program known as MAGPIE (maintenance training based on an adaptive game-based environment using a pedagogic interpretation engine)[14] that can inject malfunctions and errors into training scenarios for students to "fix" on virtual aircraft. This exercise may prove valuable in progressing the student's cognitive understanding of the system, but it does not provide the same progression in the psychomotor skills required to perform tasks on real-life systems. According to Dr. Millican's research, Dr. Benjamin S. Bloom's taxonomy is core to professional military education in the US Military.[15] With Bloom's taxonomy for learning in the cognitive domain, student knowledge may increase from remembering to applying or analyzing,[16] but will not provide student growth in the psychomotor domain (imitate, manipulate, perfect, articulate, embody). Most students need to experience performing tasks in order to advance in the psychomotor domain.

Mock-ups are training devices developed specifically to train students on a particular task (or set of tasks). Due to their specialized nature, mock-ups can be relatively expensive, and therefore they exist in very low numbers in the Air Force. In technical schools, most classes share mock-ups and take turns training on the procedures. Mock-ups are also not always designed to look and feel like the real thing. Sometimes, they are designed only to teach a concept or principle, so they also lack the experiential element of actually performing the task on a real system. An example would be mock-ups used by the 5th Space Launch Squadron at Cape Canaveral Air Force Station that are used to train mission assurance tasks.[17] Mission assurance is the "identifying, tracking and assessing risk for assembly, testing and operations [of space launch vehicle processing and operations]."[18] The mock-ups do not represent real space systems that students will be evaluating. They are designed to demonstrate the principles of mission assurance through validation of compliance with standards developed specifically for the mock-up itself. This trains space systems evaluators to inspect the efforts of contract workers on common evaluation criteria, but not on the exact systems (or compliance data that can number over a thousand pages) that they will be performing oversight on operationally.

Real systems come in the form of previously operational, decommissioned systems or actual production models that were set aside for training from the beginning. Real systems are highly valuable in the training environment as students get the opportunity to train on the real thing. The downside is many real systems do not work, especially if they are older decommissioned systems. The systems set aside for training may have initially worked, but over time, several hundred or thousand practice procedures performed by students wear out the systems in ways that become too costly to repair or refurbish. The cost is in both financial and opportunity terms due to the fact training systems rate below operational systems in the supply priority system. Since many parts are in high demand with few in number available, the supply system may take months or years to deliver a part for a training system due to higher priority requests. Real systems also face the same problems as mock-ups in that there are too few systems available requiring students to take turns practicing tasks, and they are costly to modify to meet current operational configurations.

Schools design laboratories to teach concepts and theory, not to provide students with operational experience with a system. For example, an electronics lab will be set up with different types of electronic test equipment and test circuit boards. Students either will have their own set of equipment or will pair up with another student to share. Instructors then lead the students through proper setup of the laboratory equipment to generate a signal through the test circuit while using other test equipment to see the output at different areas of the circuit board. This teaches the students the theory of operation of the test equipment and some electronic fundamentals with the test circuit boards. Laboratories are expensive to set up and maintain. Schools must keep test sets and apparatuses in working order or the value of the lab is lost. Due to the pace of technology, the laboratories become quickly outdated requiring continual replacement (i.e. “tech refresh”) of equipment to keep training current and relevant to today’s Air Force.

Current Uses of Extended Reality Technologies in Non-Government Training

Industry is using virtual technologies in several applications such as medical training and industrial applications. Companies such as Walmart and UPS are using VR to train new employees for both routine and uncommon tasks or circumstances (such as how to work during a "Black Friday" sale).[19] Much of current virtual environment training is done using VR and MR. Medical training has used VR and MR (mixed reality) setups with medical tools which provide haptic feedback to mimic its feel against real flesh or bone since the 1990's.[20] In the HMD, the user sees the tools they are using recreated in the virtual environment with a virtual patient they are working on. Their surroundings may be an emergency room, a surgery unit, or even outdoors in a simulated first responder scenario.[21] The medical community is also beginning to look towards the use of AR as well, such as bedside surgeries (surgeries conducted in patient rooms versus a surgical ward) that overlay important vital information within the field of view of the surgeon so they do not have to look for a monitor for critical information.[22]

Students from Full Sail University created an award winning MR experience called "Dental Madness" in 2018 using 3D printed dental tools with built-in trackers and a realistic 3D printed mouth recreated in VR. A user could reach out and touch the teeth they saw in VR, and using the dental tools, locate cavities, or check for gum disease. When asked by the author how long it took them to develop the program, a student remarked, "About six months."[23] They achieved this with less than $10,000 worth of hardware compared to the medical community spending over six figures for a single MR surgery simulator in recent years. These prices are quickly dropping with more companies coming out with systems using low-cost VR components bringing system cost to the sub $10,000 range.[24]

Industrial training with virtual environments is in the VR domain, but branching out into MR and AR. One demonstration of a VR environment is in a water treatment facility where the instructor is present in the same VR environment where trainees work through an industrial filter change out.[25] A couple of MR examples are the virtual welding simulator by Miller Welding

Machines and Industrial Training International (ITI) VR cranes, rigging, and lift planning simulations. The welding simulator puts the user in a VR environment (VR built into a welding helmet) and uses realistic welding wands with haptic feedback to allow a user to practice welding on multiple shapes, materials, and styles of welding. The system also scores the welds for instructor use in trainee feedback. The ITI VR systems use realistic crane controls, pedals, multi-axis pods and belly boxes to train on cranes and lifting all in a virtual environment. According to the company, a big user of their technology is construction companies going into foreign countries construction projects where crane licensing is not as stringent. The company can use the ITI VR system to verify the operator is as capable as they claim to be before trusting them to operate the real thing.[26]

Current Uses of Extended Reality Technologies in Air Force Training

There are several applications of VR in Air Force training already. Some use completely commercial off the shelf (COTS) systems such as the welding simulator in use by the 30th Space Wing, 30th Operations Support Squadron, Training Device Design and Engineering Center (TDDEC).[27] They use the simulator to practice critical welds before conducting them on real life systems which saves money from waste of costly stock from failed welds. They also allow other units on the installation to use the machine for teaching basic welding techniques to young troops and new employees.

Some program managers contract-out XR program development. One example is the company Mass Virtual© who were contracted by the US Navy to create a maintenance trainer for the MQ-8 Fire Scout unmanned aerial vehicle (UAV).[28] The training program runs completely on a gaming laptop with an unmodified commercial off-the-shelf (COTS) HTC Vive

Pro© VR system. With the program, trainers can manipulate the simulation to insert problems into the results of procedures so the technician must troubleshoot the vehicle to find what is wrong. They can also set up the scenario so the virtual vehicle is ‘damaged’ if the technician makes a procedural mistake (e.g. over-pressurize pneumatics or use the wrong tool for a task). This provides realism to the scenario in that a technician can see the results of their mistake.

Another VR system under contract is Lockheed’s space systems mission assurance training simulator currently still under development for the 5th Space Launch Squadron at Cape Canaveral Air Force Station, Florida.[29] This system simulates the inside of the Lockheed Astrotech Space Operations (ASO) facility responsible for spacecraft processing. The ASO is an 110,000 square foot facility that has been recreated in VR with accuracy down to a thousandth of an inch. In the real facility, military specialists must verify the proper accomplishment of all tasks by contractor personnel on government spacecraft. When asked by the author how many tasks they may observe while processing a spacecraft, Staff Sergeant Street, a mission assurance instructor with the 5th Space Launch Squadron responded, “It depends on the spacecraft, but it’s in the thousands. Printed out, they stack about this high” indicating with his hand around his upper thigh.[30] Since the number of people allowed in a processing bay is limited, the ability to train new mission assurance personnel is quite strained.

With many operations not having the room to bring in a single trainee, leadership began looking into the development of a VR processing facility. In it, instructors can spend as much time as they want walking through the facility with trainees pointing out tasks and common mistakes. They can even run a simulation of a spacecraft being processed, complete with ‘agent’ (artificial) contractor personnel roaming around the bay completing various tasks. Once the VR program is complete, users from the sister unit at Vandenberg Air Force Base, California, will be able to logon to the simulation in their own VR sets and meet with Cape trainers in Florida in the same virtual space. They can get familiar with the Cape ASO or conversely, Cape personnel can get familiar with the Vandenberg ASO (which has also been modeled in VR) to prepare for missions before traveling across the country to meet with fellow space professionals in the real facilities.

Air University in Montgomery, Alabama, has begun using VR as a meeting space for a joint Air Command and Staff College and Air War College class in the study of virtual environment technologies (the sponsor of this paper). In this case, classes were held in VR with multiple students across the country meeting in the same virtual environment. The avatars participants used were not realistic iterations of their physical bodies due to limitations of the software. In fact, some participants changed their avatar several times over the four months of the course. Despite the changes in appearance, participants grew to recognize each other through voice, mannerisms, and conduct. This form of classwork also forced participant's attention on each other and the discussion at hand. While it was possible for some to get distracted by the virtual environment (picking up objects or simply 'exploring' the virtual world), it was difficult to get distracted by the real world. Use of the HMD precluded the ability to look at smart phones, eat, or even to easily drink coffee. In short time, participants were immersed in the virtual world and the guided discussions prepared by Air University staff.

Air Education and Training Command (AETC) has begun a program within undergraduate pilot training (UPT) called Pilot Training Next (PTN). In this program, instructors train new pilots using MR systems instead of traditional flight simulators. The MR systems use physical stick and rudder systems that are recreated in the virtual environment to provide realism and presence. Due to the relatively cheap cost of the PTN system, AETC was able to provide three systems to every two students (one each in the classroom and one shared between two students in student housing). This ratio allows students to train as often they choose at any time of day.[31] The inaugural class graduated 13 of 20 students in half the time of the traditional UPT program. Even with reduced training time, PTN students completed their first successful solo flight with 43% fewer real flights than UPT students.[32]

Major General Timothy Leahy, 2nd Air Force Commander, gave direction to the 82nd Air Wing to “Go do AR/VR” in January 2018.[33] From that direction, Maj Edwin Gaston was installed as technology coordinator for the 82nd and given direction to find ways to implement XR technologies in the technical schools at Sheppard AFB, Texas. With this direction, Maj Gaston set out with his team to create two AR and two VR training scenarios. The two AR scenarios they created were a C-130J engine hologram and an A/M32A-60 Generator (also known as a “Dash 60 generator” or “Dash 60 start cart”) hologram using a Microsoft HoloLens. Trainees can walk around the simulation, get in close to look at it, and an instructor even remove components from the model to display various aspects of the units.

The two VR scenarios created by the 82nd are an HH-60 armament safe for maintenance procedure and a “fear of heights” simulation.[34] The HH-60 scenario is still in work, but the fear of heights scenario has already garnered high-level attention. The scenario is designed to create the sensation of being on a high platform to evaluate if a trainee is going to be too fearful to work in elevated locations (such as at the top of a telephone pole). In the simulation, the trainee ‘rides’ a virtual elevator up several stories and then must step out onto a ply board platform. There is also a fan in the room blowing air on the student to simulate wind in their face. Students must walk to the end of the virtual platform and perform a simple task. If they cannot, then they are evaluated for a valid fear of heights by mental health professionals and possibly re-assigned to another career field. In the past, instructors had students climb a real pole and had to rescue the students if they froze in fear. The traditional method put lives at risk and created training delays. The MR method eliminates the risks while accomplishing the same task.

Section III: Analysis of Implementation of XR Training Programs

The ability of XR to provide the level of experiential learning comparable to that provided by mock-ups, test sets, or real systems is within the capability of modern commercial XR systems. There are limiting factors in XR in the area of fidelity through tactile interaction with the virtual environment. Commercial XR uses wands and controllers, so a technician is not going to feel a wrench in their hands or the difficulty of removing a stubborn bolt. They will simply experience simulated ‘grabbing’ of a tool by reaching out with a controller and selecting it with a button on the controller. Many controllers have simple haptics providing clicks, buzzes, and shakes. Current XR fidelity is wholly adequate when the experience desired by educational program managers is for students to pick the right tool and know where on the system to use it. If instead the training task requires the use of a tool such as a torque wrench and instructors need students to ‘feel’ the effect of a torque wrench, COTS XR may not provide the fidelity required in that training scenario.

The quality of VR displays is continually improving. Current models provide adequate quality to see and experience a virtual environment, and higher quality displays (better resolution and wider field of view) will increase the level of immersion a user experiences (i.e., their mind more easily slip into a feeling of actually being in the virtual environment).[35] The limiting factor in VR environments is the level of detail provided in the virtual environment. The more models (technically the more polygons used to draw the models) in the virtual environment to create a sense of ‘realism’, the more powerful a computer is needed to provide the computational work to run the simulation.[36] If the simulation is too intense for the computer hardware to keep up, there will be a lag between the movements of the user and what they see. This lag is a major contributing factor to simulator sickness (an experience similar to motion sickness). For this reason, program managers must make effort to provide programmers with accurate plans of what details are needed in the virtual environment to provide the fidelity of experience needed to accomplish the training tasks. For example, a simulation on how to change a tire on an F-16 needs to include accurate details of the jet, the tires, tools, and anything else in which to provide an accurate training experience (e.g., fire-bottles, power generators, etc.). While a real flight line may be busy with many other technicians, aircraft, ground operations personnel, etc., experiencing these other details of a real flight line may not be relevant to the training scenario. Managers may opt to leave those other ‘realistic’ elements out of the simulation to provide a smoother running experience.

From an educational perspective, XR training experiences normalize a training course to ensure each student receives the same high-quality instruction. Pre-programmed scenarios walk trainees through training tasks in the virtual environment requiring minimal input from instructors. While instructors should be able to join in the virtual environment with students on occasion, the more content that is pre-programmed, the more standard the course will be for students. Course content creators may develop analysis of the trainee’s progression in XR experiences and automatically repeat scenarios or tasks the trainee is deficient on without constant instructor involvement. The analysis would be better than standard classroom tests or quizzes as the trainee can be measured in their spatial awareness, gaze-time, and identify potentially dangerous errors (e.g. trainee attempts to perform a task in a way which could damage real equipment or hurt themselves or others). An example would be the AC-130 virtual reality part task trainer (vrPTT) created by Vertex Solutions© for Air Force Special Operations Command (AFSOC). In this training experience, vrPTT trains students copilot checklists and cockpit knowledge. As part of the training practice experience, the system provides hints whenever students take too long to complete a checklist item.[37]

The real advantage of XR over mock-ups and real systems used for training is the amount of time trainees may get in practicing tasks. The cost of XR is low enough a class of students could each have their own XR setup and run through the task exercise at the same time versus taking turns on a mock-up. An example would be AETC's PTN as previously discussed. This leads to either increased task training for trainees, decreased training time for the overall class, or a little of both depending on the goals and desires of the course managers. VR provides more options for the schoolhouse over traditional training methods.

There are some negative attributes to using XR systems. As previously mentioned, simulator sickness is a real possibility, though there are ways to mitigate this issue. Many instances of simulator sickness are due to sensory inputs among the visual, vestibular, and non-vestibular proprioceptors providing different inputs to a user's mind.[38] What a user sees (visual), what their inner ear senses (vestibular), and how their brain interprets what the body is feeling (non-vestibular proprioceptors), all need to agree about the perception of a user's position in 3D space. If these do not connect properly, the disconnect leads to the symptoms of simulator sickness. For example, many users will experience symptoms of simulator sickness when riding a roller coaster in XR. Despite the visual and auditory input of the jarring nature of a roller coaster ride, their body is sitting in an office chair in the real world. The brain cannot handle the mismatch between the visual cues and the vestibular system and the non-vestibular proprioceptors. This mismatch causes nausea, headaches, and potentially retching or vomiting.[39] Symptoms may last anywhere from a few hours to a few days. Like motion sickness on a boat, a user may obtain their 'sea-legs' or 'XR-legs' through experience with the system. For this reason, course managers need to ensure a slow introduction into XR training with students to allow them time to adapt to virtual environments. The use of AR does not typically deal with simulator sickness issues since the user still sees the real world around them keeping their senses in agreement with perceived motion and body orientation.

Another potential negative with XR is the difficulty in content creation. Enthusiasts may create simple VR experiences with minimal training using gaming engines such as Unreal or Unity, but scaling experiences up to useable training scenarios becomes extremely time consuming and difficult for a novice. It is outside the realm of capability for regular military school instructors to take on VR development as an additional duty (though one who takes it on as a hobby, dedicating a large portion of personal time to the endeavor, may find some success in content creation). To create content in-house, the Air Force will need developers dedicated to the mission of content creation. There will need to be people with some programming experience, or the ability to learn. Alternatively, school leadership may elect to contract with a commercial company to create XR content. Several companies now specialize in XR content creation.

Despite their varied uses, XR systems are currently not as well suited for some tasks. Present systems are primarily only able to provide sight, sound, and minor haptic feedback through controllers. While some specialized haptic devices, suits, and gloves exist, they are currently at a price point above the value they provide for most Air Force training environments. Training managers may find the fidelity they want with a tactile device is not as obligatory to the training tasks as originally thought. For example, a torque wrench could be trained on a simple bench setup and from then on, procedures using it could be virtualized in an XR training environment. Many tasks can be ‘gamified’ to enable task completion (e.g. when adjusting for a reading on a small screen, the system could make the screen pop out and enlarge so the trainee easily sees the reading). In the end, instructors and training managers need to determine the fidelity required to teach each specific skill in virtual environments and resist the temptation to add superfluous features in the simulation.

Finally, XR systems are cyber systems requiring upkeep and maintenance. It would be beyond the scope of what is required of instructors to maintain and upkeep more than a small handful of XR systems. Value is realized when XR systems are provide for each student to maximize training throughput. To gain the most benefit from XR, schools should have one or more XR labs, each with the capacity to outfit each member of the largest classes. These labs require cyber personnel dedicated to maintaining, updating, troubleshooting failures, and providing cyber security on the XR systems.

Section IV: Alternative Uses of XR

Once the use of XR technology in the Air Force has matured, there are some tangible benefits to the availability of XR systems in operational units. The following vignette is a small glimpse at the vision some Air Force leaders have given for the future use of XR technologies.[40]

> It is a brisk morning on the flight line without a cloud in the sky, and A1C Foster is getting ready to serve as the panel operator for a refueling operation. She has observed refueling operations as part of her OJT, but this will be her first time actually taking part. There are several other apprentices around ready to take part or observe, but due to NCO shortages, there is only one journeyman available to assist the team with this task.
>
> SSgt Ward is currently working with others, so A1C Foster decides to pull out her Air Force issued AR goggles and run through the panel operator refueling tasks while waiting to begin. In the goggles, she sees an overlay of information describing each gauge. When she points to a switch, a window pops up that describes the function of the switch. She swipes up with her hand, and that brings up an app tray where she selects the eTools AR reader by "touching" it with her finger. When it opens, she speaks into the empty cool air, "bring up the refueling tasks." Almost instantly, a window pops up next to the panel as if a tablet were floating in mid-air. She adjusts its position to a comfortable location, resizes it using pinching gestures, and reviews her tasks. SSgt Ward comes over to observe her as the refueling operations begin; he notes she performs her tasks flawlessly.

The implementation of XR systems in the field could take on multiple forms, either with individual units maintaining a few of their own systems, or with an established XR lab at each installation. An entire lab would face the same dilemma of mustering a workforce to maintain the systems as the schoolhouses, but they may see more use than XR systems scattered across the installation within separate units. The advantage of unit owned and maintained XR systems are they would be more likely able to maintain the systems with existing personnel.

Once Air Force schools develop XR content, it could easily be distributed to the field for use as training aids and familiarization with rarely performed tasks. It would also be simple for schools to develop more advanced content using existing models for use in the operational environment. Currently, some career fields maintain a cadre of specialists that perform advanced training for field units (called CHOT for "Consolidated Hands-On Training"). This training uses advanced theory and performs advanced task training with unit personnel on their own operational equipment. If these courses were migrated to XR systems, then units could conduct advanced training without paying to bring in the specialists, without taking down valuable operational assets, and without risk to damaging operational assets while conducting training.

Air Force personnel may also use XR systems for conducting meetings, classes, or collaboration efforts in a virtual environment. Several commercial programs already offer a way for both VR users and non-VR users using a standard desktop computer and keyboard to share in virtual environments as a way of incorporating more users. The Air Force may wish to develop its own social gathering space to control access and information discussed in official meetings. Leaders could use these same systems for familiarization training or pre-deployment training.

Cheap and simple standalone VR systems would also be a great tool for using 360-degree videos that show great promise for value. Videos of this nature are easy to produce using a commercial 360-degree camera. The company STRIVR© demonstrated success with 360-degree videos by mounting a 360-degree camera on the helmet of Carson Palmer, an NFL quarterback, to record practice footage. Palmer would review the footage with an HMD six days a week off the field. The following season, Carson Palmer led the Arizona Cardinals through their most successful season in franchise history. He said this method of practice "helped me absorb very complex systems, faster. I definitely got more reps."[41] Mounting similar cameras in aircraft would provide aircrew the ability to experience a flight or portion of flight without the need to actually go up in an aircraft. Any career field where events happen fast with no time to observe all details of the scenario as events unfold would benefit from 360 video experiences. Re-watching videos would allow a user to concentrate on different aspects of their surroundings each time.

Section V: Recommendations for Use of XR in the Air Force

To reap the most benefit from the latest advancements in virtual and augmented technologies, the Air Force needs to conduct a concerted, multi-disciplinary effort to advance these systems into main-stream use. Attempts to implement XR technologies at the unit level result in various outcomes, and there is no good place to share experiences with XR. There currently is no well-represented community of practice (CoP) for virtual technologies. Another limitation is lack of support from Air Force Cyber for XR systems. They are not authorized to run on existing Air Force networks, and there is no process or program in place to ensure the computers used for XR systems are maintained with security patches and program updates. In many duty locations, there is not even a way to connect XR systems to the internet.

Air Force XR Community of Practice

The XR CoP needs close ties to Cyber, Education and Training, Medical and Contracting communities. The Air Force XR community will need collaboration tools to enable working together from across the globe on XR projects and sharing best practices and lessons learned. They will need server space to maintain copies of models and virtual environments created for each application for the purpose of re-use in other simulation development projects. For example, if the schools for ground equipment technicians create models of ground support equipment, XR developers in the pilot community could use those same models in their simulations for training aircraft taxiing and parking. These practices are only possible if the types and format of models and environments are standardized to allow for cross-utilization. Standardization may develop organically within the CoP, but will more than likely require a designated office of primary responsibility to begin developing standards for the XR CoP to use.

The community needs to develop an effects-based approach to XR system development to prevent under-purchasing (attempting to cut costs) or over-purchasing (obtaining XR system recourses beyond required to accomplish the mission). An effects-based approach to XR would guide program managers in the development or procurement of XR systems that meet the needs of the mission they are being designed for. Finally, the XR CoP needs to collaborate on XR systems evaluation data. The community can develop XR program evaluation criteria to determine if pilot programs are producing results as expected.

The XR CoP needs to work closely with education and training managers, the medical community, and human factors experts to ensure virtual environments are created and used in a manner to resist the causation of simulator sickness and eyestrain. These issues could lead to lost training time as trainees (and instructors) may require several days to heal enough to re-enter a virtual environment. The community needs to develop standard practices for implementing VR technologies to ensure they are as successful as possible in implementation (e.g. limiting use to 15 minutes per session for the first week of a course). The CoP should track any reports of simulator sickness or medical complaints stemming from the use of VR technologies in order to develop best practices for future implementation.

Air Force Network Limitations

A large barrier encountered by many XR implementers is the inability to place XR systems on the Air Force Network (AFNet) and lack of promulgated Air Force standards for secure wireless networks. Neither the software, nor the hardware is currently approved for connection to AFNet. Similarly, some HMDs require wireless internet to download content. Many locations do not have access to wireless internet, nor are the HMDs approved network devices. Most XR systems operate in stand-alone configurations with no network access. Either content is transferred to the stand-alone system with portable media, or the devices are taken to a location with commercial internet (such as a base library).

The 5th SLS space mission assurance simulator currently under development as part of a one million dollar contract is unable to be put online and connected with its sister unit across the US. They are currently unsure how to connect the systems.[42] In addition to the issues with connectivity, the computers used to run the XR systems are not currently under the purview of any cyber professionals to ensure they are updated with the latest patches to ensure cyber security. Some units take it upon themselves to keep computers up-to-date, but the process is not formalized.

The XR CoP would be a great starting point to develop formalized procedures for ensuring XR systems are maintained with updates and patches. The community could also provide links and instructions on downloading Air Force anti-virus tools or other security software for use in protecting XR systems. The community should work with cyber leadership to determine the best course of action for obtaining commercial internet access for XR systems until they are either approved to be on the AFNet, or a separate government network created for use of XR systems.

Section VI: Conclusion

The use of XR systems are promising technologies for use in Air Force technical schools. The Air Force has a history of leading the use of emerging technologies and should take full advantage of all the great tools XR can provide. These systems can provide experiential training and special awareness of training scenarios that nothing other than actual time on real equipment can achieve. With rapidly falling prices for equipment, it is affordable to provide systems that enable all students to simultaneously perform tasks in a virtual environment, which used to require them to take turns to complete on a mockup or training system. Some experiences would be simple enough to load onto a stand-alone XR system and send with a struggling trainee back to their housing unit to train on the task as many times as they need until they understand the skill.

In order to maximize potential of XR technologies, the Air Force needs to create or delegate an organization to coordinate implementation, standardization, and communication efforts. This organization must have the influence and resources to affect how the rest of the Air Force views and uses XR technologies. They would be responsible for aligning efforts and helping develop solutions in XR. Eventually, implementation would flow through this organization, which would develop or acquire, test, analyze, and implement these technologies for the whole Air Force.

Without an enterprise wide solution to connecting systems, XR technologies will remain second tier training systems relegated to random units and organizations who have leaders that see the value in the technology. XR programs will not reach full potential without a way to network and share resources. Air Force Cyber is needed to assist in leaning forward with providing a viable solution that will ensure the security of virtual systems and provide secure communications. Unlike AFNet, the solution must provide a flexible enough environment to allow applications and devices that are continually being created and updated.

When these initial issues are overcome, the use of virtual technologies will provide a revolution in Air Force training and development. Students will no longer be simply taught skills, but allowed to experience them in a way previously thought impossible. Just like the fighter pilot that has flown several engagements before their first real battle, an aircraft maintainer will have already performed multiple pre-flights before their first red-ball (a priority maintenance event that can delay a flight). A deployed radar maintainer will have already spent hours working on a deployable radar before touching their first system, and a Security Forces member will have already spent hours on-scene as a virtual security forces member before coming up on their first real incident. Airmen will be able to experience risky, complicated, or seldom performed tasks multiple times before conducting the task in real life. Their HMDs will provide tips, pointers, and helpful information during actual task completion. In the end, the effect of XR technologies will be Airmen more skilled, confident, and prepared to complete the technical tasks their profession demands.

Notes

(All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

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Abbreviations

AETC	Air Education and Training Command
AFNet	Air Force Network
AFSOC	Air Force Special Operations Command
AR	Augmented Reality
ASO	Astrotech Space Operations
CGI	Computer-Generated Imagery
CHOT	Consolidated Hands-On Training
CoP	Community of Practice
COTS	Commercial Off The Shelf
HMD	Head Mounted Display
ITI	Industrial Training International
MAGPIE	Maintenance training based on an Adaptive Game-based environment using a Pedagogic Interpretation Engine
MR	Mixed Reality
NFL	National Football League
PTN	Pilot Training Next
SLS	Space Launch Squadron
TDDEC	Training Device Design and Engineering Center
UAV	Unmanned Aerial Vehicle
UPT	Undergraduate Pilot Training
VR	Virtual Reality
vrPTT	virtual reality Part Task Trainer
XR	Extended Reality

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