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VIRTUAL REALITY FOR REMOTELY PILOTED AIRCRAFT TRAINING

by

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Biography

Calvin Chang is assigned to the Air War College, Air University, Maxwell AFB, AL. Prior to his assignment at the Air War College, he was a supervisor at Space and Naval Warfare Systems Center (SSC) Pacific. Calvin developed multiple US military network systems at SSC Pacific between 2002 and 2018. During his last assignment at SSC Pacific, he led an Integrated Product Team (IPT) to develop tactical network systems for multiple Navy manned and unmanned air platforms. He also led IPTs to develop enterprise network systems for the US Navy surface platforms. Calvin holds a Master of Science degree in Electrical Engineering from San Diego State University, and holds a Bachelor of Science degree in Electrical Engineering from the University of California San Diego.

Abstract

This paper recommends the United States Air Force (USAF) implements Virtual Reality (VR) simulators as part of Remotely Piloted Aircraft (RPA) training that can provide a cost-effective and flexible learning environment for the future RPA crews. VR is the latest technology that can help USAF to meet training objectives with lower costs, and it should be the most suitable technology for RPA simulation training. VR can create the RPA cockpit immersivity with commercial equipment, and requires less space for training compare to the traditional flight simulator. RPAs can provide combatant commanders with clear situational awareness, and lift the fog of war. Due to the high demands of RPA support, the USAF must train significant amount of new RPA crews each year. However, these new RPA crews could benefit from enhanced training opportunities before they start missions in the operational environment. The Air Force Research Laboratory evaluated the USAF RPA flight mishap history, and discovered that operator error has become the predominate cause of the RPA mishaps. The researchers believe the USAF RPA training process can be changed to mitigate the human performance problems. As each mishap can cost millions of dollars to taxpayers, any improvements in RPA crew performance with an enhanced training approach can significantly reduce the unexpected expenditures. It is necessary to train RPA crews with a system that facilitates efficient simulation to increase knowledge, build teamwork, and hone critical decision-making skills. This training goal can be achieved by implementing VR simulators, which can facilitate flight simulations in a virtual environment at anytime from anywhere for instructors and students.

Introduction

This paper recommends the United States Air Force (USAF) implements Virtual Reality (VR) based simulators as part of Remotely Piloted Aircraft (RPA) training that can provide a cost-effective and flexible learning environment for the future RPA crews. VR is the latest technology that can help the USAF to meet training objectives with lower costs, and it should be the most suitable technology for RPA simulation training.

RPA are among the most effective instruments to perform ISR missions. RPAs can provide combatant commanders with clear situational awareness, and lift the fog of war. Due to the high demands of RPA support, the USAF must train a significant number of new RPA crews each year. However, these new RPA crews could benefit from enhanced training opportunities before they start missions in the operational environment.

The Air Force Research Laboratory analyzed the USAF RPA flight mishap history, and discovered that operator error has become the predominate cause of RPA mishaps.[1] The researchers believe the USAF RPA training process can be changed to mitigate the human performance problems. As each mishap can cost millions of dollars to taxpayers, any improvements in RPA crew performance with an enhanced training approach could reduce the number of mishaps resulting in a significant savings.

This paper assesses the adequacy and cost-effectiveness of aircraft and simulators currently used in the USAF RPA training pipeline through the lens of Experiential Learning Theory. The result shows that the current aircraft and simulators are expensive and inflexible and do not train the RPA crew effectively. Training new RPA crews with an innovative approach based on realistic simulations to hone hands-on flight skills effectively could reduce flight mishaps. This training goal could be achieved by implementing VR simulators, which facilitate flight simulations in an immersive virtual environment at anytime from anywhere for instructors and students with affordable costs.

The recent lessons learned from the USAF's Pilot Training Next (PTN) program show that VR simulators have the potential to improve cost-effectiveness of undergraduate manned aircraft pilot training. This paper recommends conducting a similar experimental program to evaluate the suitability of VR simulators for undergraduate RPA training as well. If VR simulators are suitable for RPA training, replacing the current aircraft and simulators used for undergraduate RPA training with VR simulators could create better-trained pilots and reduce costs.

Thesis

Using VR-based simulators in RPA training could improve cost-effectiveness.

Analysis of USAF RPA Training

ISR Mission and the USAF RPA System

The combatant commanders' expectations and demands of unique ISR capabilities provided by the USAF have grown significantly in the past decade. General McChrystal, US Army, retired, states in his book, Team of Teams,

> ISR assets like Predator unmanned aerial vehicles…became coin of the realm in our fight in Iraq and Afghanistan. ISR dramatically expanded our ability to gather intelligence on targets and develop new ones…Without ISR, a raid might require an additional platoon or more of troops, more helicopters, and more support. Simply put, the more ISR a unit had access to, the more operations it could execute.[2]

In response to the extensive ISR operational needs, "The Air Force surged [RPA] operations nine times over the last eight years."[3] The USAF also developed a get-well plan to fill the gaps of RPA pilot shortages in 2015 to increase the RPA schoolhouse throughput to 300 RPA pilot graduates per year.[4]

A fully operational RPA system consists of four aircraft units (with sensors), a ground control station (GCS), a Predator Primary Satellite Link, and approximately 55 personnel for deployed 24-hour operations."[5] Beyond the large MQ-1 system team, it is also part of a much larger command and control network in the battlespace, and a way to exercise the MQ-1 team in the entire network is desired.[6] Figure 1 shows the RPAs, Figure 2 shows the RPA GCS, and Figure 3 shows the cockpit inside the GCS. The unique RPA operational environment makes communication and teamwork internal and external of the RPA crews critical to success during each mission.

FIGURE 1. USAF RPAs. *Left*, MQ-1 Predator; *right*, MQ-9 Reaper (Adapted from briefing, Lt Col Jack Stallworth, Headquarters Air Education Training Command [AETC], 558th Flying Training Squadron Commander, subject: Undergraduate Remotely Piloted Aircraft Training, 2016.)

FIGURE 2. RPA GCS. *Upper left*, outside of the RPA GCS cockpit; *lower right*, RPA satellite terminal (Adapted from briefing, Lt Col Jack Stallworth, Headquarters Air Education Training Command [AETC], 558th Flying Training Squadron Commander, subject: Undergraduate Remotely Piloted Aircraft Training, 2016.)

FIGURE 3. RPA cockpit. (Adapted from briefing, Lt Col Jack Stallworth, Headquarters Air Education Training Command [AETC], 558th Flying Training Squadron Commander, subject: Undergraduate Remotely Piloted Aircraft Training, 2016.)

USAF RPA Training

Two members form the USAF RPA crew: a pilot and a sensor operator. Pilots are "rated officers"[7] in the RPA pilot career field, and usually go through Undergraduate RPA Training (URT) and RPA Formal Training Unit (FTU).[8] URT includes three phases: RPA Initial Flight Screening (RFS), RPA Instrument Qualification (RIQ), and RPA Fundamentals Course (RFC).[9] The RFS is two months long and held in Pueblo, CO. Students receive basic academics, which include basic flight maneuvers, flight safety, emergency procedures, navigation, and communication,[10] and need to finish 39.3 hours of hands-on flight with the Diamond DA-20 aircraft.[11] Students need to pass the FAA's Private Pilot Knowledge Test at the end of the RFS.[12] After RFS, students transition to Randolph Air Force Base, TX to complete RIQ training and

RFC.[13] RIQ training is two and half months long, and students receive classroom academics and 46.8 hours of T-6 simulator training.[14] At the later stages of RIQ training, the instructors link the T-6 simulators, and students can interact with each other in an air traffic pattern.[15] Students receive the FAA certification to fly an RPA within the national airspace with the successful completion of the RIQ.[16] The RFC is the last phase of URT, which is one month long. In the RFC, Students receive academics focused on RPA tactical and theater operations, threats, and sensors, and complete 23 simulator hours with the Predator Reaper Integrated Mission Environment (PRIME). "PRIME is a PC-based Desktop Training System that emulates the functions of an MQ-9 Reaper GCS for both Pilot and Sensor Operator in a low-cost networked PC hardware configuration."[17] RPA FTU training follows URT, and it utilizes the PRIME as well for simulation training.[18] Students need to qualify for takeoff and landing during FTU before performing them during operations. FTU is done in combat zones or at training locations by dedicated crews.[19]

The USAF developed URT based on its 65-year-old manned aircraft pilot training experience.[20] However, "unlike traditional pilots who would expect to be wingmen or co-pilots in initial combat mission ready status, the RPA pilots are immediately solo and in charge of their mission ready status."[21] The USAF also expects the RPA pilots to be ready for combat upon reaching mission ready status. It is critical that the RPA students receive as many basic flight skills as possible during URT to be ready for the FTU for the assigned RPA.[22]

USAF RPA sensor operators are enlisted aviators, who support pilots with RPA weapons employment and sensor systems management. RPA sensor operator training has two phases: Aircrew Fundamentals Course (AFC) and Basic Sensor Operator Course (BSOC).[23] AFC is a six-day training held at Lackland Air Force Base, TX to transition the enlisted personnel to the aviation career. After the AFC, students transition to the Randolph Air Force Base, TX to start the BSOC for one and half months. During the BSOC, sensor operators are paired up with the pilot students to complete the course as flight teams.[24] Like pilots, sensor operators also need to complete the FTU, which happens right after the BSOC for three to four months. Students who can graduate from the FTU transition to their combat squadrons, and complete a combat mission ready certification before flying in the operational environment.[25]

The USAF RPA Flight Mishap History and Analysis

The USAF flight mishap history shows that the numbers of mishap in all categories of the MQ-1 and MQ-9 have positive linear trendlines, which means the mishaps are steadily increasing for both platforms. Each Class B mishap costs the USAF $500,000 or more but less than $2 million, and each Class A mishap costs $2 million or more. [26] If an aircraft cannot be fixed due to a mishap, it is counted as destroyed. On average, each year the MQ-1 has 6 Class A mishaps, 1.27 Class B mishaps, and 5.23 aircraft destroyed, and the MQ-9 has 2.53 Class A mishaps, 0.35 Class B mishaps, and 1.59 aircraft destroyed. In 2009, the MQ-1 cost was about $4 million per unit,[27] and the MQ-9 cost was about $8.5 million per unit.[28] Based on the above average mishap counts and RPA unit costs, the estimated average combined annual cost of the MQ-1 and MQ-9 mishaps is $52 million or more for the USAF.[29] The potential cost savings from improving the RPA crews' performance is significant.

The Air Force Research Laboratory conducted a study to identify the causes of the steadily increased USAF RPA mishap counts, and the result was published during the Interservice/Industry Training, Simulation, and Education Conference in 2007. The study reviewed 30 USAF MQ-1Class A mishaps that occurred between 1995 (the year MQ-1 entered service) and 2006, and realized the root causes have been shifted over time.[30] Equipment failure, operator error, or a combination of the two, were found to be the typical cause of RPA flight mishaps. In the first few years, the equipment failure tended to be the primary cause, but, in the later years, operator error caused 80% of the mishaps.[31] The study further categorized the operator error causes, and concluded that "Recent mishap reports often cited shortfalls in skill and knowledge (checklist error, task misprioritization, lack of training for task attempted, and inadequate system knowledge), situation awareness (channelized attention), and crew coordination."[32] The researchers believe these shortfalls were mainly driven by lack of experience or training.[33] They recommended improving RPA training, and eventually increasing the training scope from two-person domain to a more realistic representation of the battlespace.[34]

Adequacy of USAF RPA training

URT as the primary RPA training program for new pilots provides limited RPA hands-on flight experiences. URT provides pilot students a total of 39.3 flight hours and 69.8 simulator hours before they graduate from the program. Out of the 69.8 simulator hours, only 23 hours are allocated to the RPA simulator (PRIME), and the simulation is not immersive. This means after almost six months of URT each graduated pilot only has 23 hours of RPA experience with a simplified simulator. Sensor operators receive total of 36 simulator hours during the BSOC.[35] Part of the sensor operators' simulator hours are paired up with pilots. The flight team simulator hours are equal to or less than 23 hours. Is this short amount of time enough for pilots and sensor operators to master their RPA crew skills together? There is no simple answer to this question, because each student has a different learning curve. However, the Experiential Learning Theory (ELT) can be utilized to understand the learning process that a team needs to go through before the team members can learn effectively together, which can help flight instructors better allocate hands-on learning hours.

According to the Experiential Learning Theory, "learning is the process whereby knowledge is created through the transformation of experience."[36] For individuals to learn new knowledge, skills, or attitudes, first, learners must involve fully without bias in new experiences. Second, learners must be able to reflect on and observe their experiences from different viewpoints. Third, learners must be able to create concepts that consolidate their observations into logical theories. Fourth, learners must use these theories to make decisions and solve problems.[37] Learners continue repeating this four-step learning cycle to improve their knowledge and skills, which means learners can advance knowledge and skills by obtaining and processing more experiences.[38] In general, learning involves transactions between the person and the environment, and Experiential Learning Theory supporters believe that obtaining experiences from the "real world" is the most effective way of learning.[39]

The team learning process is more complex than the individual learning process. Teams need to go through a similar experiential learning process as individuals to obtain new knowledge, but there are also other factors that can interrupt the team learning process. When a team is just formed, individual needs and goals predominate the team learning process, and new team members usually lack common experiences,[40] which makes the team learning process less effective and less efficient at beginning. Team learning experiences start gaining efficiency as team members learn to manage issues of team size, compatibility, and cohesion. Trust among team members is built to allow honest feedback to be shared.[41] Feedback is critical as it can prevent errors. Proper communication and coordination skills can help team members to improve team performance especially for the smaller teams.[42] A fully developed team has good feedback mechanisms that allow the team to decide the best course of action to achieve challenging goals.[43] Team members with past working experiences can benefit the most from team training.[44] In comparison with individual learning, more time is required for team to be fully developed and learn effectively together to achieve complex goals.

A study was conducted by the Air Force Research Laboratory in 2002 to analyze impact of prior flight experience on learning MQ-1 pilot skills. This study found that basic manned aircraft pilot experiences have positive impact on learning RPA pilot skills, but advanced manned aircraft pilot experiences had either no impact or negative impacts on learning RPA pilot skills.[45] The researchers utilized a high-fidelity MQ-1 simulator to analyze the RPA operational performances of seven groups of pilots. The group with experienced USAF MQ-1 pilots was used as the reference group, which outperformed the other non-RPA pilot groups as expected.[46] The striking finding of this study was that a group of experienced manned aircraft pilots did not perform significantly better than some of the other groups with less flight experience such as the T-38 newly graduated pilots.[47] The researchers believe that the T-38 aircraft has some similarities to the MQ-1, which gave the T-38 graduates the advantage in performing well during the study.[48] One of the groups was the Reserve Officers' Training Corps (ROTC) students who did not receive any flight training. This ROTC group did poorly in most of the RPA tasks, but had close performance compare to the other manned aircraft pilots with the basic maneuvering and landing tasks.[49] The researchers explained that "while many aspects of pilot skill transfer to flying the Predator, other aspects may not. Experienced pilots may need to "unlearn" some aspects of piloting…whereas nonpilots who train only on the Predator would not."[50]

In summary, URT and BSOC allocate most of the time to academics and manned aircraft flight and simulator hours. Students have no opportunity to operate a real RPA in either programs, and their time to work on the RPA simulator is compressed, which is insufficient for them to fully develop RPA skills. This issue is more significant for flight team training as team learning requires longer time before it can be effective. If students cannot fully learn the necessary skills in school, then they must learn the skills in combat zones, which increase the risk of flight mishaps. Increasing immersive RPA simulator hours during URT and BSOC for pilots and sensor operators should be the most effective approach to improve mission readiness of the graduates with affordable costs.

Cost-Effectiveness of USAF RPA Training

URT utilizes the Diamond DA-20 aircraft, T-6 simulator, and PRIME to provide hands-on flight training to pilot students. The PRIME is the only RPA-based hands-on training experience. Figure 4 shows the DA-20, T-6 simulator, and PRIME.

FIGURE 4. URT aircraft and flight simulators. *Left*, the Diamond DA-20 is used during RFS; *center*, the T-6 flight simulator is used during RIQ; *right*, the PRIME is used during RFC (Adapted from briefing, Lt Col Jack Stallworth, Headquarters Air Education Training Command [AETC], 558th Flying Training Squadron Commander, subject: Undergraduate Remotely Piloted Aircraft Training, 2016.)

The DA-20 costs around $200,000 per unit in the commercial market.[51] There are also other associated costs to maintain and operate the aircraft. The USAF utilizes the DA-20 for its initial flight screening program to qualify new pilots in Pueblo, CO.[52] However, the DA-20 cockpit does not resemble the RPA GCS. As stated in the last section, manned aircraft pilot experience is not critical for RPA pilots. As the use of automation on RPAs continue to grow, this trend will transform the pilot role from operator to supervisor. This transformation requires RPA pilots to apply knowledge and skills for a different set of tasks.[53] This means that instead of spending more time on practicing manned aircraft pilot skills, the USAF should offer more training time to enhances RPA pilots' supervisory skills. In fact, the RPA GCS is more like a traditional video game environment and less like a manned aircraft cockpit. [54] A pilot in the GCS operates to accomplish a mission with limited information via sensor feed, displays, and controllers which are similar to a video game player trying to accomplish goals by interacting with a game via a screen and game console.[55]

The T-6 simulator is a traditional flight simulator that allows students to receive flight experience with one type of aircraft. It allows pilots to be trained at a significantly lower cost per hour than actual aircraft maintenance and operations would cost. However, the simulator is based on the T-6 and the RPA GCS does not directly apply. As a result, skill sets learned would not directly transfer. The unit cost of the latest T-6 simulator procured by the 558th Flying Training Squadron is $270,000.[56] The T-6 simulator is sizeable, and needs to be installed in a classroom or laboratory environment.

The PRIME is the only flight training instrument utilized by URT and BSOC that simulates the RPA GCS. It is not immersive, but allows the pilots and sensor operators to practice RPA functions. Its unit price is not available, but would be much lower than the T-6 simulator. Like the T-6 simulator, PRIME is stationary, and is usually installed in a classroom or laboratory environment.

Overall, all the URT and BSOC flight training aircraft and simulators are not easily moved, which restricts the location and time that students can exercise their skills. Both the DA-20 and T-6 simulator are expensive, and do not resemble the RPA GCS. The PRIME somewhat resembles the configuration inside the RPA GCS, but does not provide immersive experience. A VR simulator can provide immersive flight experience with much lower cost compare to the DA-20 and T-6 simulator, and a VR simulator only needs a desktop space with small amount of power to operate, which allows additional hours of use based on the student's choice outside of classroom.

What is a VR Simulator?

A VR simulator is a system included computer hardware and software. The purpose of the system is to allow a user interacting with a computer without the standard forms of interaction such as a keyboard and mouse. It is a new form of human-machine interaction. Immersion is the aim of VR simulation. A good VR system can make a user deeply absorbed in a virtual scenario, and makes him forgot about the real-world. Audio and visual effects are the most important elements for a VR system to create immersion experience, and the performance of these effects relies on the capability of the hardware and software of VR system.[57]

In general, a VR system includes a headset, controllers, tracking sensors, a Personal Computer (PC), and software applications. In Figure 5, two USAF pilot students were using VR simulators for pilot training. Each of the students wore a VR headset (the blue head-mounted device) that allows them to see virtual scenarios through the lenses within the headset, and they can hear sound effects from each side of the headset. Some headsets have the eye tracking function, and can interact with or measure user eye activity. Some headsets are wireless, which give users better VR experience without tethering to a computer. Some headsets have the head tracking function, which can track user head movement. VR controllers allow a user to interact with virtual scenarios with his hands. In Figure 5, the students were utilizing a set of controllers that simulate a cockpit environment. Most VR headsets depend on a computer to host software applications and connect to the Internet. A graphics card is the most important part on a PC within a VR system, as its capability directly impacts user experience. Users can see lag if a graphics card has low performance. Motion tracking sensors are used to track user movements, and can be mounted on wall or stands.

Figure 5. VR system. (Reprinted from photo, Sean Worrell, US Air Force, 21 June 2018, https://www.af.mil/News/Photos/igphoto/2002041992/)

There are many VR software applications available in the field of military, healthcare, education, video games, engineering, sport, film, media, and business.[58] In the military, VR applications have been developed for flight simulation, battlefield simulation, medic training (battlefield), vehicle simulation, and virtual boot camp.[59] VR applications allow military personnel to be trained without the risk of death or serious injuries. For example, new pilots can be trained in combat operations without facing real-world risks. This makes training safer and less costly than traditional training methods.[60] VR simulators can train military pilots for combat missions which include coordination with ground operations, emergency evacuation.[61] In the USAF, VR simulators have been utilized to train pilots recently, and the result was successful.

Successful USAF VR Training

The Pilot Training Next (PTN) is a successful program that utilizes VR simulators to enhance the USAF aviation skills learning processes. The USAF started looking into the possibility of accelerating Undergraduate Pilot Training (UPT) with VR simulators recently. UPT mainly trains manned aircraft pilots for the USAF. The USAF brought 20 Airmen to Austin, TX to establish the PTN Program. The program aims to train the same flight skills that students can learn from UPT in half of the time. PTN is part of the overall USAF efforts to overcome the pilot shortage issue.[62] Figure 6 shows a PTN student demonstrating the VR simulator capability to the Secretary of the Air Force Heather Wilson.

Figure 6. Secretary of the Air Force Heather Wilson visited the PTN. (Reprinted from photo, Johnny Saldivar, US Air Force, 27 June 2018, http://www.jbsa.mil/News/Photos/igphoto/2001938101/)

The PTN program has identified several benefits that can accelerate UPT with VR simulations. VR technology provides flexibility to allow quick improvement of students' flight skills. For example, VR technology lets instructors to record students' flight simulation practice, and replay it. For students who need to correct a specific flight error, they can replay the flight records in VR, and repeat the same flight until the error is corrected.[63] This capability allows a cost-effective way for students to repeat the same flight maneuver until they are able to correctly execute the maneuver.

For students who are ready for advanced challenges, VR technology allows instructors to quickly modify training to the level that is suitable for students' current capabilities to enhance skills more rapidly. Instructors can change the platform from a T-6 to a F-22 in less than 10 seconds in VR simulation without extra cost, and this same modification would require millions of dollars and months to years with the traditional simulator.[64]

VR technology can also easily enable collaborative training. It is very simple to link up all VR simulators on networks, and allow multiple students to practice flight formations.[65] This means VR technology can allow students and instructors to meet in virtual environment for training even if they are geographically separated.

The cost of VR simulators is extremely low compare to the costs of the traditional simulators. The PTN Program Deputy Director, Major Scott Van De Water, states, "we can buy 300 of VR simulators for the price of one legacy simulator."[66] The prices of VR simulators may go even lower if more people purchase them in the future.

VR simulators are mobile, significantly smaller than traditional simulators, and can be carried around. The PTN allows students to bring VR simulators back to their living quarters, which gives them unlimited access to simulated flight training. This creates a unique individualized and continuously accessible training environment that permits the student to learn outside of classroom at their own pace.[67] This unique environment cannot be replicated with traditional simulators.

As the result of the first PTN iteration, 13 students graduated on 3 August 2018 after 24 weeks of training. The training program included 184 academic hours, 70 to 80 flight hours in the T-6 Texan II, and 80 to 90 hours of formal VR simulated flight training, which does not include the students' self-learning time.[68] This compares very favorably to the traditional 49-week, 190-flight hour, 80-simulator hour, $1M program. The success of the PTN program demonstrated that VR simulators can effectively train pilots with a much shorter timeline compared to the traditional UPT program. Since the RPA GCS cockpit ground-based, the simulators do not need to simulate aircraft motions and the gravitational force (g-force). This makes VR simulators very realistic in a physical sense.

Summary of Analysis

USAF RPA undergraduate training has four major issues in providing students hands-on flight experiences. First, the most limiting ability of URT is that the training is not hands-on RPA based. Second, the compressed RPA simulator hours are not enough for individual and crew to master basic RPA skills. Third, URT does not have a cost-effective RPA training approach. Aircraft and T-6 simulator are expensive and are not RPA GCS-based. The PRIME is RPA GCS-based, but does not provide immersive simulation. Fourth, the traditional simulators are sizeable, which limits students' access for practice. Based on the PTN lessons learned, VR simulators can mitigate or solve these four issues. They have the potential to make RPA training more cost friendly, effective, and flexible.

Recommendations

VR Training Implementation Options

There are three options to add VR simulator hours in URT without increasing the overall training timeline. Option 1, the USAF can start by replacing the PRIME hours first, and allocating 23 simulator hours to VR training. For consistency, the FTUs should also replace their PRIME systems with VR simulators. VR simulators provide more immersive flight experience to students compared to the PRIME, which should increase the effectiveness of simulation training.

Option 2, on top of Option 1, the USAF could also replace the T-6 simulators with VR simulators. The flexibility of VR simulators allows instructors to switch platforms during training, which cannot be done with the T-6 simulator. This change can free up 46.8 hours from the T-6 simulator training, and allow instructors to allocate some, or all, of these hours to RPA GCS-based VR training. This could be tailored based on the needs of each student. VR simulators are also much cheaper compared to the T-6 simulator.

Option 3, on top of Option1 and Option 2, the USAF can replace the DA-20 aircraft flight training with VR simulation. There is no direct skill development function for DA-20 flights. If the USAF is willing to replace the DA-20 flight training with VR training, the cost saving will be significant. Also, instructors would have another 39.3 hours to train students on any platform.

This paper recommends Option 3 for optimal cost savings, and it can give URT total of 109.1 hours to allocate to VR flight training (see Table 1.) However, URT may need less flight training hours with VR. Based on the PTN program lessons learned, 80 to 90 VR hours would be enough for pilot training. If this can be applied to URT, URT could save about 20 to 30 hours

(18 to 27%) from the 109.1 flight training hours. A study should be conducted to identify the optimal amount of VR flight simulator time for URT.

Table 1. Current URT Flight Training Time Allocations

	Allocated Training Hours
PRIME	23
T-6 Simulator	46.8
DA-20	39.3
Total	109.1

VR Training Implementation Timeline

In the short term (one to two years), an experimental program similar to the PTN program should be conducted to evaluate the effectiveness and efficiency of URT based on VR simulators. The result of the experimental program should guide the USAF decision on whether to modify its RPA training programs with use of flight and simulator hours. The experimental program should also inform the USAF on whether VR technology can accelerate URT.

In the mid-term (three to five years), if VR is effective for RPA GCS-based training, the USAF should aim to replace all URT training aircraft and flight simulators with VR simulators. This reduces training costs for the USAF, enhances training flexibility for instructors, and increases learning opportunities for students. Students and instructors could also meet in the virtual environment for training even if they are geographically separated in the real world.

In the long term (five to ten years), the USAF should develop a virtual environment that could train its RPA crews to perform full ISR and other missions beyond two-person domain as the Air Force Research Laboratory researchers suggested. Developing an immersive training that can simulate the entire RPA operational environment is technically challenging with traditional simulators. However, VR technology has the potential to overcome these challenges.

Beyond the RPA training, VR simulators can be used to train operators in many other areas such as Command and Control. How does the USAF train operators efficiently with affordable costs in the Multi-Domain Operational Center to conduct multi-domain operations in the air, space, and cyberspace simultaneously in 2035? VR may be the most cost-effective training approach for the Multi-Domain Command and Control (MDC2) missions in the future. The MDC2 training discussion is beyond the scope of this paper, but the RPA virtual training environment suggested by this paper could be integrated as part of the MDC2 virtual training environment in 2035. It could be the USAF's initial step to form the future MDC2 virtual training environment.

Conclusion

This paper offers multiple options for how the USAF can implement VR simulators in its RPA training processes, and recommends to replace all the physical flight training equipment with VR simulators. The recommended options allow the USAF to provide immersive training to its RPA students with optimal effectiveness, low cost, and high flexibility. The USAF should first conduct an experimental program for URT that is similar to the PTN to examine these options. If the experimental program is successful, the USAF should replace the current aircraft and simulators with VR-based simulators in RPA training. In the long term, the USAF should develop a virtual environment that can train its RPA crews to perform full ISR or other missions beyond the two-person domain. Ultimately, the USAF should look beyond the RPA training to utilize VR technology for training in other areas such as command and control for multi-domain operations.

Notes

[1] Nullmeyer, Robert T., Gregg A. Montijo, Robert Herz, and Robert Leonik. *Birds of prey: Training solutions to human factors issues*. Air Force Research Lab Mesa AZ Human Effectiveness Directorate, 2007, 1.

[2] Stanley McChrystal, *Team of Teams,* (New York, NY: Penguin Random House, 2015), 181-182.

[3] Secretary of the Air Force Public Affairs. "Air Force senior leadership addresses need to stabilize RPA enterprise." US Air Force, 15 January 2015, https://www.af.mil/News/Article-Display/Article/560282/air-force-senior-leadership-addresses-need-to-stabilize-rpa-enterprise/. (accessed 4 December 2018)

[4] Secretary of the Air Force Public Affairs. "AF rolls out details to improve RPA mission." US Air Force, 15 July 2015, https://www.af.mil/News/Article-Display/Article/608716/af-rolls-out-details-to-improve-rpa-mission/

[5] 1st Special Operations, "MQ-1 Predator Unmanned Aerial Vehicle." US Air Force, 8 July 2008, https://www.hurlburt.af.mil/About-Us/Fact-Sheets/Fact-Sheets/Article/204581/mq-1-predator-unmanned-aerial-vehicle/. (accessed 4 December 2018)

[6] Nullmeyer, Robert T., Gregg A. Montijo, Robert Herz, and Robert Leonik. *Birds of prey: Training solutions to human factors issues*. Air Force Research Lab Mesa AZ Human Effectiveness Directorate, 2007, 11-2.

[7] Rated officers: officers whose primary job is flying.

[8] Carretta, Thomas R., Mark R. Rose, and Kenneth T. Bruskiewicz. "Selection Methods for Operators of Remotely Piloted Aircraft Systems." *Remotely Piloted Aircraft Systems: A Human Systems Integration Perspective* (2016): 140-1.

[9] Headquarters, Air Education Training Command/A3F. "AETC- Undergraduate Piloted Aircraft Training (URT)". 2016.

[10] Carretta, Thomas R., Mark R. Rose, and Kenneth T. Bruskiewicz. "Selection Methods for Operators of Remotely Piloted Aircraft Systems." *Remotely Piloted Aircraft Systems: A Human Systems Integration Perspective* (2016): 140.

[11] Headquarters, Air Education Training Command/A3F. "AETC- Undergraduate Piloted Aircraft Training (URT)". 2016.

[12] Matwick, Seward E. *AF RPA Training: Utility and Tradition in Conflict*. SCHOOL OF ADVANCED AIR AND SPACE STUDIES AIR UNIVERSITY MAXWELL AFB United States, 2017, 19.

[13] Carretta, Thomas R., Mark R. Rose, and Kenneth T. Bruskiewicz. "Selection Methods for Operators of Remotely Piloted Aircraft Systems." *Remotely Piloted Aircraft Systems: A Human Systems Integration Perspective* (2016): 140-1.

[14] Headquarters, Air Education Training Command/A3F. "AETC- Undergraduate Piloted Aircraft Training (URT)". 2016.

[15] Matwick, Seward E. *AF RPA Training: Utility and Tradition in Conflict*. SCHOOL OF ADVANCED AIR AND SPACE STUDIES AIR UNIVERSITY MAXWELL AFB United States, 2017, 19.

[16] Carretta, Thomas R., Mark R. Rose, and Kenneth T. Bruskiewicz. "Selection Methods for Operators of Remotely Piloted Aircraft Systems." *Remotely Piloted Aircraft Systems: A Human Systems Integration Perspective* (2016): 141.

[17] Cubic Corporation, *PRIME DTS*, 1 June 2017, MPEG video, 4:30, https://vimeo.com/219864940.

[18] Matwick, Seward E. *AF RPA Training: Utility and Tradition in Conflict*. SCHOOL OF ADVANCED AIR AND SPACE STUDIES AIR UNIVERSITY MAXWELL AFB United States, 2017, 19.

[19] Carretta, Thomas R., Mark R. Rose, and Kenneth T. Bruskiewicz. "Selection Methods for Operators of Remotely Piloted Aircraft Systems." *Remotely Piloted Aircraft Systems: A Human Systems Integration Perspective* (2016): 141.

[20] Air Education & Training Command, "Flying Training", US Air Force, https://www.aetc.af.mil/Flying-Training/. (accessed 4 December 2018)

[21] Ibid.

[22] Ibid.

[23] Headquarters, Air Education Training Command/A3F. "AETC- Undergraduate Piloted Aircraft Training (URT)". 2016.

[24] Carretta, Thomas R., Mark R. Rose, and Kenneth T. Bruskiewicz. "Selection Methods for Operators of Remotely Piloted Aircraft Systems." *Remotely Piloted Aircraft Systems: A Human Systems Integration Perspective* (2016): 141.

[25] Ibid.

[26] Aviation Safety Division, "Aviation Statistics", US Air Force, https://www.safety.af.mil/Divisions/Aviation-Safety-Division/Aviation-Statistics/. (accessed 4 December 2018)

[27] USAF, FY 2011 Budget Estimates, Aircraft Procurement, Air Force Volume 1, February 2010, 4-118, https://web.archive.org/web/20120304052331/http://www.saffm.hq.af.mil/shared/media/document/AFD-100128-072.pdf.

[28] Ibid., 4-123.

[29] Ave. Annual Mishap cost >= Class A Mishap Avg. * Mini. Class A Cost + Class B Mishap Avg. * Mini. Class B Cost + MQ1 Destroyed # * MQ1 Unit Cost + MQ9 Destroyed # * MQ9 Unit Cost = (6 + 2.53) * $2,000,000 + (1.27 + 0.35) * $500,000 + 5.23 * $4,000,000 + 1.59 * $8,500,000 = $52,305,000.

[30] Nullmeyer, Robert T., Gregg A. Montijo, Robert Herz, and Robert Leonik. *Birds of prey: Training solutions to human factors issues*. Air Force Research Lab Mesa AZ Human Effectiveness Directorate, 2007, 4-6.

[31] Ibid., 1.

[32] Ibid., 1.

[33] Ibid., 10.

[34] Ibid., 11.

[35] Headquarters, Air Education Training Command/A3F. "AETC- Undergraduate Piloted Aircraft Training (URT)". 2016.

[36] David A. Kolb, *Experiential learning: Experience as the source of learning and development*,
(Englewood Cliffs, NJ: Prentice Hall, 1984), 38.

[37] Ibid., 30.

[38] Ibid., 27.

[39] Ibid., 32-4.

[40] Kayes, Anna B., D. Christopher Kayes, and David A. Kolb. "Experiential Learning in Teams." *Simulation & Gaming* 36, no. 3 (2005): 341-2.

[41] Ibid., 344.

[42] Salas, Eduardo, Deborah DiazGranados, Cameron Klein, C. Shawn Burke, Kevin C. Stagl, Gerald F. Goodwin, and Stanley M. Halpin. "Does team training improve team performance? A meta-analysis." *Human factors* 50, no. 6 (2008): 927.

[43] Kayes, Anna B., D. Christopher Kayes, and David A. Kolb. "Experiential Learning in Teams." *Simulation & Gaming* 36, no. 3 (2005): 349.

[44] Salas, Eduardo, Deborah DiazGranados, Cameron Klein, C. Shawn Burke, Kevin C. Stagl, Gerald F. Goodwin, and Stanley M. Halpin. "Does team training improve team performance? A meta-analysis." *Human factors* 50, no. 6 (2008): 927.

[45] Schreiber, Brian T., Don R. Lyon, Elizabeth L. Martin, and Herk A. Confer. *Impact of prior flight experience on learning Predator UAV operator skills*. AIR FORCE RESEARCH LAB MESA AZ HUMAN EFFECTIVENESS DIRECTORATE, 2002, 33-37.

[46] Ibid., 33.

[47] Ibid., 34.

[48] Ibid., 34-35.

[49] Ibid., 36-37.

[50] Ibid., 37.

[51] Diamond Aircraft, "2013 DA20-C1 Eclipse with Garmin G500," Diamond Aircraft, accessed 4 December 2018, https://archive.is/UiVQl.

[52] TSgt Mike Hammond, "Initial Flight Screening operations begin today," AETC, 12 October 2006, https://www.aetc.af.mil/News/Article-Display/Article/263488/initial-flight-screening-operations-begin-today/.

[53] Ibid., 3-4.

[54] Wheatcroft, Jacqueline M., Mike Jump, Amy L. Breckell, and Jade Adams-White. "Unmanned aerial systems (UAS) operators' accuracy and confidence of decisions: Professional pilots or video game players?." *Cogent Psychology* 4, no. 1 (2017): 23.

[55] Ibid., 6.

[56] Capt Ashley Walker, "AETC commander presents Duckworth Award to 558th FTS," 12th Flying Training Wing Public Affairs, 8 March 2013, https://www.aetc.af.mil/News/Article-Display/Article/261228/aetc-commander-presents-duckworth-award-to-558th-fts/.

[57] Virtual Reality Society. "Virtual Reality Immersion." https://www.vrs.org.uk/virtual-reality/immersion.html.

[58] Virtual Reality Society. "Applications of Virtual Reality." https://www.vrs.org.uk/virtual-reality-applications/.

[59] Virtual Reality Society. "Virtual Reality in the Military." https://www.vrs.org.uk/virtual-reality-military/.

[60] Ibid.

[61] Ibid.

[62] Air Force TV, *BLUE: Episode 25 Pilot Pipeline*, 28 June 2018, MPEG video, 8:32, https://www.af.mil/News/Article-Display/Article/1562801/blue-episode-25-pilot-pipeline/.

[63] Air Force TV, Air Force Tech Report: Pilot Training Next, MPEG video, 3:00, https://www.af.mil/News/Article-Display/Article/1576965/air-force-tech-report-pilot-training-next/.

[64] Ibid.

[65] Ibid.
[66] Ibid.
[67] Dan Hawkins, "Pilot Training Next cadre discuss lessons learned, way forward," Air Education and Training Command Public Affairs, 19 September 2018, https://www.af.mil/News/Article-Display/Article/1638707/pilot-training-next-cadre-discuss-lessons-learned-way-forward/.
[68] Ibid.

Bibliography

1st Special Operations, "MQ-1 Predator Unmanned Aerial Vehicle." US Air Force, 8 July 2008, https://www.hurlburt.af.mil/About-Us/Fact-Sheets/Fact-Sheets/Article/204581/mq-1-predator-unmanned-aerial-vehicle/. (accessed 4 December 2018)

Air Education & Training Command, "Flying Training", US Air Force, https://www.aetc.af.mil/Flying-Training/. (accessed 4 December 2018)

Air Force TV, Air Force Tech Report: Pilot Training Next, MPEG video, 3:00, https://www.af.mil/News/Article-Display/Article/1576965/air-force-tech-report-pilot-training-next/.

Air Force TV, *BLUE: Episode 25 Pilot Pipeline*, 28 June 2018, MPEG video, 8:32, https://www.af.mil/News/Article-Display/Article/1562801/blue-episode-25-pilot-pipeline/.

Aviation Safety Division, "Aviation Statistics", US Air Force, https://www.safety.af.mil/Divisions/Aviation-Safety-Division/Aviation-Statistics/. (accessed 4 December 2018)

Bliss, James P., Alexandra B. Proaps, and Eric T. Chancey, "*Human Performance Measurement in Virtual Environments.*" In Handbook of Virtual Environments: Design, Implementation, and Applications. New York: CRC Press, 2015: 749-780.

Capt Ashley Walker, "AETC commander presents Duckworth Award to 558th FTS," 12th Flying Training Wing Public Affairs, 8 March 2013, https://www.aetc.af.mil/News/Article-Display/Article/261228/aetc-commander-presents-duckworth-award-to-558th-fts/.

Carretta, Thomas R., Mark R. Rose, and Kenneth T. Bruskiewicz. "Selection Methods for Operators of Remotely Piloted Aircraft Systems." *Remotely Piloted Aircraft Systems: A Human Systems Integration Perspective* (2016): 137-162.

Carroll, Meredith. "Empirical Evaluation of the Effectiveness of Eye Tracking-based Search Performance Diagnosis and Feedback Methods." (2010).

Cooke, Nancy J., Janie A. DeJoode, Harry K. Pedersen, Jamie C. Gorman, and Olena O. Connor. *The role of individual and team cognition in uninhabited air vehicle command-and-control*. ARIZONA STATE UNIV EAST MESA AZ, 2004.

Cubic Corporation, *PRIME DTS*, 1 June 2017, MPEG video, 4:30, https://vimeo.com/219864940.

Dan Hawkins, "Pilot Training Next cadre discuss lessons learned, way forward," Air Education and Training Command Public Affairs, 19 September 2018, https://www.af.mil/News/Article-Display/Article/1638707/pilot-training-next-cadre-discuss-lessons-learned-way-forward/.

David A. Kolb, *Experiential Learning: Experience as The Source of Learning and Development* (Englewood Cliffs, NJ: Prentice Hall, 1984).

Diamond Aircraft, "2013 DA20-C1 Eclipse with Garmin G500," Diamond Aircraft, accessed 4 December 2018, https://archive.is/UiVQl.
Driskell, Tripp, Eduardo Salas, and William B. Vessey, "*Team Training in Virtual Environments: A Dual Approach.*" In Handbook of Virtual Environments: Design, Implementation, and Applications. New York: CRC Press, 2015: 1001-1028.
Eastgate, Richard M., John R. Wilson, and Mirabelle D'Cruz, "*Structured Development of Virtual Environments.*" In Handbook of Virtual Environments: Design, Implementation, and Applications. New York: CRC Press, 2015: 353-389.
Headquarters, Air Education Training Command/A3F. "AETC- Undergraduate Piloted Aircraft Training (URT)". 2016.
Kayes, Anna B., D. Christopher Kayes, and David A. Kolb. "Experiential Learning in Teams." *Simulation & Gaming* 36, no. 3 (2005): 330-354.
Kowalski, Jordan. *The Future of Remotely Piloted Aircraft in Special Operations: Methods to Improve AFSOC MQ-9 Effectiveness for Supporting Special Operations*. Air University Press, 2017.
Matwick, Seward E. *AF RPA Training: Utility and Tradition in Conflict*. SCHOOL OF ADVANCED AIR AND SPACE STUDIES AIR UNIVERSITY MAXWELL AFB United States, 2017.
Montijo, Gregg A., David Kaiser, V. A. Spiker, and Robert Nullmeyer. *Training interventions for reducing flight mishaps*. CREW TRAINING INTERNATIONAL INC MEMPHIS TN, 2008.
Moore, Kristin. "Comparison of eye movement data to direct measures of situation awareness for development of a novel measurement technique in dynamic, uncontrolled test environments." (2009).
Munro, Allen, Jim Patrey, Elizabeth S. Biddle, and Meredith Carroll, "*Cognitive Aspects of Virtual Environment Design.*" In Handbook of Virtual Environments: Design, Implementation, and Applications. New York: CRC Press, 2015: 391-410.
Nullmeyer, Robert T., Gregg A. Montijo, Robert Herz, and Robert Leonik. *Birds of prey: Training solutions to human factors issues*. Air Force Research Lab Mesa AZ Human Effectiveness Directorate, 2007.
Rehmann, Albert J., Robert D. Mitman, and Michael C. Reynolds. *A Handbook of Flight Simulation Fidelity Requirements for Human Factors Research*. CREW SYSTEM ERGONOMICS INFORMATION ANALYSIS CENTER WRIGHT-PATTERSON AFB OH, 1995.
Salas, Eduardo, Deborah DiazGranados, Cameron Klein, C. Shawn Burke, Kevin C. Stagl, Gerald F. Goodwin, and Stanley M. Halpin. "Does team training improve team performance? A meta-analysis." *Human factors* 50, no. 6 (2008): 903-933.
Schreiber, Brian T., Don R. Lyon, Elizabeth L. Martin, and Herk A. Confer. *Impact of prior flight experience on learning Predator UAV operator skills*. AIR FORCE RESEARCH LAB MESA AZ HUMAN EFFECTIVENESS DIRECTORATE, 2002.
Secretary of the Air Force Public Affairs. "AF rolls out details to improve RPA mission." US Air Force, 15 July 2015, https://www.af.mil/News/Article-Display/Article/608716/af-rolls-out-details-to-improve-rpa-mission/
Secretary of the Air Force Public Affairs. "Air Force senior leadership addresses need to stabilize RPA enterprise." US Air Force, 15 January 2015, https://www.af.mil/News/Article-

Display/Article/560282/air-force-senior-leadership-addresses-need-to-stabilize-rpa-enterprise/. (accessed 4 December 2018)
Stanley McChrystal, *Team of Teams,* (New York, NY: Penguin Random House, 2015).
TSgt Mike Hammond, "Initial Flight Screening operations begin today," AETC, 12 October 2006, https://www.aetc.af.mil/News/Article-Display/Article/263488/initial-flight-screening-operations-begin-today/.
USAF, FY 2011 Budget Estimates, Aircraft Procurement, Air Force Volume 1, February 2010, 4-118, https://web.archive.org/web/20120304052331/http://www.saffm.hq.af.mil/shared/media/document/AFD-100128-072.pdf.
Virtual Reality Society. "Applications of Virtual Reality." https://www.vrs.org.uk/virtual-reality-applications/.
Virtual Reality Society. "Virtual Reality Concepts." https://www.vrs.org.uk/virtual-reality/concepts.html.
Virtual Reality Society. "Virtual Reality Immersion." https://www.vrs.org.uk/virtual-reality/immersion.html.
Virtual Reality Society. "Virtual Reality in the Military." https://www.vrs.org.uk/virtual-reality-military/.
Wang, Xuezhong, and Brent Winslow, "*Eye Tracking in Virtual Environments.*" In Handbook of Virtual Environments: Design, Implementation, and Applications. New York: CRC Press, 2015: 197-210.
Wheatcroft, Jacqueline M., Mike Jump, Amy L. Breckell, and Jade Adams-White. "Unmanned aerial systems (UAS) operators' accuracy and confidence of decisions: Professional pilots or video game players?." *Cogent Psychology* 4, no. 1 (2017).