Efficacy of Virtual Reality Flight Simulators in Pilot Training

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Abstract

The paper explores the application of virtual reality (VR) in aviation training, emphasizing its transformative impact on cockpit and pilot training. VR flight simulators (VRFS) technology enables aviation trainees to interact with virtual aircraft components, practice emergency procedures, and familiarize themselves with cockpit controls through immersive simulations. This approach aims to enhance learning, increase skill acquisition, and provide a cost-effective alternative to traditional flight simulators, while providing a flexible, risk-free training environment adaptable to individual skill levels. VRFS offers high fidelity in replicating critical flight scenarios, fostering proficiency in decision-making, situational awareness, and multitasking under pressure. VR's advantage over traditional flight simulators include improving access to training and allowing repeated practice, which aids in building muscle memory and confidence. Although VRFS cannot fully replace traditional simulators, this paper explores VRFS training effectiveness and transfer of training when utilized as a complementary tool. Limitations such as VR sickness and controller sensitivity are acknowledged, with recommendations for future improvements. Ultimately, VRFS is positioned as a promising tool to augment traditional aviation training frameworks, contributing to safer and more effective pilot training programs.

Virtual reality (VR) has transformed the aviation industry by enhancing training and operations such as pilot training, aircraft maintenance, and cabin crew training. Aircraft maintenance personnel can explore aircraft components in 3D, providing them the opportunity to manipulate complex components, thus avoiding the need to physically disassemble the parts later. Maintenance technicians can practice assembly, disassembly, diagnostics, and repair before working with real equipment, thereby accelerating the training process and increasing proficiency. VR can be an effective tool in training the cabin crew on procedures such as medical emergencies, evacuations, depressurization, fire, water landings, and how to handle disorderly passengers. VR can simulate real world scenarios, allowing them to practice their skills and communication, while preparing them for unthinkable high-pressure situations.

The immersive nature of VR has propelled its adoption in the aviation industry, notably, its use in pilot training from cockpit instruction to flight simulation. In one example of cockpit training, KLM Cityhopper developed a VR training course to train pilots on the Embraer 175 and 190 aircraft controls, replacing the paperboard mock-ups previously used for cockpit training. The VR training course consisted of three parts, an interactive cockpit where a pilot can sit and see all flight control panels, a 360-degree POV instructional video in which the pilot watches a video of a flight, and a virtual walk-around where pilots can walk around the aircraft. VR-based flight simulators (VRFS) are also used to provide training simulations that replicate varied scenarios, weather conditions, and emergency situations. VRFS enables pilots to experience critical conditions and practice emergency procedures, in a safe and controlled environment without real-world risks. Furthermore, VRFS is a cost-effective option compared to traditional flight simulators due to its reductiong in fuel costs, physical infrastructure, and need for expensive equipment.

The primary objective of a VR pilot training program is to build a pilot's proficiency and competence before operating a real aircraft. Cockpit Familiarization Training (CFT) is an essential component of pilot training, during which a pilot learns the location and purpose of controls and switches, including the correct management of the pilots' checklist. A contributing factor in aircraft accidents is the unsuitable use of checklists, which highlights the importance of CFT. However, CFT is considered basic training, making it cost prohibitive for traditional flight simulators, while low-cost alternatives lack the desired fidelity to teach spatial relations and physical qualities (Auer et al., 2021). VR can bridge this gap between cost-effectiveness and realism, without compromising on quality.

Traditional flight simulators have been used in aviation training for decades, designed to replicate the exact cockpit layout, controls, and instrumentation of specific aircraft models. The high fidelity of traditional flight simulators provides pilots with a highly realistic experience, replicating the physical sensations of flight such as turbulence, acceleration, and deceleration. Traditional flight simulators are approved by regulatory authorities like the FAA and EASA for certification training, ensuring that pilots receive a standardized level of training that meets industry safety and competency requirements. In addition, simulators can be credited towards required flight hours for certifications, helping pilots achieve milestones in their training more efficiently.

Despite the inability of VRFS to fully replace traditional flight simulators, VRFS has become a complementary tool in enhancing a pilot's learning experience. VR preserves the risk-free environment of traditional simulators while providing greater flexibility and versatility, providing training environments that can be customized to an individual pilot's training needs. This adaptability ensures that pilots receive instructional challenges that align with their skill level and objectives, while providing high fidelity aviation challenges that build self-confidence and self-assurance (Thomas et al., 2023). VR training is accessible remotely, allowing pilots to access the VR training programs at home, in absence of a physical classroom, or restrictions of a time-dependent simulator. The increased flexibility and accessibility of VR training affords the repetition necessary for skill augmentation and acquisition of muscle memory (Allerton, 2009). Furthermore, VRFS is a cost effective alternative to traditional flight simulators, with students reporting greater comfort with flying the VR simulators, as opposed to expensive flight training equipment (Guthridge & Clinton-Lisell, 2023).

As with any learning tool, an evaluation of performance can illuminate its efficacy in accomplishing the intended goals, as well as identify areas in which the program is not achieving the learning objectives. If trainees consistently perform well, it suggests that the program's structure, content, and methodology are effective. However, if multiple trainees struggle with a particular skill or scenario, it could indicate specific areas that need to be improved. Furthermore, tracking performance over time can reveal how well the program adapts to evolving industry standards or regulatory requirements. In aviation programs, transfer of training must be evaluated to determine if a training program can effectively prepare a pilot to operate safely and proficiently in real-world conditions. Successful performance in a training program may not translate to successful performance on the job, thus performance measurements can act as a feedback loop to understand a training program's impact on its students.

Transfer of training outcomes can either be positive, zero, or negative. Zero transfer results in no change in performance after training, while negative transfer results in a decrease of performance. Positive transfer of training results in an improvement of a trainee’s performance, including the effective application of training goals to real-world situations on the job. The training program must establish performance benchmarks to determine the desired level of proficiency when pilots are tested on higher-fidelity physical simulators, then establish benchmarks for performance in a real aircraft. Establishing baseline performance at the beginning of training, while tracking improvement across sessions, allows instructors to view progression and ensure that pilots meet required standards before advancing to the next stage.

Pilot training should produce fundamental skills such as operative knowledge about the cockpit, proficient control handling, navigation, communication, and accurate implementation of emergency procedures. In addition, pilots should produce accuracy and consistency in flight maneuvers such as takeoffs, landings, turns, climbs, and descents. Measuring timing and efficiency is critical for performance in changing real-world situations, such as air traffic control communication and fuel management. Furthermore, manual control skills can decline with reduced practice due to increased reliance on automation and limited hands-on flying experience, specifically for long-haul pilots who have fewer opportunities to handle the controls (Lefrançois et al., 2021). In addition to new pilots, VRFS can be used to refresh the skills of experienced pilots. VRFS has the advantage of providing high fidelity dangerous situations, as well as the ability to implement a 360-degree angle of scenery view.

The adaptability of VRFS makes it uniquely capable in using complex, scenario-based training exercises to strengthen a pilot's ability to make decisions under pressure. Simulating scenarios such as engine failures, adverse weather, and instrument malfunctions can be used to evaluate a pilot's ability to handle unexpected changing variables. The enhanced realism of a VR flight simulator can also help build reaction skills for extreme or hazardous situations (Oh, C.-G., 2020). Spatial and environmental awareness is essential for a pilot's ability to monitor position, altitude, airspeed, and air traffic. Adept visual scanning is necessary for monitoring various aircraft system states, and "the issue of improper monitoring was identified by the National Transportation Safety Board (NTSB) as being involved in 84% of major accidents in the United States from 1978 to 1990" (Lefrançois et al., 2021). VRFS can be used to implement eye-tracking technology to improve situational awareness of pilots, similar to the strategy used by F16 instructors in the US Air Force (Wetzel et al., 1998). Emergency situations require a pilot to locate relevant warnings, gauge readings, and effectively communicate the situation to their copilot and air traffic controllers. A VRFS that can produce a high degree of presence contributes to the development of good situational awareness, with pilots reporting greater involvement, immersion, and control of the flight simulator (Cross et al., 2023). Presence can be used as a performance metric of VRFS, representing the effectiveness of the virtual environment in providing exposure to real-world situations (Walters & Walton, 2022).

Some limitations of VRFS technology include controller sensitivity that can limit precision when handling the cockpit, and future iterations should be optimized to follow cockpit system design that avoids accidental manipulation of switches (Oh, C.-G., 2020). Simulator sickness is another important factor when evaluating VRFS training effectiveness, with training tolerance affecting comfort and duration of training sessions, thereby affecting pilot engagement and completion of training without adverse effects. A study by Thomas et al. (2023) found that VRFS was successful in incorporating visual and vestibular illusions, leading to a noteworthy increase in trainee performance. Although some pilots experienced eyestrain and fatigue, the discomfort did not lead to any participants ending the program. The significant increase in both knowledge and testing scores provides persuasive evidence supporting VRFS as a meaningful training approach, with trainees increasing in self-efficacy and understanding of complex concepts.

The goal of VR in pilot training is to enhance learning, improve skill acquisition, and increase accessibility to training by providing an immersive, cost-effective, and scalable environment where pilots can practice essential skills. VRFS aims to enhance learning by providing a training environment where pilots can practice safety-critical procedures, and develop the cognitive and emotional resilience required for real-world flying. The increase in training availability should translate to better multitasking and information processing, providing the necessary practice that leads to better decision-making and stress management, in addition to proficiency in managing cognitive load. VRFS can support traditional training methods and contribute to a more comprehensive, flexible, and accessible training framework.

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