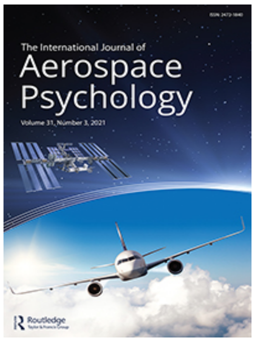

The International Journal of Aerospace Psychology

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/hiap21

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THE INTERNATIONAL JOURNAL OF AEROSPACE PSYCHOLOGY
2021, VOL. 31, NO. 3, 219–229
https://doi.org/10.1080/24721840.2021.1881403

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ABSTRACT

Objective: This study compared learning and skill transfer among university aviation students using interactive Augmented Reality (AR) technology versus traditional paper-based instruction. While similar AR use and research in university education exists, this study piloted a comparative method assessing knowledge retention and transfer.
Background: AR technology is a popular tool used in technical education. But learner behaviors observed like game play and exploration during this study could impact future learning strategy design as AR use increases.
Method: 36 university undergraduate students enrolled in a university aeronautical engineering technology program were divided into AR and paper-based groups and compared on first-time task execution times for starting an aircraft auxiliary power unit (APU). A two-sample Kolmogorov-Smirnov test comparing times for task completion was used.
Results: Learner task times using AR were consistently faster, replicating similar AR studies, compared to learners using paper-based. However, AR test subjects also took longer interacting with the technology, including gaming-style "play" and exploration of the digital twin AR flight deck environment. This is believed to enhance learner innovation, knowledge retention and transfer, warranting further study.
Conclusion: AR users had significantly reduced task execution times. Pre-task "gamification and play" were also observed among the AR users, which could impact how educators and the industry assess and leverage learning strategies when using AR for job task training.

KEYWORDS
Augmented reality; aviation education; aerospace education

AR as a teaching and learning adjunct continues to transform classroom pedagogy. Increased use of digital and remote learning paradigms along with demand for graduates who can resiliently transit between digital and real-world environments make Augmented Reality (AR) an attractive active learning solution. Educators in aviation must continually adapt teaching methods and tools to keep pace with the technological advances across aviation and aerospace domains. As those who prepare and supply the industry workforce, aviation educators are challenged to adapt the learning context to include innovative technology tools new graduates will be required use at some level. Specific to aeronautical engineering technology and air vehicle maintenance, this requires blended active learning

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experiences incorporating both traditional paper-based work instructions, very similar to the evolving industry. The modern aviation worker can often transit in and out of a digitally augmented environment without much thought. This has many implications for safety as well as efficiency.

To equip graduates with adequate competencies to function in the network-enabled aviation environment, aviation educators must include learning *with*, not just about, new digital tools and philosophies accompanying the new world of "smart", sensor-embedded aircraft. Big Data, the digital thread, the Industrial Internet of Things (IIoT) and 3D graphics-augmented work instructions are now part of the everyday aviation maintenance workspace. This notion of the networked, interconnected world is part of the new Industry 4.0 revolution (Kinard, 2018) where the human, machine and processes are linked and networked together (Bonnard et al., 2019) (Daimler, 2018). The modern aviation graduate is entering a world where they will transit in and out of a digitally enhanced workspace where work more closely resembles gaming in some respects, and tools of the virtual work environment are becoming as ubiquitous as those within the physical toolkit.

To keep pace aviation and engineering educators must adapt to include the use of the digital thread, IIoT and sensor-connected "smart air vehicle" philosophies to ensure graduates effectively wield the tools of this new paradigm. Educators must be mindful though of not simply "dropping in" new gaming technologies into the learning space. It is essential to know where these tools leverage the learning and skill transfer as well as limitations. This is critical to ensure key learning and performance-based outcomes required by accrediting bodies and the industry are achieved.

Background

The ability to access mission and task critical information, visualize the process and even an individual component's design to an in-service maintenance life is now possible because of the digital thread of connected and accessible data (Bonnard et al., 2019) (Tuegel et al., 2011). Research has shown historically the value of integrating the power of modern mobile computing tools into the learning environment, especially when equipped with lightweight graphics and rapid delivery capabilities, and that learners perform better when technology is integrated meaningfully into the curriculum (Ropp et al., 2012). Empirical evidence on newer and rapidly advancing technologies, like AR has lagged (Borsci et al., 2015) and drawbacks remain to be evaluated for gaps in unconsidered factors such as the effects of motion sickness, skill recall and decay, and user motivation to use newer technologies. Additionally, Ross (2019) cites difficulties faculty themselves experience implementing an active learning experience with innovative technology and aptly defines student-centered, active learning as "engaging material in adaptive and interactive manner". Using Roger's five-stage model of diffusion of innovation Ross describes a commonly observed resistance of educators to progress beyond an agreeable interest level and into implementation. The innovation curve described is more succinctly described as a "process that occurs as people adopt a new idea, product, practice, philosophy (Kaminski, 2011). Important to this innovation adoption concept then for this study is that the technology (its strengths and weaknesses) be understood and adopted to fit people at all stages of the diffusion of innovation model with proper learning outcome expectations.

As with most new technologies, familiarization and learning how the system functions for the first time can add to initial time-to-completion. This is noticeable in studies using combined scores to evaluate similar training performance when using AR and VR. Research shows that when accounting for initial extended orientation and training time for the participants to become familiar with a given device platform there was no significant difference between the results (Gavish et al., 2015). This pattern is consistent with earlier research on graphics-enhanced work instructions and early generation AR and 3D graphic-based applications for aviation maintenance and flight deck operations, where users indicated some benefit for information clarity, but struggled with, or became distracted by, characteristics of the data delivery device itself (Kim et al., 2010) (Hartman & Ropp, 2013) resulting in similar near net-zero changes related to time on task.

But with improved power, portability and capabilities of application-based computing devices this seems to be shifting. In addition to traditional general familiarization and on-the-job training (OJT) methods, graphics-based/3D visualization and product definition AR technologies are emerging in various aviation services on the ramp (Wong, 2017) aircraft Maintenance Repair and Overhaul (Aviation Week, 2015; De Bree, 2016) and aerospace manufacturing (Bellamy III, 2017; Boeing, 2018; Kellner, 2017; Ong & Nee, 2013). Additional research on AR in aviation maintenance curriculum indicated that learners in undergraduate aviation laboratories were willing to accept and utilize AR and other graphics-based technology as part of the learning experience, provided they gained a perceptible benefit (Wang et al., 2016).

Research Design

The purpose of this study was to compare task time and accuracy for learning to start a gas turbine APU using an AR device as a self-learning adjunct, versus traditional paper-based learning methods. It was designed in part to replicate previous results reported using AR in university-level learning. Akcayir et al. (2016) reported previously on AR technology as a learning tool with positive results both qualitatively in university student positive attitudes toward the learning environment and direct skill transfer. Brown (2017) reported similar improvement in learner performance and retention using AR for flight deck operations. As such, researchers in this report were interested in assessing for differences in time on task required of both groups to successfully perform an APU start procedure on the flight deck, hoping to replicate and observe similar time reductions. However, the researchers were additionally interested if/what specific ancillary learning impact, if any, the AR platform might impart along the learning pathway, such as gaming-like distractions or user excursions from task at hand and how these might be taken into account as the technology use case evolves. Both AR module and paper-based test groups utilized the same aircraft checklist to perform the start procedure according to protocol requirements.

Research Questions and Hypotheses

The research hypothesis was that use of an Augmented Reality digital model in full scale as a pre-task immersive training adjunct would impact procedural task time and accuracy (correct order and execution of key steps) compared to using traditional classroom paper-based review practices alone. The null and alternative hypotheses developed were:

H_0: There is no difference in learner task performance time when an Augmented Reality digital twin is used in the learning process than without.

$H_{1:}$ There is a difference in learner task time when an Augmented Reality digital twin is used in the learning process.

Method

Research Protocol and Setting Development

Human subjects and Institutional Review Board approval from the university was obtained. Researchers were also trained and qualified (including FAA Airframe and Powerplant certification) to operate all aircraft systems, including emergency procedures and evacuation on the actual aircraft used in the test. Volunteers were obtained using signed informed consent as a sample of convenience comprised junior and senior level students within the aerospace engineering technology curriculum. To help mitigate bias and participation influence, the assisting PI and graduate research assistant presented the callout for volunteers and coordination of the exercises. Participant identification was coded so names and other personally identifiable information were eliminated. Participants scheduled times of convenience to engage in the testing. None of the participants had performed the studies test procedure before.

Testing was accomplished within a large aircraft airframe laboratory on the School's Bombardier Canadair Regional Jet (CRJ) 100-series jet. The aircraft is a fifty-passenger twin jet with fully functioning systems and powerplants, including an onboard Garrett GTPC36-150(RJ) gas turbine auxiliary power unit (APU) used for the test.

Technical Procedure Task Selection

To ensure relevance and transfer to both the learning and real-world aviation operational environments, researchers selected a checklist procedure for starting the aircraft's APU. The APU is a self-contained gas turbine engine used on many large aircraft. It is operated by maintenance and flight crews to provide pneumatic bleed air and electrical power for the airplane during ground operations or during certain emergency flight conditions. Most APU starting procedures consist of required checklist tasks which must be accomplished in a specific sequence in order to safely start the APU. Successfully navigating and performing this multi-step task requires locating and manipulating multiple switches and reading and monitoring system status information on various multi-function display screens, and continuous team communication.

Because this procedure is accomplished within close quarter confines of the flight deck (Captain and/or First Officers seats), participant actions were able to be unobtrusively observed and recorded from the flight deck entry doorway just behind the participants. This provided the ability to unobtrusively observe subjects' verbal communication responses, search times, task-saturation responses and timing for task completion. It also ensured researchers direct safety and emergency procedure intervention for protection of personnel and equipment.

3D Test Platform Selection and Development

Device testing was performed using the Microsoft HoloLens head-mounted device. The HoloLens was selected for its portability, stable programming platform, and overall visual fidelity and realism. At the time the study was conducted the HoloLens 2 had been announced, but not made available for purchase. Therefore the HoloLens 1 was used for all testing and development. A flight deck hologram of the jet was modeled in a 1:1 scale replicating the CRJ-100 flight deck's center console, forward and overhead panels in first-person perspective (Figure 1). Switches, system selector push-buttons, and indicators on the aircraft were recreated and labeled in the 3D model in first-person view as they are on the actual aircraft.

Only the systems called out by the APU checklist could be operated in the virtual learning environment. Remaining switches and locations were rendered to present as realistic view as possible. The flight display panels also illuminate with the correct display images and text depending on the step in the checklist.

The flight deck AR model was created using a development platform called Blender and a realistic visual representation including colors and lighting effects was attained. Unity Game Engine software was then used to create interaction between the 3D model flight deck components and the user. Additional user-assist features were included such as a switch to operate a flashing bright orange light to assist the user in locating the correct system switch. Additionally, an interactive "follow me" floating directional green arrow (Figure 1) was programmed to guide the participant toward the correct switch control. The switches and system displays would also illuminate showing the correct data page depending on the step in the APU checklist. Not all switches and push-buttons contained lights or changed the display panel which was a limitation to the amount of visual feedback provided by this AR test model version.

Design limitations in this phase of model development included a lack of aural announcements (normally generated by the air vehicle's onboard Engine Indicating and Crew Alerting System (EICAS) and fire warning system) and tactile feedback for switches and buttons. Participants reported inclusion of these aural and tactile components would have been helpful components of learning in general. Researchers verbally announced warnings and messages where they would normally occur on the actual flight deck. The HoloLens also contains built-in microphones to detect voice commands for programs. While voice commands were available, they were omitted from integration into the program to help build muscle memory of button location.

Study Design

Human subjects and Institutional Review Board approval was obtained from the university and all researchers trained in CITI Human Subjects Group 2 Behavioral research. Participants recruited were aeronautical engineering technology student volunteers from the university's Federal Aviation Administration (FAA) Part 147 aviation maintenance curriculum. Participants were randomly assigned into two test

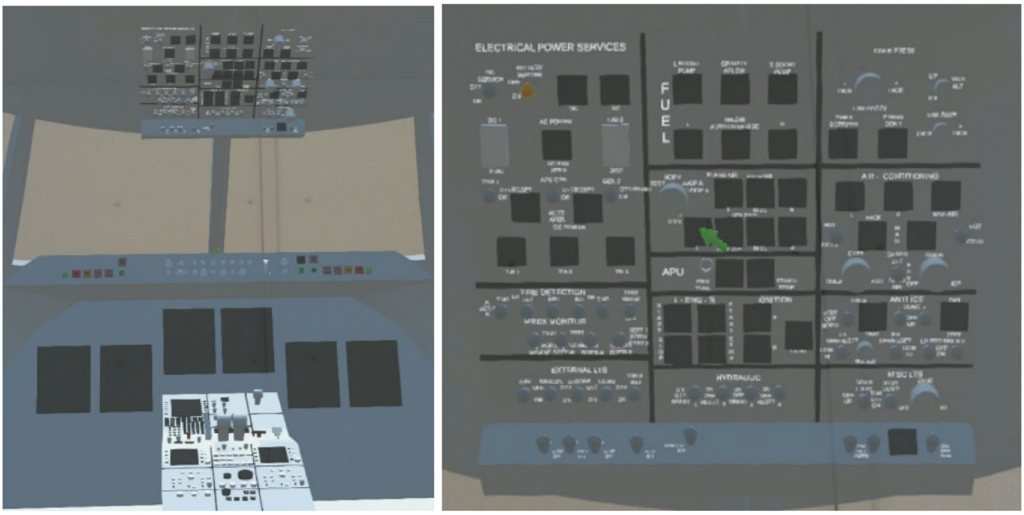

Figure 1. CRJ flight deck hologram: first-person perspective.

groups labeled Group 1 (control group) and Group 2 (experimental group). A total of 36 students participants volunteered for the research, with control and experimental groups evenly distributed. Prior to starting the experiment both groups were provided informed consent and briefed on basic aircraft and ramp safety protocols and required personal protective equipment.

Group 1 test subjects were set up as the control using on-the-job training (OJT) style of studying a paper-based procedure covering the start of the APU. This involved reviewing the paper-based checklist for the procedure in the normal laboratory classroom prior to going to and entering the aircraft. Once on the aircraft, students would perform the task using the paper-based checklist. Control group participants were given as long as they needed to review the paper-based checklist. The only instruction given was that they felt they had sufficient preparation for the task prior to performing. Both the time to review the paper-based instructions and checklist as well as actual time to perform the procedure once on the flight deck to the point of starting the APU were recorded.

Group 2 test subjects were the experimental group. They were provided the AR-equipped device with the interactive guided instruction and flight deck simulation for performing the APU start. As with the control group, participants self-determined the amount of time they felt they needed to review the instructions and checklist using the device. This instruction time and the actual time to perform the procedure once on the flight deck to the point of starting the APU were recorded. Group 2 AR participants performed an introductory familiarization tutorial standard to the device. The orientation program was pre-loaded by the manufacturer, Microsoft, to orient first-time users regarding basic navigation and gestures for operating the HoloLens. Once familiar with the operation of the HoloLens, participants were directed to the researchers' aircraft orientation/checklist program to begin the virtual learning experience. The tasks conducted for AR participants included going through the device's built-in orientation program, practicing the APU engine start in the virtual environment and then actual task time in the real-world environment on the flight deck. After reviewing the same procedure using either paper-based or the wearable AR device, both groups performed the identical APU start procedure using the required onboard standardized APU checklist. Only the time performing the APU start was used in the calculation of the results.

Results

Using the time measured to perform an APU start on the CRJ-100, a two-sample Kolmogorov-Smirnov test was used to assess the two different time outcomes for the experimental and control test groups. Times shown in Table 1 are shown as minutes: seconds and also equivalent total seconds in parenthesis. A selected alpha value of significance set at 0.05 was used. K-S Test 1: Task-only time (APU starting task completion only) as shown in Table 1. The K-S test resulted in a D value of 0.4444 with a corresponding p value of 0.039. The null hypothesis is rejected when comparing task-only time.

Table 1 Assessment

Results for the AR group had the initial device on boarding time of 3:11.4 ± 1:53.0. The time to perform the APU checklist in AR took 4:06.1 ± 1:09.6. The APU start time took 4:38.9 ± 2:01.9.

The time difference came when comparing just the task of starting the APU, participants who used the AR pre-task learning module had significantly faster task performance times, averaging 135 seconds faster than the paper-based pre-task learning module control group. Additionally, time within running through the checklist was very close together. This was most likely due to the navigation aids that showed where the locations of the pushbuttons and switches were located. The navigation aids limited the amount of time that a student would be stuck on a certain task. The AR group displayed notably more fluency and ease in ability to locate and procedurally "flow" through checklist items required. The control paper-based group participants were noted to search longer to locate the same checklist items thus resulting in increased overall time on task.

The interactive element of the AR pre-task training was believed to play a role in enabling shorter task completion times recorded for the test and set the stage for further evaluation using more complex and varied technical tasks common to the aircraft maintenance environment. Regardless, the time reduction noted on tasks using the AR platform is significant for maintenance training and education. The reduction in task learning time potentially could carry forward to benefit the industry, where worker resilience in learning new job roles is required. Faster orientation and overall reduced time for task mastery such as checklist flow patterns and learning switch-panel locations quickly is also important in aviation maintenance where being assigned to different aircraft fleet types or upgraded models is not uncommon.

Table 1. Task-only time (APU starting task completion only).

	Task only time average	Standard Deviation
Group 1 (Paper)	6:59.9 (419.9 seconds)	1:41.3 (101.3 seconds)
Group 2 (AR)	4:38.9 (278.9 seconds)	1:09.6 (121.9 seconds)

Participant Pre-Task Training Module Impact on Results

Participants in both groups received a pre-task learning module (either paper-based or immersive AR version) for starting the CRJ-100 APU; a routine step for the laboratory curriculum task performance. The times taken to perform the pre-task training segments are shown in Table 2.

Participant use of the HoloLens was significantly longer due to participant's unfamiliarity with the device requiring orientation and training for the use of the device.

The experimental group was provided an additional brief introduction on how to use the HoloLens training device headset. The training consisted of an approximately one-minute introduction to the HoloLens device and its capabilities, followed by a Microsoft orientation program on how to operate and use the HoloLens. The Microsoft orientation program teaches tasks that are not used by the students, such as drag, zoom, and rotate. Due to this only the select and bloom were taught as these were the two gestures required by the AR flight deck program. The shortened orientation program completion time with the device is shown in Table 2. After completion of the first stage of the program the orientation program was ended and the AR flight deck was loaded. Even with the inclusion of the orientation program and the HoloLens being based on Windows 8.0, some participants struggled with the concept of using their hands and body to operate the device.

The gaming-like nature of the HoloLens device also prompted some participants to dwell at certain points to explore and play with the virtual learning space or wanting to run through the simulation again. The time taken to learn how to use the Microsoft HoloLens was significantly longer than the group using the paper-based checklist, which included unscripted exploration by the users. These orientation times and exploration excursions with the AR device were not used in calculating timed task results but were of interest to the researchers for further follow up. This participant behavior should be a consideration for preparing future tests and making inferences on total time. All participants from both test groups were allowed to try the HoloLens headset after the study had concluded.

The paper-based control group was only provided the paper-based checklist to review. For task orientation the paper-based group had a significant range in times due to students either reading through every step of the checklist on one hand, or just the opposite, later indicating they only skimmed the task headings then proceeding to the aircraft. This was most likely due to the limited instruction provided by the researchers for this portion of the task. The only instructions given were to read through the checklist; once they felt comfortable with their knowledge of the task at hand, they were instructed to notify the researcher to proceed.

Table 2. Pre-task time.

	Device orientation	Pre-task
Group 1 (Paper)	X	1:47.6 (107.6 seconds)
Group 2 (AR)	3:11.4 (191.4 seconds)	4:06.1 (246.1 seconds)

Study Limitations and Future Work

This study looked at learning and skill transfer efficacy using Augmented Reality technology as an assistive instructional tool compared to paper-based learning only. Growing class sizes, physical accessibility, and industry demand for a resilient technical workforce with competencies that include rapid, continuous learning and change management competencies make AR an attractive part of a blended, expedited active learning solution for both education and industry settings. This study evaluated short-term learning outcomes using AR. Longitudinal studies of long-term skill retention, ability to re-train and for changing job roles (common in the industry) and subsequent training time impacts using immersive AR platforms should be carried out for a more comprehensive evaluation and to help standardize useful, consistent strategies.

As discussed, one limitation of the study was the quality of the custom AR program developed. This was primarily attributed to time constraints to accomplish the study. Second was the lack of tactile confirmation on button/switch selection by the users. Because they were using only one of the body senses (visual) in the AR program, participants occasionally had difficulty confirming if a button was actually completely depressed, even with the button assist features. Future development will look to add simple vibration or a sound effect to address this. Additional limitations involve the available student pool being limited to students who were either a junior or senior by classification and had not previously been through the capstone class involving the large aircraft.

Possible iterations of future study would test for skill degradation/retention and speed related to the task. This would provide insight into which method elicited better overall learning retention.

During the study, correct task order was assessed by observing actual correct or incorrect button/switch presses. As the study progressed however, participants began to ask for researcher confirmation of the correct button presses before proceeding, either due to fear of unintentionally activating a system or wanting affirmation before proceeding. This forced the researchers to confirm the participants they were okay to proceed, and therefore corrupted accuracy of time measures when this occurred. It was difficult to completely normalize and/or remove these instances from contaminating some of the performance numbers. This is being used for design of a refined test protocol and user instructions for future design of a more refined and stable test case.

Conclusion

Application-based mobile computing is part of the culture of the current generation of learners and is also rapidly emerging (along with other IIoT devices and networks) in growing numbers throughout the aviation and aerospace industry. Fluency integrating and wielding these technologies as part of a continuous learning and competency-building tool required of the next generation workforce could become as important as the task performance itself.

While this study indicated reduced task times attributed to AR, it revealed additional nuances for future study. As mobile computing versions and capabilities continuously evolve and are adopted into education, impact on knowledge retention and transfer must still be better understood. More study is needed in particular on behavioral phenomenon observed in this study known as “gamification effect” (Dichev & Dicheva, 2017) where learners explored device features, branched temporarily into other flight deck features salient to learning the overall flight deck layout but was not part of the test procedure. This phenomenon was replicated and observed (though not intended) in our study as participants acclimated interactively with the AR technology before and during the module. While initially seen as a potential time penalty for this report’s initial metrics, literature does support gamification in education as a method for expanding student creativity and knowledge retention overall (Caponetto et al., 2014; Dichev & Dicheva, 2017). This should be studied further as it relates specifically to aviation and aerospace education and workforce development using AR and other immersive teaching aids and represents next steps in the research.

Disclosure Statement

No potential conflict of interest was reported by the authors.

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