A Review of Virtual Reality Application in Airline Pilot Training

This study examines virtual reality (VR) technology as a key tool in airline pilot training. With VR technology—as the most significant software system—the development of information displays has increased rapidly since the third industrial revolution. VR-based simulation, on the other hand, differs significantly from earlier simulation techniques.[1] Within the Third Industrial Revolution, Jean Baudrillard divided the modifications in simulation process into three phases.[2] The process of replicating and copying the original occurs in the first simulation stage, which takes place prior to the this Industrial Revolution. In this case, it is evident that the replica differs from the original, hence it cannot take the place of the real element and the human brain automatically recognizes it as such. The second phase involves simulating production using machinery. This is a labor process simulation, and despite disagreements, reality and the copy coexist because of the copy's good functioning; with a little imagination, the copy can be perceived as the original. Replicating feeling and thinking is the third step in the simulation process, which takes place after the Industrial Revolution. At this point, the copy achieves unique functioning and actuality, surpassing the simple reproduction, known as the last phase of VR simulation process. VR has a stronger sense of realism than real reality, additionally it can be more vivid and interesting than real reality by enhancing the senses and mental processes. In its third step, VR also accepted as hyper-reality since it has more sensory information than the real world.[3] VR in this third step becomes a useful training tool.

Since the twenty-first century, display technologies have evolved from ray tubes to flat panels and from liquid crystal display (LCD) to organic light-emitting diode (OLED).[4] In the 2010s, new technologies became widespread not only for flat panels but also for more innovative systems such as next generation displays. These innovative systems provide the interaction between the user and their ambient environment.[5] These developments are pioneers of the VR display as the field of view (FOV) by tranfering the whole environment into a fast-moving virtual experience. The advanced version was designed for the users as an advanced version of a real-life experience that was produced according to the VR technology by adding tactility. This version is defined as Augmented Reality (AR). AR provides tactility not only for high-quality vision performance but also presents software like the real-world with tactility digital specifications. The optical technology improvements and the user's experience increased the number of AR and VR display examples. The potential of these appealing practices is not only related to health care, but they also cover education, design of engineering and manufacturing, retail selling, and recreational activities related to entertainment. These practices can also be used for the optimum purpose of technology. They improved high-reality crystal-clear displays that can assimilate, merge, and reconstruct the ambient area by avoiding equipping discomfort simultaneously. These displays are still as competitive nowadays as the former launching stages. AR systems are the most demandable ones not only for advanced performance increment, but they can also for miniaturizing the visual and tactile appearance of the scenes related to power and cognitive usage in training.[6]

Educational fields have been using VR technology for more than a half-century, however, its recognition was not widespread. The outcome of numerous shortcomings arose in the technology level, expenses, and logistics that distribute these products globally.[7] This technology was not new in the application of education area. The first VR application was manufactured in 1966 as a flight simulator. Afterward, it emerged in the United States in the training area of the Air Force.[8] VR technology has taken place in the public sector for approximately twenty-five years. In 1991, the specialized arcade game series took a position in the market by Virtuality Group Company.[9] This game series was not commerically successful and continued with different versions for only two years.[10] SEGA also produced a head-mounted display (HMD) related to VR in 1993. Some game studios worked on this software, but they never released it to the market.[11] In July 1995, Nintendo launched a new game system, the Virtual Boy. It was a VR-based system, and all samples related to monochromatic HMDs were evaluated as a commercial fail and sales were stopped fewer than six months after their release date. The early history of commercial VR systems declared it an enormous failure.[12]

Despite these commercially unsuccessful products, there were some positive elements of VR application in education, including increasing experiences time-on-task,[13] pleasure,[14] motivation,[15] deep learning, and retention of information over the long-term. Despite these positive outcomes, VR systems did not common acceptance in the training sector until 2010.[16]

Literature Review

Since 2010, VR technology has been a key element in Information Technology (IT) usage. After Steven Spielberg made Ernest Cline's novel *Ready Player One* a movie, millions of people learned about VR technology for the first time. However, a small population of people knew that the basic VR technology had taken place in the market since 1966,[17] with elevated equipment expenses and inadequate qualifications blocking the widespread acceptance of this Technology.[18] Several people believed that VR technology could not be successful[19] due to the unsuccessful initiatives years ago.[20] Although the purchasing trend of VR headsets which playing and pleasure was unsuccessful, VR was due for a second chance.[21] The improvement of VR technology has been one step awayy from being successful since Gartner's "slope of enlightenment" arrived in 2016, and was not adequately developed. VR imitates a virtual ambiance to their users related to the sensation of existence.[22]

Researchers from diversified areas such as computer, social, and engineering sciences have all concertrated on VR technology in the last decade.[23] Walsh and Pawlowski (2002)[24] paid attention to the Information Systems (IS) that were designed for VR technology. Finally, IS researchers' attention to VR technology has continued with a rising trend.[25]

In the 2010s, the VR technology market quickly grew. The trend was forecasted to rise from 7.3 billion U.S. to 120.5 billion U.S. between 2018 to 2026.[26] However, the technology of VR's large share has related to user software, especially video games such as Facebook’s Oculus Quest, and HTC’s VIVE (played on VR headsets) figured out the revolution in the gaming area in terms of pleasure and recreation. Companies such as IKEA, Volkswagen, and Takeda have utilized these potency implementations in an increasing trend for non-gaming recreational areas. So, the review of VR history allocates the technologies into diversified segmentations. Eventually, the overview of VR technology provides research to determine the importance of IS. The aim is to develop diversified improvements.[27]

Additionally, VR is the process that externalizes diversified classifications related to actions which generally consolidate with this reality. VR is originally one classification of reality, and it covers mixed reality and virtuality. VR's diversified classifications include wholly virtual processes. None of them cover any actual and physical processes. Only several types of digital versions took place in this actuality related to its possibility. So, VR technology deals with demonstrated 3-D virtual visualizations similar to the actual world and the types of equipment inside it.[28]

Nowadays, aircraft cockpits include safety processes with improved and well-planned interfaces. The flight deck designation provides the interfaces of human-machine improvements on human factors feedback. These feedbacks are; ergonomics, usage ability, and cognitive perspective.[9] Karwowski, Marselo, and Neville (2011)[30] claim that ergonomics employs a user-centered, holistic approach that improves the design of elements by taking into account relevant physical, cognitive, social, organizational, environmental, and other aspects within the appropriate approaches. Ergonomics plays a decisive role about increasing the performance of products in many decision-making stages during the product development process. In this sense, usability integrates with ergonomics to allow systems and products that are tailored for the individual user by taking into consideration needs, capabilities, and constraints. Ergonomy appears as the boundary separating the user and the system components related to the usability and design together to achieve this goal and increase user pleasure.

From a simple behavioral or cognitive standpoint, learning has been understood over time to involve intricate interactions between the learner, the content, other learners, and the context in which the learning takes place.[31] A useful theoretical viewpoint on how people learn in situ is designed by cognitive constructivism.[32] This viewpoint is particularly relevant when discussing training styles in terms of cognitive constructivism. According to Bandura (1978)[33] cognitive constructivism takes into consideration learning that takes place at the individual cognitive level, or the mental model of the individual, while also taking other people's influences and the context of the learning into account.

In order to reinforce the social science element to characterize and explain the cognitive characteristics of the cockpit system, which is made up of the pilots and their informational surroundings, the researchers need “a unit of analysis.” This analytical unit is referred to as a “system of distributed cognition,”[34] which during the past twenty years have had a significant impact on learning research. In the second step, a more thorough discussion of the connected ideas of “communities of practice” and “legitimate peripheral participation” have been used.[35] In the last step, which was motivated by situated cognition theory, centered the attention on the process of mental model transformation covered an intrinsic cognitive process. Even though people are aware of indications in the virtual world, their mental models are unlikely to alter if they are not mentally involved in the process. Thus, it is anticipated that cognitive viewpoint will completely support the connections between the various forms of awareness and mental model modification.[36] According to psychological effects when using VR technology, Muhlberger, Petrusek, Herrmann, and Pauli, (2005)[37] examined anxiety-based neurotic conditions of patients under four simulated flights while monitoring the skin conductance and heart rates.

The flight phobics' increased subjective and physiological fear reactions, as revealed by the results, demonstrated that VR exposure was genuine. As a result, the authors came to the conclusion that virtual flights do trigger the same fear networks that cause real-world flight anxiety. However, it was argued that VR exposure was beneficial. Clinically, the course of treatment for flight phobia might be anticipated from the participants' perceptual and physiological reactions during exposure to VR.[38]

The improvement of VR products, increased the human factor assessment strategies and their designations. They should be selected cautiously to interrelate with vital resources.[39] Firstly, it is essential to specify the proper simulation level adherence of the design maturity and improvement stage. Secondly, the human factor strategy needs to be determined.[40] The methods for nominative inquiries are NASA-TLX and SART, while the other collected inquiries are physiological variables such as gaze behavior and heart rate. The assignment of integration ratios related to time and error needs a wide selection of applications to compose strategically successful outcomes. In civil aviation, cockpit and cabin crews, engineers, and maintenance personnel need to train with experience in particular areas. The efficiency of these areas in terms of evaluation and feedback is related to the vigorous experiments. Hence, the assessment of subject matter experts (SME) includes minor samples, turning to operational strategies for the suggested resolution.[41]

Aslandere, Dreyer, Pantkratz, and Schubots (2014)[42] clearly explained the feasibility of the flight technology system and the stages that can be applied to this system. Aslandere et al., (2014)[43] evaluated the simulation stages by applying the human-machine display interface, optic examination, and following systems related to the interior design of the VRFS. This stage consists of a virtual cockpit, outside visual, and pilot capability. Some of the required hardware components are used in this VR system as flight control panels. VR prepares almost the same environment as the real one, and the assumed components create the mixed model. All these constituents are maintained within the systematic VR structure.[44] The system ensures the management of these hardware elements, flight indicators as external hardware and software components without fail.[45] Therefore, the VR system evaluates the design process related to engineering, cockpit visuals, and human-machine interface elements.[46]

These processes include various flight stages suitable for the cockpit and deal with challenging elements arising from the virtual framework. So, it is revealed that the simulator flights are compared to whether the actual flight scores are similar or not. The study points out that this system can be successfully performed by evaluating the pilot's situational awareness decision-making processes and flight performance. In the acceleration of flight stages and adaptation for different types of aircraft, the processes should be used in harsh weather conditions. The VFRS system ensures the best planning of human factors engineering in the early stages of the application process. In particular, after the pilot training that ends with the PPL and ATPL licenses, getting aircraft-type training provides training practice for students. Therefore, trying different aircraft types at type training will increase the situational awareness, knowledge, and ability of a student pilot. The compliance of actual flights related to the simulator ones provides easy practice and nearly has no cost except for the first purchase. Despite all the positive assessments, the primary issues include the measurement of performance and workload according to actual, and simulator flights. When applying VR, the most accurate scoring is based on actual and simulated flights with the correct valuation. The reason why this research was designed is related to the evaluation of all flight stages to ensure the practice of actual and simulator flights. So, it needs to evaluate the positively developing applications in VR technology. VR applications can also perform in the industries mentioned below:[47]

- Marketing purposes in the retail sector,
- Surgical training in the health sector, psychology, and psychotherapy,
- In marketing and promotional activities, planning, management, and entertainment activities in the tourism sector,
- Training activities in defense and public safety and related fields.

Furthermore, VR simulators used in pilot training can categorize full-flight simulators with realistic mobility. They are also fixed-based simulators with similar features to full flight simulators, but without motion features that include only one software. ASL Airlines took part in research to use the VR application in pilot training due to the purchase costs of these simulators. According to this research, they are not portable and cheap for flight and training programs in small companies, so the costs of purchasing this service are relatively expensive. The VR equipment includes gloves and headset (a device similar to VR glasses) with sensors detect finger movements in the simulator. According to these sensors elements such as fluidity, interaction, and sensitivity features can be used. These features have been tested by the technical pilots of ASL. These tests have revealed additional adjustments for the VR applications, which are a potential tool in pilotage training.[48] Another study focuses on human factors engineering in cockpit design with VR concepts using VR glasses and other motion tracking systems. Cockpits are safety-critical products with advanced and well-researched user interfaces. Production costs and final product prices are high due to high-quality standards for both hardware and software. The development of human-machine interfaces in cockpit design requires feedback in terms of human factors (usability, ergonomics, etc.) in the early stages of design.[49]

Oberhauser and Drayer (2017)[50] used different methods to analyze human factors in cockpit design with a VR concept. After the simulator experiences, subjective surveys such as NASA-TLX (NASA Payload Index) and SART (Situational Awareness Rating Technique) were applied to users. In addition, it is possible to have information about the gaze behavior, the number of glances and transitions, and the pilot workload by using eye-tracking. Therefore, data based on gaze behavior emerges as a method for obtaining visual data for the cockpit. Physiological data such as heart rate, which can easily be measured with a pulse sensor attached to the ears of the pilots, and psychological concepts such as mental load and effort can also be evaluated.[51] Thus, a suitable environment will provide human-machine development in the interfaces of the cockpit design's early stages with both subjective and objective methods.[52]

According to the data in “Design and Development of the F-16 Combat Pilot Training System: First Views” that was presented at the conference named “Advances in Human Dynamics for Progress in Contemporary Societies” about Portuguese Air Force's F16 pilots “Joint Helmet Mounted Cueing System” during flight. The collected data had great importance, so pilots could see possible hazards and warnings. This importance has increased because the high costs of actual flights cannot be practiced by trainers enough.[53] In VR, there is no contact with the actual environment, and data completely transfers to the hardware used for VR so that the user is not confused with the environment contact. Also, VR hardware can be used in any environment.[54] In conclusion, the necessity of using a VR flight simulator that can transmit data with higher efficiency, accuracy, and more varied shapes and colors has emerged from the interviews with the pilots and the related research.[55] In the semi-structured interviews with the pilots, open-ended questions are asked of trainers, and a prototype is prepared according to the features, which is a result of different interface reviews.[56] These prototypes have been tested so that pilots can understand and relate to the interface. The requirements as a result of this usage test are as follows:[57]

- VR hardware should develop for adding both cockpit and airplane views,
- The data provided must be accurate,
- In addition to other data, speed, altitude, and time should be evaluated in terms of the performance level,
- The most basic requirement for the interface; is for the simulation to be as close as possible to actual flight visualizations through VR glasses,
- Developing the color scale by adding new colors rather than the green color that are use in other simulations,
- In night vision, implementing the comparison of data suitable for this mode,
- Adding suitable data to unlikely emergencies and extraordinary situations in the simulator,
- Developing the tactile senses.

Data and Methodology

Grade Comparison of Task-Based Flight Stages

		Virtual Reality	**Real Flight**	
		Mean±SS Med. (Min.-Maks.)	**Mean±SS Med. (Min.-Maks.)**	**p**
TAKE-OFF STAGE	External and Internal Controls	3.1±0.3 3- (3-4)	3±0 3- (3-3)	0.083
	Engine Start	3±0.3 3- (2-4)	3±0.2 3- (2-3)	0.102

	Taxi and Take-off	2.9±0.7 3- (1-4)	3±0.2 3- (2-3)	0.532
CONTROLLING AIR MOVEMENTS IN AIR TRAFFIC PATTERN	Climb, Ascending and Cruise Flight	2.9±0.7 3- (2-4)	2.9±0.3 3- (2-3)	0.827
	Low and Normal Bank Turns	3±0.6 3- (2-4)	3±0.2 3- (2-3)	0.637
	Turns in Climb and Descent	2.9±0.6 3- (2-4)	3±0.2 3- (2-3)	0.317
	Speed Altitude Tracking	2.5±0.7 2- (1-4)	2.9±0.4 3- (1-3)	**0.002**
APPROACH AND LANDING STAGE	Trianulation Tracking	2.7±0.8 3- (1-4)	3±0.2 3- (2-3)	0.058
	Approach Pattern	2.5±0.8 2- (1-4)	2.9±0.4 3- (2-3)	**0.006**
	Landing	2.3±0.8 2- (1-4)	2.5±0.6 3- (1-3)	0.286
	Leaving the Runway and Taxiing	2.8±0.6 3- (1-4)	3±0 3- (3-3)	0.083

Wilcoxon test.[58] (Wilcoxon signed-rank test, 2024).

According to the grade comparison of task-based flight stages with wilcoxon test in Table 1, a statistical difference was found between VR and real flight performances in terms of Speed Altitude Tracking, Approach Pattern tasks (that are shown in bold), and real flight scores were relatively higher than VR according to the p values ($p<0.05$).

Conclusion

VR enables the technological application of real-life experience in a virtual space similar to reality by repeating the experiences as much as necessary. Therefore, it is significant to use VR-related equipment to perform VR flight experiences with lots of practice. So, the current rules applied in real flight trials will increase the training qualification in terms of the experience of various aircraft types. Actual flights improve students' cognitive abilities by increasing difficulties in different scenarios (planning, route selection, weather conditions, etc.). Especially at the end of real flights, scoring the processes is significant to obtain outcomes from VR hardware in the same environment at real flights. So, this hardware can perform nearly the same scoring in terms of real flights, increasing the pilotage students practice related to the 2 main purposes. The primary purpose is to show how VR experience can enhance the knowledge and skills for pilotage students by observing them. The secondary purpose is to develop the VR system for pilotage students according to the new enhancements in real flight experiences. Correspondingly, students can benefit from this system related to future technology in pilotage training. Besides, the other students who are interested in this area can use this technological system. The importance of this study is to evaluate and configure the need for information and communication technology that is related to future VR. The increasing interest in this technology can be carried out under sustainability criteria. The effective usage of cognitive skills will increase the training qualification with experience in various aircraft types. The study analyzes the capabilities of a VR Flight Simulator (VRFS) with the comparison of real flights that are carried out in flight school. The pilot's reaction time, deviation from the optimum flight routes, emergency, and unexpected situations, and advanced technology are evaluated by creating different operational scenarios. This evaluation aims to compare the statistical diversity of the flight routes, solve the altitude problem, fly under severe weather conditions, and plan routes during the control process.

Although performing safe and effective flight duties seems easy in VR technology, it can be determinant for demonstrating possible situations during flight time and indicate the importance of human factors in terms of VRFS.

In future studies, VR technology can combine with AI or augmented reality, and new observations and experiences can be obtained from all pilotage students. Especially studying pilotage and adaptation processes to nowadays technology will accelerate taking advantage of future trends.

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