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The Role of Flight Simulators in Pilot Training

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Abstract

Aviation is one of the most advanced and multifaceted industries in the world. One of the most critical aspects of aviation, which cannot be overlooked, is flight safety. Pilot training is a specialized form of education that is a crucial component of the aviation industry. The training process serves as a fundamental interface between pilots and the potential environments they will encounter in real flight operations. At present, a significant portion of pilot training is performed in flight simulators, which replicate real flight environments, making pilot training both cost-effective and safe. For example, a full flight simulator can provide accurate force feedback through its system for the flight control inputs of the pilot. Equipped with diverse systems to simulate various flight parameters (e.g. altitude, acceleration, speed, etc.), a flight simulator can generate a large amount of data on flight and pilot activity during training. With the continuous development of software and hardware technologies, flight simulators are becoming increasingly sophisticated, offering training across a broad range of tasks. Therefore, finding ways to enhance the efficiency and quality of simulator-based training is crucial. This study conducted a comparative analysis of the utilization of flight simulators both globally and within our country. The review of studies stresses the critical significance of pilot training in the aviation industry and the advantages that flight simulators bring to the training process. Furthermore, the need for objective evaluation of pilot performance is identified as a key issue that warrants global research attention.

1. Introduction

Positive developments in the field of aviation nowadays help improve air traffic. The demand for improving the practical and theoretical skills of the crew, including pilots, increases every day with the application of new technologies in aviation. Errors caused by human factors occur when the pilot has inadequate skills or gives unexpected reactions in an adverse situation. Although the consequences vary, the human factor plays a role in about 70 to 85 percent of aircraft accidents (Maurino et al., 2017). The majority of pilot-related errors, accounting for 80 percent of human factor-induced mistakes, are associated with deficiencies in pilot skills. Notably, approximately half of these errors serve as the initial trigger in the sequence of events culminating in flight accidents. (EASA, 2024). A primary approach to mitigating errors attributable to human factors involves improving pilot training, addressing unexpected in-flight situations through simulation, and continuously enhancing the overall training process (Socha et al., 2016).

Due to recent technological advancements, flight stimulators have become close enough to reality to eliminate concerns and doubts that may arise among pilots, aircraft manufacturers, airlines, or regulatory bodies. This has led to the significant spread of flight stimulators and their use as tools in the training and examination of military and civil flight crew qualifications. In response to the aforesaid developments, international standards and regulations have defined and detailed the requirements for the operational usage of flight simulators (EASA, 2018). Hence certified flight simulators are utilized in training, implementation of flight procedures, and pilot testing on a routine basis (Socha et al., 2016).

Including flight simulators in pilot training has provided some advantages, such as reducing risks arising from human factors, increasing training quality, increasing general flight training, and reducing training and aircraft operational costs (Aragon & Hearst, 2005). Furthermore, flight stimulators increase training effectiveness due to the possibility of adjusting the training course according to the skills of pilots or the outcomes of completed flights. Additionally, possible non-standard situations (caused by weather conditions or the aircraft's technical condition) can be created, and ways to cope with these situations can be worked on. Flight records can be accessed instantly, and accurate feedback is provided to pilots, which contributes to their progress (Haslbeck et al., 2014; Taylor et al., 2007).

In contemporary aviation, flight simulators are essential for pilot training and the reinforcement of critical skills. Simulation technologies have gained significance not only for educational purposes in both commercial and private aviation but also for investigating aircraft accidents, evaluating aircraft designs, and gaining deeper insights into ergonomic interactions. (Boril et al., 2015).

Advancements in avionics have significantly increased the complexity of both civil and military aircraft, leading to a heightened demand for crew training and a stronger reliance on flight simulators. Flight simulators have not only completely changed flight training methods with regard to decreasing risks and improving training quality; they have also considerably increased flight safety, reduced traffic density, and affected the environment positively. All of these have been ensured by reducing the costs of flight training. It is expected that the above-mentioned trends will continue in the foreseeable future (Allerton, 2010; Foyle and Hooe, 2010).

Pilots' manual flight experience decreases with the development of automation systems, which can lead to the loss of skills. Accidents, such as Air France 447 and Asiana Airlines 214 flights, are examples of accidents revealing the potential consequences of a lack of manual flight skills (Final Report, 2014; NTSB, 2012).

The present study investigated the potential of using flight stimulators and especially their contributions to basic flight skills and needs through a detailed literature review. The study examined the impacts of the transition from stimulated to real flights on the progress/regression in the maneuvers conducted. It also examined the applicability of mathematical methods in evaluating pilot training experience. The current work comprehensively reviewed research in the field of flight simulators and aimed to stress the contributions of different research topics from a general perspective, considering that simulators represent a complex human-machine system. Furthermore, it addressed the application areas of these training devices and discussed the terminology used in the literature.

2. Literature Review

The demand for new pilots increases every day with the growth of the aviation industry on a global scale. For instance, Boeing estimates that commercial aviation will need 674,000 new pilots worldwide in the following 20 years (Boeing, 2024). As of February 2023, aviation markets have fully recovered from the pandemic shock. It is expected that long-haul markets will recover to a considerable extent by the end of 2024. Overall, airlines have lost approximately four years of passenger growth because of the pandemic. It is expected that travel numbers will exceed 2019 levels in 2024 and reach an average annual growth rate of 3.8% by 2043 (IATA, 2024).

The most important question is not whether a pilot shortage will reoccur but when it will occur and how large the gap between supply and demand will be. A shortage of 34,000 pilots is predicted by 2025, with the most possible scenarios. In the most extreme scenarios, this shortage reaches 50,000. Ultimately, the impact of dismissals, retirements, and departures from the industry will create significant challenges for even the largest airlines. Airlines have a buffer of 100,000 pilots who are still receiving salaries but working reduced hours or are on voluntary company leave (Oliver Wyman, 2021).

According to the results of a survey conducted by Oliver Wyman in 2019 (Oliver Wyman, 2021), 62% of flight operations leaders indicated a shortage of qualified pilots as a major risk. The main reason for this impending pilot shortage varies by region. In the US, mandatory retirements due to an aging workforce, a decreased number of pilots leaving the military, and barriers to entry, such as training costs, are among the reasons for this shortage. In China and some other regions, capacity should be rapidly increased to meet the increasing demand for air travel with the rapid growth of the middle class. This impact also varies by airline class; 83% of regional carriers experience difficulties finding skilled personnel, while only 22% of low-cost carriers experience the same difficulties. Despite these differences, very few regions are not struggling to provide enough pilots to support future growth.

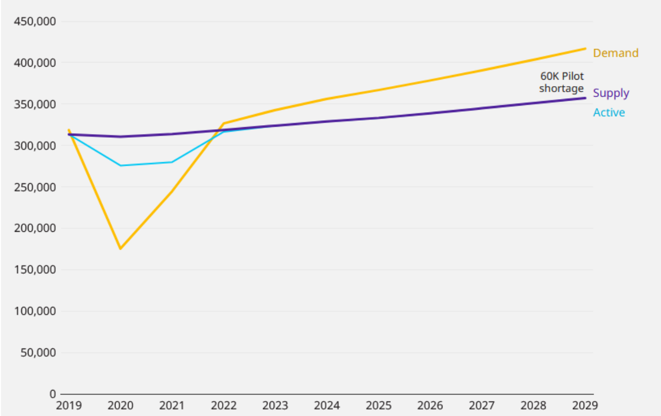

Figure 1. Global pilot demand versus supply (Oliver Wyman, 2021)

Student pilots have very little or no flight experience when they start their training (McLean et al., 2016). Training programs usually involve theoretical (ground school) and practical components (flight training). Ground courses include topics directly related to flight, such as aerodynamics, meteorology, navigation, and aircraft systems. This training is completed with a theoretical exam that students must pass before proceeding to more advanced practical courses (Marques et al., 2023).

Pilot training typically relies on a combination of various training aids and learning methodologies, structured around three key learning concepts: (1) theoretical studies, (2) training using Flight Simulation Training Devices (FSTDs), and (3) live training. The goal of flight simulation is to reproduce an aircraft's behavior as experienced by cockpit crew members during flight (on the ground) so that pilots can develop and maintain the skills required to operate the real aircraft safely and efficiently by flying the simulator and demonstrate their competence to the examiner (Baarspul, 1990).

Although the COVID-19 pandemic has created a temporary surplus of pilots, the time and costs associated with training, industry expansion, early retirement, and pilots transferring to other careers will continue to make a contribution to the pilot shortage in the foreseeable future. Considering the predicted increase in demand for new pilots, there is a need for faster and less expensive flight training programs to meet the demand better (Schaffernak et al., 2020).

In this regard, it is essential to review the literature to advance knowledge about the position of flight simulators in pilot training. Although numerous studies have been published on the subject, the literature has spread to various thematic areas, and studies have been published in various journals and conference proceedings. Characterizing the information in the literature and identifying opportunities for future research are some of the study's main objectives.

Socha et al. (2016) examined the effects of flight stimulator training before real flights on performance accuracy. The study was conducted on 35 student pilots who received private pilot training. The participants logged a total of 11 hours in a flight simulator, one hour in a Diamond DA40 aircraft, followed by an additional three hours in the simulator and two hours in real traffic. The maneuvers performed included 180° climbing and descending turns with a 30° pitch, maintaining a vertical speed of 500 ft/min. During the flight sessions, the instructor documented any deviations from the desired flight parameters. Socha et al. (2016) emphasized that the usage of flight simulators was partially reasonable but that five flight hours (for PPL - Private Pilot Licence) were inadequate to master basic flight skills.

Numerous studies have been carried out on modeling human behavior, including that of pilots. The majority of these studies are based on a definition initially proposed by D.T. McRuer in the 1970s, which focuses on modeling human behavior in conjunction with feedback (1). This model is a linear representation (transition function) of the proportional-derivative regulator, incorporating a second-order delay and time (response) delay. Each constant within the model has a specific neurological or physiological interpretation. (Hess and Marchesi, 2009; Lone and Cooke, 2010; McRuer, 1974).

$$F(s) = \frac{Y(s)}{X(s)} = K \, \frac{(T_3 s+1)}{(T_1 s+1)(T_2 s+1)} = e^{-\tau s} \qquad (1)$$

Here,

•K represents the pilot gain, which reflects the pilot's habitual response to a specific action. Additionally, it is associated with the ratio of the input to the output signal.

•T1 is the neuromuscular delay time constant, which quantifies the delayed response resulting from the pilot's neuromuscular system. This value ranges from 0.05 to 0.2 seconds and is independent of the intensity of training.

•T2 represents the delay time constant that characterizes the pilot's quickness and agility. It is linked to the execution of learned stereotypes and routine procedures. The value of T2 ranges from 0.1 to 5 seconds.

•T3 is the lead time constant, which is associated with the pilot's experience. It reflects the pilot's ability to anticipate potential situations. This ability, developed through training and experience, ranges from 0.2 to 15 seconds.

•τ represents the time constant that indicates the delayed response of the pilot's brain to a movement.

•s is the Laplace operator, commonly used in the analysis of dynamic systems in the Laplace transform domain.

To evaluate pilots’ reactions to simulated flight tasks, Boril et al. (2015) investigated pilots’ reaction times and ability to adapt to control dynamics by analyzing the data obtained from simulators. In the study, a flight scenario was defined on a flight simulator based on the originally developed X-plane (X-Plane, 2024) (altitude 2900 ft, speed 170 mph, pitch angle of approximately zero degrees). At a specific moment, the altitude was abruptly changed to 2600 ft, and the pilot was required to correct the altitude back to the original flight level of 2900 ft. A total of six student pilots, each with approximately 60-80 flight hours of real flight experience, were tested in this flight scenario. The altitude of each pilot was changed 10 times in succession, each time returning the aircraft to its initial flight state. The study empathized that pilots’ reaction times could improve with training and experience and pilots would adapt better to control dynamics with flight simulator training. The author stated that more studies were needed to develop research in this field and validate the methodology.

Haslbeck et al. (2014) researched how repetitive training and daily flight practice affected pilots' manual flight skills throughout their careers. The study was performed in collaboration with a leading European airline. Fifty-seven airline pilots with diverse levels of flight experience flew a 45-minute simulated landing scenario. Participants were divided into two groups: short-haul first officers (FOs) and long-haul captains (CPTs). The said groups represent high and low levels of practice and training, respectively. Pilots were evaluated in full-flight simulators in Airbus A320-200 or A340-600 configuration. The scenario required pilots to land manually after disabling the autopilot. Flight performance data were measured with the data recorder of the simulator in an objective way. The study results demonstrated that CPTs with low practice and training levels deviated more from ideal approach parameters. For instance, seven out of 27 CPTs (25.9%) failed to meet at least one of the allowed Instrument landing systems (ILS) deviation parameters. On the contrary, only two out of 30 FOs (6.7%) failed to meet these standards. The study findings showed that manual flight skills decreased over time and that regular practice was critical to maintaining these skills. High automation levels in long-haul operations may contribute to the deterioration of pilots’ manual flight skills.

In their study, Tanasković et al. (2020) determined that the difficulties experienced by pilots in transitioning from visual to instrument flight rules were the main cause of the accident that occurred with a Cessna 340 aircraft. This accident stressed the importance of pilots being prepared for sudden changes and challenging weather conditions. The study emphasized that transitioning from visual flight rules (VFR) to instrument flight rules (IFR) was a very complex process. Flight simulators come into play at this point. Simulators ensure that pilots experience crisis situations that they may encounter in real life in a safe and controlled environment. This helps pilots develop correct responses to emergencies and control their aircraft safely.

Liu et al. (2018) aimed to develop a system to assess pilots' flight performance based on Quick Access Recorder (QAR) data. This system was employed to assess, analyze, forewarn, and enhance pilots' flight performance by providing practical technical support to airlines in monitoring and controlling flight risks. The system developed employs a quantitative method to evaluate pilot performance. The evaluation model presented in the article is based on the statistical analysis of QAR data. This model ensures that one or more flight parameters are combined to objectively evaluate pilots’ flight performance.

Macchiarella et al. (2006) showed that student pilots practicing in the Flight Training Devices (FTD) required four more lessons to reach practical test standards for taxi and takeoff in comparison with students undergoing training in a real aircraft. McLean et al. (2016) concluded that flight simulators reduced the number of training hours before reaching the solo flight stage in the aircraft. The researchers found that total hours decreased from 16 to 14.7 hours, but the overall training time increased from 43 to 46.6 hours. A study by Goetz et al. (2012) yielded similar results. Whereas the experimental group that received training on a flight simulator required 77 days to be ready for solo flight, the group that started training in the aircraft required 86 days. The authors accepted that a sample consisting of only 12 students might have impacted the results adversely.

The study by Burki-Cohen et al. (2001) demonstrated that radio communication in flight simulators was usually performed by the instructor through role-playing and did not reflect the difficulties in the real-world environment. The authors stressed that realistic radio communication was one of the widely accepted deficiencies in flight simulators.

In the literature, desktop computer-based simulators are referred to as an alternative to expensive simulators without compromising student performance (l Reweti et al., 2017). Considering the rapid technological advancements in computers, there is an increasing interest in using flight simulation platforms, including Microsoft Flight Simulator (MFS, 2024), Lockheed P3D (Prepar3D, 2024), and X-plane (X-Plane, 2024). In addition to being an affordable platform, such simulators are also accessible to students even outside of the teaching field. A survey by Beckman (2003) showed that students and instructors found desktop flight simulators effective for homework and for helping students practice at their own pace, which increased their performance perceptions.

Recently, there has been considerable interest in applying augmented reality (AR) and virtual reality (VR) in flight training. Some studies have revealed that AR and VR benefit flight training and can improve learning since they allow users to fully immerse themselves in the virtual environment (Koglbauer et al., 2016). Furthermore, VR presents a faster learning process compared to traditional classroom approaches. Students who use VR can remember information longer and learn faster than those who learn with traditional methods (Pennington et al., 2019). Both AR and VR are promising techniques for transforming flight training since they can be utilized for the purpose of bridging the gap between classroom, simulation, and practical operations. The aforesaid techniques can be used for aircraft recognition and procedure training; thus, students can interact with the aircraft and understand processes better (Schaffernak et al., 2020).

Oh (2020) compared the perceptions of student and instructor pilots concerning flight operations using VR headsets. Participants thought that the VR simulator operated similarly or performed better than the traditional simulator and stated that it was more challenging to manage the cockpit systems and panels in VR than in the traditional simulator.

Furthermore, Dubois et al. (Dubois et al., 2015) stated that eye-tracking devices might be helpful as teaching and monitoring tools in flight training. These devices can identify students' scanning patterns so that instructors can intervene appropriately (Muehlethaler & Knecht, 2016).

3. Flight Simulators Used in Aviation

Although the first commercial pilot ground training devices emerged in the early 20th century, the actual usage of flight simulation began in the military field during World War II. The Link Trainer, the first commercially built flight simulator, gained significant recognition in 1934 following a series of accidents in the U.S. Army Air Corps, which highlighted the critical need for training pilots in Instrument Flying Conditions to prevent loss of life (BAATraining, 2024). Following World War II, flight simulation transitioned from the military to commercial aviation by the late 1950s (Schreiber et al., 2009). Simulators have been utilized in airline pilot training and evaluation since the 1950s. Nowadays, major airlines perform their recurrent training entirely on simulators and even use simulators in initial, transition, and upgrade training and certification processes.

At present, flight simulation training devices are utilized to train cockpit crew, maintenance personnel, and command and control personnel (Macchiarella et al., 2006). Additionally, these devices are utilized in the design and development of flight training programs (Wise et al., 2016) and accident investigations (Tydeman, 2004).

In the last four decades, flight simulators have contributed significantly to flight safety and have become indispensable for civil and military flight operations (Allerton, 2010; Chung, 2000). Training with FSTDs reduces the operating and maintenance costs of an aircraft fleet by reducing the number of training hours required in the air for a student to achieve a particular proficiency level (Smode, 1966). Flying a real aircraft involves coordination with various services, such as air traffic control and maintenance, as well as reliance on favorable weather and visibility conditions. These factors are mitigated through the use of FSTDs, which eliminate the need for such coordination and environmental dependencies. In this respect, FSTDs make a contribution to reducing pilot preparation time. From an environmental perspective, ground training devices are a more advantageous alternative to training in aircraft (Allerton, 2010; Vidakovic et al., 2021).

Additionally, the literature review demonstrates inconsistencies in the terminology applied to flight simulation training devices. This can lead to confusion in the analysis and application of existing research, as there is limited published material on the classification and broader application of FSTDs.

Due to the technical complexity of flight simulators utilized in pilot training worldwide, also known as Synthetic Flight Training Devices (FSTDs), standard terminology should be used everywhere. European Union Aviation Safety Agency (EASA) defined the following main terms and abbreviations in the document CS–FSTD(A) to eliminate this confusion (EASA, 2018).

A FSTD refers to a training device meeting the definition in Table 1.

Table 1. Categorization of Flight Simulators According to EASA (EASA, 2018)

FFS	FTD	FNPT	BITD
A	1	I	
B		II	
C	2	MCC	
D			

A Full Flight Simulator (FFS) is a complete, full-size replica of the cockpit of a specific type, brand, model, and series of aircraft. It incorporates all the necessary equipment and software to simulate the aircraft's ground and flight operations, including a force feedback motion system and a visual system that offers a view from the cockpit.

A Flight Training Device (FTD) is a full-size replica of the instruments, panels, equipment, and controls of a specific aircraft type, typically situated in either an open flight cockpit area or an enclosed cockpit. It includes all the necessary equipment and software to simulate the aircraft's ground and flight conditions but does not require a force feedback motion system or visual system.

A Flight and Navigation Procedures Trainer (FNPT) is a training device that simulates the flight cockpit environment, incorporating the equipment and computer software necessary to represent an aircraft or a group of aircraft in flight operations.

A Basic Instrument Training Device (BITD) is a ground-based training device that replicates the student pilot station of a specific aircraft class. It typically uses screen-based instrument panels and spring-loaded flight controls, offering a training platform primarily for the procedural aspects of instrument flight.

Other Training Device (OTD) refers to any training device, apart from a FSTD, used for training purposes where a full flight cockpit environment is not necessary.

EASA provides a comprehensive guide for the design, manufacture, testing, and operation of FSTDs. The document clearly defines the requirements, terminology, and test procedures to ensure that FSTDs accurately simulate aircraft in order to provide safe and effective flight training (EASA, 2018).

- Field of Application and Terminology
- FSTD Levels and Compliance
- Performance Tests
- Motion System
- Visual System
- Audio System
- Functions and Subjective Tests
- Verification Test Tolerances

Table 2 provides a general summary of FSTDs approved by EASA. An FFS is not required to replicate all physical aspects of flight; it only needs to meet the minimum standards set by the qualified authority. In (EASA, 2018), FFS levels are categorized as A, B, C, and D, ranging from the lowest to the highest level, respectively. These levels encompass the minimum requirements for visual, audio, and motion simulation systems, including factors such as flight controls responding to inputs, vibration simulation effects, and wind shear.

Flight simulators are devices that artificially replicate aircraft flight and various elements of the flight environment. They incorporate the equations that govern aircraft behavior, including how the aircraft responds to controls, aircraft systems, and external environmental factors such as turbulence, air density, precipitation, and clouds. Flight simulators can be further classified according to diverse criteria and areas:

According to their areas of use:

- Flight simulators for commercial flight training
- Flight simulators for military flight training
- Flight simulators for ab initio flight training
- Engineering flight simulators
- Skill test flight simulators (device)
- Flight simulators providing computer-based training (CBT)
- Usage of flight simulators for maintenance training

According to the purpose of training:

- Cockpit Procedures Trainer (CPT)
- Aviation Training Device (ATD)
- Basic Instrument Flight Training Device (BITD)
- Flight and Navigation Procedures Trainer (FNPT)
- Integrated Procedures Trainer (IPT)
- Flight Training Device (FTD)
- Full Flight Simulator (FFS)
- Full Mission Simulator (FMS)

According to the ICAO proficiency levels:

FSTDs are divided into seven types according to International Civil Aviation Organisation (ICAO) Doc. 9625:

- **Type I:** The first level including an enclosed or perceived cockpit/flight deck.
- **Type II:** It meets the same requirements as the first level but also includes Air Traffic Controller (ATC) environment simulation.
- **Type III:** It meets the previous requirements but also includes the runway condition simulation.
- **Type IV:** The level in question meets the same requirements as the previous levels. Additionally, it also involves features such as ATC environment simulation, external sounds, and voice control.
- **Type V:** The said level meets the same requirements as level IV, but features such as runway condition simulation, aircraft systems simulation, and dynamic control feel are added.
- **Type VI:** The level in question meets the same requirements as level V, but features such as expanded ATC environment simulation, motion system, and weather conditions simulation are added.
- **Type VII:** It is the highest level approved. It must meet all previous requirements, realized in a detailed and authentic way, as in the real aircraft.

4. The Importance of Flight Simulators in Pilot Selection

The costs of acquiring pilot certificates required by the Federal Aviation Administration (FAA) to work for airlines can reach a considerable figure, including flight time. The cost of a bachelor's degree can reach or exceed $100,000 at a private university, with additional costs for flight training added to this amount. Although pilot training programs at public universities are usually considerably less expensive, they still cost tens of thousands of dollars. It is estimated that costs for four-year university education with flight training can reach $50,000 per year. Other routes to obtain a pilot certificate, such as non-college flight schools, involve considerable costs for potential pilots. Despite the long-term earning potential, these costs are thought to adversely impact enrollment in pilot training programs (Croft, 2015)

Table 2. FSTD classification requirements according to EASA (EASA, 2018)

FSTD Type	Flight deck/cockpit environment	Simulation capabilities	Equipment and software specifications	Visual system	Force cueing motion system
FFS	A full-size replica of a flight deck or cockpit refers to a complete, scaled reproduction of the cockpit of a specific aircraft type, make, model, and series. This replica includes all relevant instruments, controls, and equipment found in the original cockpit.	Represents the aircraft in both ground and flight operations, simulating the behavior and functionality of the airplane during various phases of flight, as well as its operations on the ground.	Includes a complete set of all necessary equipment and incorporates computer software programs required to accurately simulate the aircraft's systems and operations, both on the ground and in flight.	Required to provide a view from the flight deck or cockpit, simulating the external environment during flight operations.	Required
FTD	A full-size replica of a specific aircraft type’s instruments, equipment, panels, and controls refers to a complete, detailed reproduction of the cockpit’s interior layout, including all functional components found in the original aircraft, such as flight instruments, control panels, and flight controls.	Represents the aircraft in both ground and flight conditions, based on the systems installed in the device, simulating the behavior and functionality of the aircraft according to the specific equipment and software within the training device.	Includes an assembly of all necessary equipment and incorporates computer software programs required to simulate the aircraft’s systems and operations, enabling realistic training in both ground and flight conditions.	Not required	Not required
FNPT	The flight deck/cockpit environment	Represents an aircraft or a class of airplanes in flight operations, ensuring that the systems function as they would in a real aircraft, providing a realistic simulation of aircraft behavior and performance during flight.	Includes an assembly of all required equipment and computer software programs, which together simulate the aircraft’s systems and operations, enabling accurate representation of flight operations.	Not required	Not required
BITD	The student pilot’s station	Provides, at a minimum, the procedural aspects of instrument flight for a specific class of airplanes, focusing on training for navigation and operation under IFR.	Not explicitly specified, but likely involves the use of screen-based instrument panels and spring-loaded flight controls to simulate the aircraft's systems and response during training.	Not required	Not required

Since pilot selection has substantial costs, it is essential to use robust processes based on scientific foundations, even if there is a limited pilot supply relative to demand. The risk of accidents is the most evident cost of wrong choices. For instance, deficiencies in basic piloting skills, e.g. understanding how to respond to an impending or existing aerodynamic stall, have played a role in accidents, including Air France 447 and Colgan 3407. One of the causes of accidents is the over-reliance on computerized flight systems by airlines and aircraft manufacturers, which has been indicated to impair pilots’ ability to operate the systems in emergencies manually (Oliver, 2017). Selecting pilots with better piloting skills can increase the margin of safety. On the contrary, not eliminating pilots with weak piloting skills can increase risks to property and safety. Such risks to property and safety increase the significance of sound selection procedures. Another evident cost is the training time needlessly lost by the mainline or regional carrier. Investments in pilot training are basically avoidable costs for the employer in case of the failure of that pilot. A scientifically based pilot selection process can decrease such avoidable costs (Broach et al., 2019).

As specified by Damos (2014), two factors have complicated pilot selection in the past two decades. First, despite over 100 years of research on pilot selection, the dissemination and implementation of research findings in pilot selection worldwide has been a continuous problem. A portion of the problem lies in communicating psychological and statistical concepts, data, and recommendations in a language that corporate executives can understand, trust, and utilize. Second, the supply of pilots has shifted significantly, at least in the United States of America (U.S.) market and probably in other non-U.S. employment markets. Former military pilots have been a dominant source from World War II until the early 1980s. U.S. military pilots represent the product of an intensive, rigorous, and continuous elimination process. Those who have transitioned from military service to civilian airlines have successfully passed that elimination process. In selection terms, they are pre-selected regarding job-related factors, including emotional stability, cognitive ability, and the piloting skills displayed. However, nowadays, former military pilots constitute only a part of new pilots in the U.S. Most pilots hired in the last two decades have not undergone the same level of examination as that applied to aspiring military pilots. Moreover, it can be said that entry into civilian flight training programs nowadays is based more on the "wallet test" than all other factors. Consequently, variability in factors including cognitive abilities, attitudes, personality, and piloting skills among civilian pilot candidates is likely to be higher than before. This greater range of variability reinforces the need to enhance pilot selection processes to enable the recruitment of pilots at the upper end of the knowledge, skill, and ability distribution.

Time is usually a significant constraint in pilot selection. Funding for both the improvement and management of a selection process has almost always been a problem. Another difficulty is accessing and acquiring relevant predictive and job performance data for validation studies. The fourth difficulty is the balance between validity and equity (Pyburn et al., 2008). The final difficulty is candidates' reactions to the selection process. Issues, e.g. procedural fairness, perceived validity, and outcomes, can cause candidates' positive or negative reactions, which can impact an employer's reputation and ability to attract qualified candidates, especially in tight-knit communities such as pilots (Truxillo et al., 2009).

The common characteristics of pilot selection systems involve age, education, English proficiency (in non-English speaking countries), and usually a requirement to pass mathematics and English courses successfully. Interviews are also very common (Broach et al., 2019). A 2012 research report conducted by International Air Transport Association (IATA) on airlines reached the following pessimistic results: "Despite the clear benefits of an appropriate pilot selection process, the results demonstrate that only a small number of airlines have a structured and scientifically based specific selection system" (IATA, 2019). There are generally two primary models in civilian pilot selection. The Lufthansa model performs a strict selection process from the beginning, which leads to less elimination during the training process. The alternative model involves a superficial selection process from the beginning, which allows for more elimination during the training process (Broach et al., 2019).

5. Conclusions and Recommendations

The aviation industry will face a considerable pilot shortage in the following years. It is essential to adopt innovative training technologies and approaches to meet the training needs of the new generation of pilots. Collaboration between universities and airlines is of critical importance to ensure that the said technologies are effectively implemented and that future pilots are trained in the best possible way.

Flight simulators are an indispensable part of the program implemented to ensure safe and efficient pilot training. The importance of well-designed simulators and accompanying modern training programs in effective pilot training should not be ignored. Safe and efficient training provided using FSTDs is among the basic components of military, commercial, and general aviation training. In comparison with live training, increased safety and decreased costs of pilot training are the most important advantages of ground training devices.

The current work shows the importance of flight simulators in pilot training and evaluation by reviewing studies in the literature in detail. Under the information obtained, the advantages and disadvantages of flight simulators in pilot training can be listed as follows:

Advantages:

- **Safety:** Flight simulators allow pilots to experience crisis situations and implement emergency procedures without taking risks.
- **Cost:** Flight simulators are considerably more economical in terms of purchasing, operating, and maintenance costs in comparison with real aircraft.
- **Flexibility of Use:** Flight simulators can be used 24/7, regardless of weather conditions.
- **Training Efficiency:** Flight simulators increase training efficiency by providing the opportunity to repeat and analyze particular flight conditions and emergency scenarios.

Disadvantages:

- **Realism:** Flight simulators may not perfectly imitate the real flight experience.
- **Psychological Factors:** Pilots may not feel the stress and pressure in the simulator environment as they do in real life.

Consequently, flight simulators are essential tools helping pilots improve their skills, learn crisis management procedures, and contribute to safe flight operations. Performance analysis based on simulator training should be conducted. Simulator trainings covering the routes that pilots fly can also be beneficial in terms of real scenarios Airlines must implement strategies such as additional simulator training and mixed-fleet flights to help pilots maintain their manual flying skills. On the other hand, designers must explore adaptive automation approaches allowing for more flexible task sharing between humans and automation.

Abbreviations

AR	Augmented Reality
ATD	Aviation Training Device
BITD	Basic Instrument Training Device
CBT	Computer-Based Training
CPT	Cockpit Procedures Trainer
CPT	Captain
EASA	European Union Aviation Safety Agency
FAA	Federal Aviation Administration
FFS	Full Flight Simulator
FNPT	Flight and Navigation Procedures Trainer
FMS	Full Mission Simulator
FO	First Officer
FSTD	Flight Simulation Training Device (FSTD)
Ft	Feet
FTD	Flight Training Device
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IPT	Integrated Procedures Trainer
Mph	Mile Per Hour
OTD	Other Training Device
PPL	Private Pilot License
QAR	Quick Access Recorder
US	United States of America
VFR	Visual Flight Rules
VR	Virtual Reality

Ethical approval

Not applicable.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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