INNOVATING FLIGHT TRAINING:
AN ASSESSMENT OF VR'S POTENTIAL IN AIRBUS A320 PILOT TRAINING

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Abstract

This study delves into the potential of Virtual Reality as an innovative tool for Airbus A320 pilot training. Employing a mixed-method approach, the research incorporated surveys with certified flight instructors and an interview with an expert well-versed in virtual reality's application in pilot training. The findings reveal that while virtual reality might not outperform traditional methods in refining manual flight skills, it shows promise in other areas of training. Particularly, virtual reality's standardization capacity is highlighted, where all trainees receive identical lesson content, promoting a safer and more consistent operational environment. The immersive nature of virtual reality also facilitates training in normal and abnormal flight procedures without necessitating additional hardware beyond the virtual reality goggles. Despite these benefits, the study calls for more extensive research to ascertain virtual reality's capability to supplant traditional virtual procedures trainers or flight training devices. The potential of virtual reality in the realm of flight training is evident, and with further validation, it could revolutionize the industry.

Keywords: virtual reality, pilot training, flight training devices, skill development

Introduction

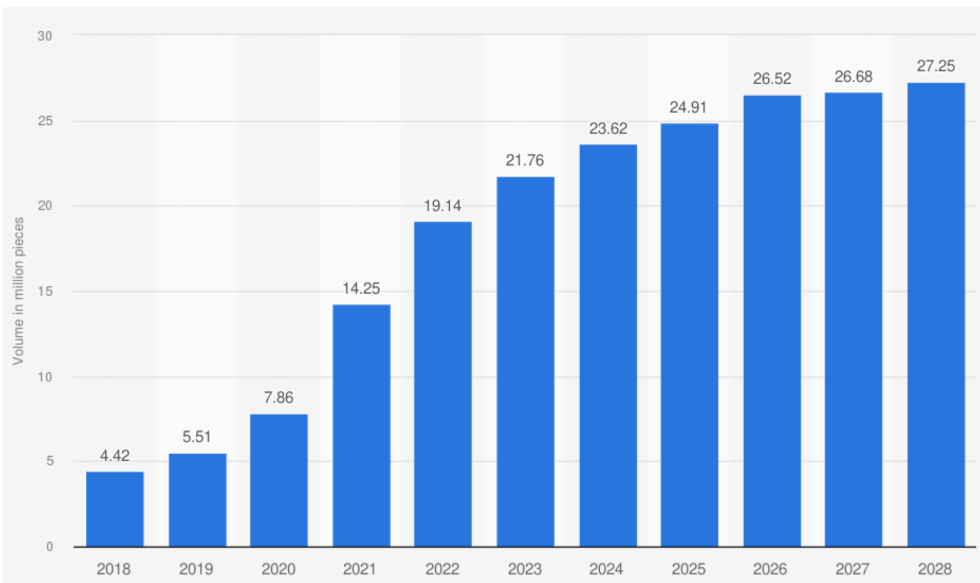
The aviation industry has always been a reference for using new technologies. With the evolution of aircraft technology, it is necessary to rethink how pilots are trained. Pilots are still training in a new aircraft using static cockpit models, often printed on paper or cardboard and attached to walls or suspended from wooden supports to simulate the cockpit layout for familiarization training (JETPUBS, 2023). It is a cost-effective solution but does not interact with the pilots. Without an observant instructor, mistakes could be made and, if left uncorrected, could bring additional risks to the operation. Computer-based flight simulators and Virtual Procedures Trainers (VPT) were introduced as a technological alternative that optimizes training time and improves the learning process (Aerosim, 2017). Those are fully interactive devices, simulating not only the cockpit layout but also replicating the operation of the aircraft's multiple systems, which can be used to train both normal and abnormal procedures. However, these devices are expensive, requiring a dedicated infrastructure and constant maintenance. Nowadays, with the high availability and constant market growth of Virtual Reality (VR) devices, as shown in figure 1, it is necessary to understand how these devices can be used in pilot training as a cost-effective alternative.

This study focuses on understanding the impact of VR devices on an airline's initial pilot´s training for procedures training. The theoretical or conceptual framework for this study is based on the theory of situated learning. This theory states that learning is best achieved when it is situated in a real-world context. VR devices can provide a realistic training environment that can help pilots to develop the skills they need to safely operate aircraft in the real world (Lave & Wenger, 1991).

After conducting research with Airbus A320 instructors of an international major Brazilian airline and identifying from them improvement opportunities to the training program, the researchers interviewed a subject matter expert (SME). It allowed a comparison between the gaps and possible improvements. The SME is a simulator and flight instructor and has been working on the implementation of VR in a Brazilian regional operator which has experience in using VR to train pilots.

Figure 1

Volume of the VR Headsets Market Worldwide From 2018 to 2028 (volume in million pieces).



(Statista, 2023)

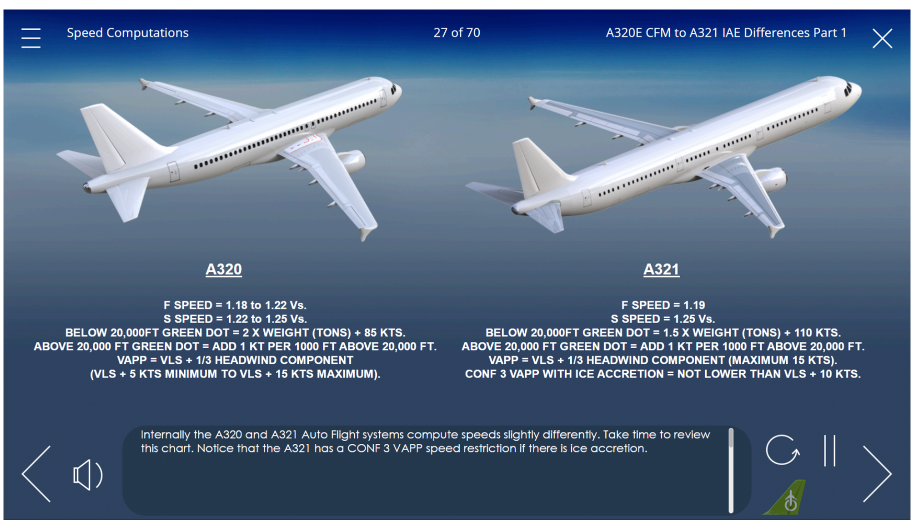
Type rating training process

The training process commences by imparting theoretical knowledge on aircraft systems through a cutting-edge computer-based training (CBT) platform. To help pilots become familiar with the cockpit and train basic normal and abnormal procedures, cockpit procedure trainers (CPT) are used. Afterward, pilots are trained in more complex abnormal procedures on flight training devices (FTD). Finally, pilots complete training in more advanced devices, known as full flight simulators (FFS) with motion platform, which also includes the aircraft handling to the training scenario (SKYBrary Aviation Safety, n.d.). After the simulator phase, pilots are then trained on the line, meaning in real flights with passengers and cargo.

CBT is a method of delivering training and educational content through computer-based platforms for self-paced learning (Figure 2). To acquire theoretical knowledge and essential skills, pilots can access interactive multimedia lessons. CBT is an efficient and cost-effective method of training as it eliminates the need for physical classrooms and instructors. It is suitable for pilots who already have a good knowledge of aviation theory. CBT is also ideal for pilots who may not have access to traditional aviation training resources. (Popov, O., Tretyakov, A., Barcz, A., & Piela, P., 2004)

Figure 2

Airbus A320/A321 CBT Course Example



(CPaT Global, n.d.)

While the CBT focuses on delivering knowledge about aircraft systems, in the CPT, pilots learn to operate the aircraft in a cockpit environment by practicing and refining procedural skills and responding to different scenarios. CPT helps pilots develop the confidence to handle challenging situations in the air. It also helps them become more familiar with the aircraft and its systems, which is essential for safe flying (FAA, 1992). Pilots can use a static CPT (figure 3) or a VPT (figure 4).

Figure 3

Static Cockpit Procedure Trainer.

(Flightvectors, 2022)

Figure 4

Virtual Procedure Trainer

(Aerosim, 2017)

In pilot training, each model serves a distinct purpose. The purpose of CBT is to acquire theoretical knowledge, while the purpose of CPT is to develop practical skills and experience handling aircraft systems. Using a VPT device, trainees can repeatedly perform procedures, thus building muscle memory and procedural knowledge (Airbus, 2022). Using software-driven components, this technology simulates real-life scenarios using computer-based environments. While the device used for CPT does not require any certification from the Civil Aviation Authority (CAA), FTD must be certified to be used for pilot training. However, in many cases, the CPT and FTD hardware are the same. In other words, VPT devices can be certified as FTDs once it complies with regulation requirements.

Virtual Reality devices are headset goggles that provide the user with an immersive experience by providing a screen right before their eyes. Associated with gyros and acceleration sensors, they can reproduce the user's head movements in the images projected, creating the feeling of being inside an interactive virtual world (Lagasse & Columbia University, 2018). It allows the simulation of situations such as being inside the cockpit of an airplane in normal or emergency operations scenarios. These devices can provide images by using one screen for both eyes or two screens, one for each eye. The simplest devices provide only lenses and a dock to attach a cell phone that can serve as a screen. The images provided on the screens can be generated by the own goggle or an external computer.

As technologies are advancing, headset goggle devices are incorporating high-definition screens, cameras, and graphics processing. With cameras attached to the device, it can integrate real-world and virtual reality visuals for the user. It results in an experience that is defined as Augmented Reality (AR). The combined use of VR and AR is also called Mixed Reality (Bolter, 2014). This study is focused on two-screen headset goggles with sound speakers, such as Meta's

Quest 3 (META, 2023) and PICO Neo3 (PICO, n.d.). Those devices require two hand-held devices to interact with the system.

Figure 5

VR Device

(Airbus, 2022)

Regulatory framework

Despite the numerous benefits of integrating VR/AR into flight training, it is not without its challenges. These devices must be certified by the CAA to be used for pilot training (Airbus, 2022).

The use of training devices must follow regulatory requirements for the operator's training program and flight simulator training devices (FSTD) certification, if applicable. Currently, in the Federal Aviation Administration (FAA) environment, CFR Title 14 Part 1 (2023) provides definitions for acronyms and terms in aviation. CFR Title 14 Part 60 (2023) provides guidance and requirements for Flight Simulator Training Device (FSTD) certification. Brazilian aviation authority ANAC publishes the same standards as the FAA, making it available both in English and Portuguese as the Brazilian Civil Aviation Regulations (RBAC) number 60.

The table below summarizes how the FAA and ANAC divide each Flight Simulator Training Device (FSTD).

Table 1

FSTD Classifications (in ascending order of fidelity and complexity)

Class	Sub-class or Level	Certification Basis
ATD - Advanced Training Device	BATD – Basic Aviation Training Device AATD – Advanced Aviation Training Device	FAA: AC 61-136B ANAC: IS 141-007C
FTD - Flight Training Device	Levels 4, 5, 6 and 7	FAA: 14 CFR Part 60 ANAC: RBAC 60
FFS – Full Flight Simulator	Levels A, B, C and D	FAA: 14 CFR Part 60 ANAC: RBAC 60

Pilots and schools can use BATD and AATD as acceptable means for Instrument Flight Rules training (ANAC, 2023), but not type rating, since they are generic in airplane models, cockpit, and its physics.

The table below provides a summary of the requirements established by FAA and ANAC for each FTD level certification per FAA’s 14 CFR Part 60 and ANAC’s RBAC 60:

Table 2

FTD requirements for certification summary

Level	Flight Deck	Displays	Controls, Switches, and Knobs	Visual System
4	Open or Enclosed	Flat/LCD or actual representations	Touch-sensitive activation or physical replication	Not mentioned

5	Open or Enclosed	Flat/LCD or actual representations	Primary and secondary flight controls must be physical, others can be touch-sensitive	Not mentioned
6	Enclosed	Flat/LCD or actual representations	Must physically replicate aircraft	Not mentioned
7	Enclosed	Flat/LCD or actual representations	Must physically replicate aircraft	Provides a wide field of view (180° horizontally, 40° vertically)

Beyond the physical and visual requirements enlisted above, there are a few other requirements to be met in certification that are related to skills building, such as:

- Aerodynamic Programming: Not required for level 4, can be generic for level 5, and must be airplane-specific in levels 6 and 7.
- Operating systems: At least one must be simulated in levels 4 and 5, while in levels 6 and 7 all applicable must be simulated.
- Control loading: is not required to be representative of aerodynamics in level 4, while they have to be representative of the real airplane only at approach speed and configuration in level 5 and representative throughout the ground and flight envelope in levels 6 and 7.
- Sound representation: is not mentioned in levels 4 and 5, but devices in levels 6 and 7 must have significant sound representation.

The touchscreen VPT devices shown in the previous paragraphs can be certified as FTD level 4 both in FAA and ANAC environments. The CPT devices are considered a learning resource in training programs and, therefore, are not certified Flight Simulator Training Devices.

Even though VR/AR devices can create virtual environments that can reproduce any airplane's cockpit, they are not defined by regulations from the FAA or ANAC yet. It makes VR/AR devices not as certifiable as FSTDs. Thus, this research focuses on the comparison of VR/AR technology with VPT/CPT in the learning contents and skills each can provide to address the scenario established in this research's introduction.

Problem Statement

Airline pilot training is complex and expensive. Type rating in the Airbus A320 costs up to EUR 25,000 (Moisejenko, 2023). Virtual and augmented reality devices have been introduced as a probable cost-effective solution that can also improve training quality and, thus, safety. However, the industry needs more research on the impacts of these devices on type rating training. This study focuses on understanding if and how VR goggles can be used during the A320 type rating training.

Project Goals

This project explores the use of VR in initial training programs for airline pilots. The goal is to assess the use of VR devices in the early stages of the A320 type rate training. It also compares its pros and cons with traditional VPT devices. This assessment has been conducted with industry data and academic research covering instruction techniques with VR, as well as a survey carried out among instructor pilots of an airline and their perception of the quality of training applied to new pilots.

This project covers only part of the full spectrum of aviation training. It covers the CPT phase of the type rating training solely. The study does not cover air traffic management, aircraft design, or aircraft maintenance. Although it may be expanded to other type ratings, it focuses on the Airbus A320.

Definition of Terms

This study explores recent technologies with different characteristics and applications. Then it is necessary to properly define and distinguish the terms used by the industry. The mentioned terms and acronyms are defined for universal reference.

Virtual Reality (VR) - Virtual reality immerses users in synthetic, real-looking environments (De Paolis & Bourdot, 2020). VR devices comprising goggles with displays, block out the real world.

Augmented Reality (AR) - Augmented reality overlays virtual objects in the real world (Azuma, 1997). It blends digital content with reality in real-time (De Paolis & Bourdot, 2020).

Goggles - Spectacles designed for a special purpose (Dictionary.com, n.d.). In this study, goggles project training scenarios and augment physical spaces.

Literature Review

Table 2
Virtual Reality Literature Review Summary

References Sources	Reference Summary
Airbus. (2022, November 10). Airbus Virtual Procedure Trainer offers an innovative way for pilots to learn procedures using Virtual Reality - Lufthansa Group becomes launch customer [Press release]. https://aircraft.airbus.com/en/newsroom/press-releases/2022-11-airbus-virtual-procedure-trainer-offers-an-innovative-way-for	Pilots can now undergo advanced procedure training without the need for traditional flight simulators or on-site procedure trainers, thanks to the innovative Airbus Virtual Procedure Trainer (VPT). This software solution fully immerses trainees in a virtual cockpit environment, providing comprehensive guidance on Airbus Standard Operating Procedures (SOPs).

ASTi. (n.d.). SERA: Simulated Environment for Realistic ATC. https://seraatc.com/	ASTi's Simulated Environment for Realistic ATC (SERA) generates a dynamic and artificially intelligent simulation that encompasses many aircraft and air traffic controllers.
Guthridge, R., & Clinton, V. (2023). Evaluating the efficacy of virtual reality (VR) training devices for pilot training. Journal of Aviation Technology and Engineering, 12(2). https://doi.org/10.7771/2159-6670.1286	This mixed-methods study on 120 beginner instrument pilots assessed their performance in a visual traffic pattern using VR. The results indicated VR-trained pilots performed similarly to those trained on PC-based simulators, with both groups outperforming a control group that received no training. Furthermore, VR-trained students felt they improved between pre-test and post-test and believed VR could be a viable tool in flight training.
Khenak, N., Bach, C., Drouot, S., & Buratto, F. (2023). Evaluation of Virtual Reality Training: Effectiveness on pilots' learning. IHM'23-34e Conférence Internationale Francophone sur l'Interaction Humain-Machine. Université de Technologie de Troyes, Troyes, France. https://hal.science/hal-04046414	The article evaluates the effectiveness of an immersive VR device for pilot training compared to a non-immersive 3D device that uses flat displays. With 12 participants, the study focused on usability and learning outcomes. Findings revealed the non-immersive device was better for knowledge retention, while the immersive VR reduced training time and instructor assistance for skill acquisition. No significant cybersickness symptoms were observed with the VR device. Both devices were deemed user-friendly, with a preference towards the immersive VR.
Marques, E., Carim Junior, G., Campbell, C., & Lohmann, G. (2023). Ab Initio Flight Training: A Systematic Literature Review. The International Journal of Aerospace Psychology, 33(2), 99–119. https://www-tandfonline-com.ezproxy.libproxy.db.erau.edu/doi/full/10.1080/24721840.2022.2162405?scroll=top&needAccess=true&role=tab	This article examines literature pertaining to ab initio flight training from 1990 to 2020 to uncover dominant patterns and research areas that need further investigation. The findings encompass a broad range of topical research, including the utilization of technological tools to enrich flight training. These tools encompass Personal Computer-Based Aviation Training Devices (PCATDs), simulators, eye-tracking devices, as well as AR and VR technologies.

Oh, C. (2020). Pros and Cons of A VR-based Flight Training Simulator; Empirical Evaluations by Student and Instructor Pilots. Proceedings of the Human Factors and Ergonomics Society. Annual Meeting, 64(1), 193–197. https://doi.org/10.1177/1071181320641047	A medium-fidelity VR flight simulator was designed to assess pilots' perceptions of simulated flights within the VR environment in comparison to traditional mockup-based simulators. Participants generally found the VR simulator to be on par with or even superior to conventional simulators. Nevertheless, when it came to manipulating electronic cockpit systems, the consensus was that conventional simulators remained the preferred choice, despite a perceived improvement with practice.
Visionary Training Resources [VTR]. (n.d.). The Case For VR: Training Pilots Using VR Changes Everything. Visionary Training Resources. https://www.vtrvr.com/the-case-for-vr	The affordability of consumer-priced hardware has opened up various applications for VR. One significant advantage lies in its immersive recreation of the flight deck, offering several key benefits. These include cost-effective training, savings on aircraft familiarization training, and improved information retention, all of which surpass the capabilities of traditional flight simulators.

Methodology

The focus of this study was to understand the impact of the use of high-definition VR goggles during the A320 type rating training. A qualitative online survey was conducted with certified flight instructors of a major Brazilian airline to provide a deeper understanding of the actual knowledge and skill gaps perceived by instructors during the A320 type rating training. Also, an online interview was conducted with an instructor of a regional Brazilian airline that uses VR to train its pilots. The interviewee is a Subject Matter Expert (SME) in the use of VR for training Brazilian airline pilots.

Based on the conclusions and recommendations found in the literature review, the results of the survey, and the SME interview, the group used inference to understand if and how VR can be used as a training tool and its potential to address the gaps identified in the data collected in the survey. However, the SME was never informed by the researchers about the results of the survey with the other airline's instructors before the publication of this report. The objective was not to bias the interviewee's answers regarding the gaps and possible VR support to them.

Data Source

The survey was sent to 172 professionals who are certified A320 type rating instructors in a Brazilian airline. Participants were able to fill in the survey form anonymously. By protecting identity, the research can reach more participants and retrieve sincere answers. The online survey was developed with multiple-choice and selection box questions. The objective of the survey was to understand, from the instructor's perspective, the advantages and gaps that the new pilots are presenting during the initial training. Rates were assessed using a five-point Likert scale with options ranging from "totally disagree" to "totally agree", and some questions contained open-text answers. Since all instructors are native Portuguese speakers, the survey was conducted in Portuguese. The questions were translated from English using a free translation tool available at www.deepl.com. The translated form is available in Appendix B.

The interview was conducted with one instructor of a regional Brazilian airline that uses VR devices to train its pilots. To retrieve sincere answers, the instructor was assured that his/her name would not be shown in this paper. The airline has been using VR technology in training for two years. The airline currently has 150 pilots, and the VR goggles have been used for training with part of this group.

The regional airline is a subsidiary of a major Brazilian airline and operates 20 Cessna Grand Caravan C208B's and C208EX's between destinations in all areas of Brazil. It is certified under part 135 as a scheduled operator and holds a valid Air Operator Certificate from ANAC. Pilots flying these airplanes are not required to have a type rating. In their operations, holding a valid single-engine land rating, instrument rating, and at least a commercial pilot's license is necessary.

Training is conducted under an approved program by ANAC for initial and recurrent training of captains and first officers at the airline. It includes ground school, an FTD level-4 simulator, and real airplane flying.

Data Collection

To better understand the training landscape of this Brazilian company, pilot demographic data was shared by the company. The data shared contained the age and previous experience in terms of flight hours and the most flown aircraft type. Also, the company provided training failure data related to this group of pilots. The names or any other type of data that could be used to identify the pilots were not shared.

The survey was developed, and the data was collected using the Google Forms tool. The link to the form was sent to all instructors via WhatsApp message by the airline's training management team. The instructor had to use their company's credentials to access the form. Only one answer per instructor was allowed.

The questions were focused on evaluating the following competencies:

- Knowledge: Have enough knowledge about aircraft systems, procedures, the company's operational policies, and the applicable regulations to conduct the flight without the instructor's intervention.
- Application of procedures: Adheres to procedures in accordance with published operating instructions and applicable regulations, using the appropriate knowledge.

- Communication: Effectively communicates with the Air Traffic Control (ATC) using standard phraseology. Appropriately and effectively communicates with other crew members, using standard callouts when required.
- Automation management: Controls the aircraft's flight path using automation accurately and smoothly, correcting deviations and taking appropriate measures for each situation, including the appropriate use of flight management and guidance system (FMGS).
- Manual flight: Controls the aircraft's flight path through manual flight with accuracy, smoothness, and safety.
- Decision making: Identifies risks precisely and solves problems using the appropriate decision-making process.

The form was available for the instructors from September 6, 2023, to September 20, 2023. During this period, 112 answers were registered, which represents 65.1% of the instructors group.

Handling Data and Ethical Considerations

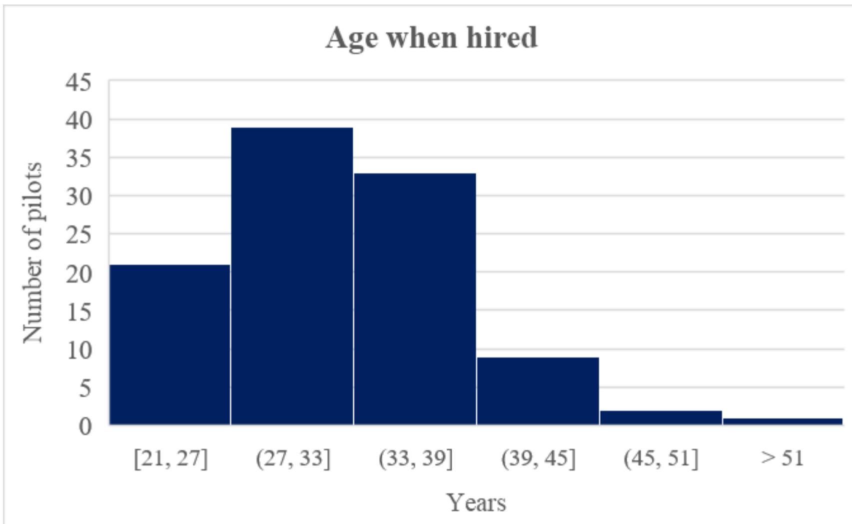
Data analysis and reporting were conducted anonymously, and participant identities were kept confidential. The collected data was transferred to a secured online sheet to prevent unauthorized access, which only the group members had access to. Microsoft Excel was the chosen tool to analyze the data. The open-text answers were organized and categorized according to the related competence.

Training Landscape

During the first semester of 2023, the Brazilian airline investigated in this study hired 105 pilots for the A320 first officer position. As shown in Figure 6, the average age of the pilots was 32.7 years (SD = 6.0).

Figure 6

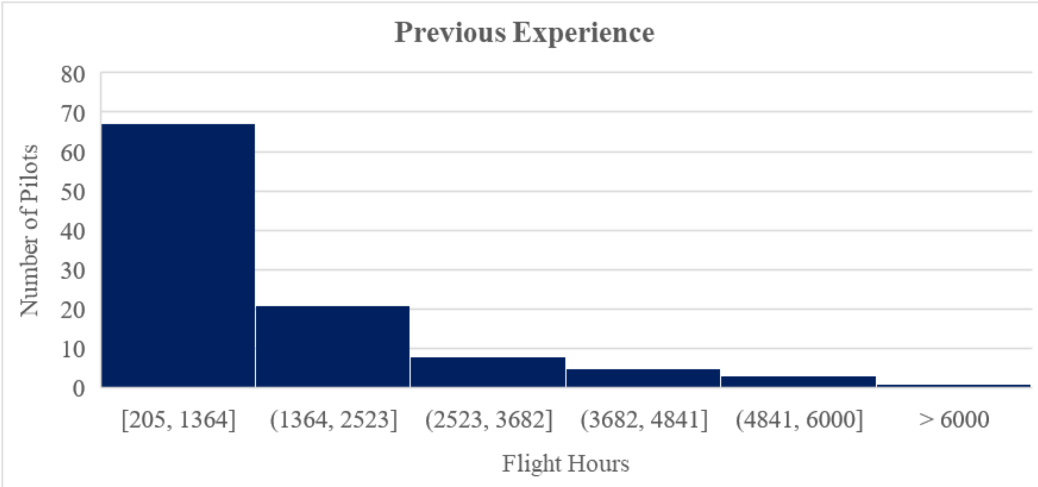
Age distribution



The previous experience, expressed in terms of flight hours, varies from 205 to more than 6,000 (Figure 5). The average previous experience was 1,542.7 flight hours (SD = 1,258). Only six pilots (5.7%) already had flight experience with the A320 Family. Most hired pilots (45.7%) only had experience on light single-engine aircraft, such as Cessna 152. 13.3% of the pilots had previous experience in regional single-turboprop aircraft such as the Cessna 208. 11.4% had previous experience in light business twin-turboprop aircraft such as the Beechcraft King Air C90. 7.6% of the pilots had previous experience in light twin-engine aircraft, such as the Piper PA34. The other 16.2% of the pilots reported experience with a variety of aircraft types, including military combat aircraft and medium regional jets, such as the Embraer E190.

Figure 7

Previous experience distribution



The wide variety of pilot profiles, most of which lack relevant experience on complex aircraft such as the A320, reveal a complex training scenario. In fact, 17.1% of pilots failed during training. 9.5% failed during the simulator phase and 7.6% during the line phase.

Data Analysis

The airline has three types of instructors:

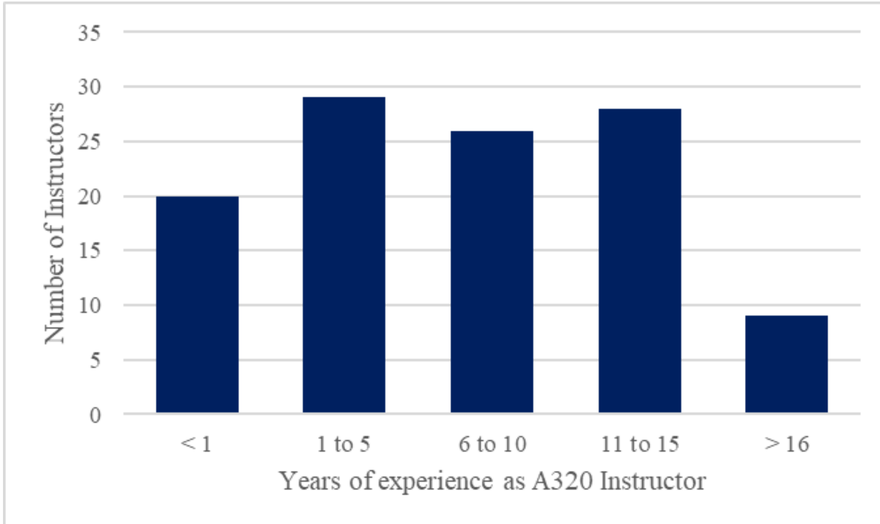
- Type A: Only provides line phase instruction.
- Type B: Only provides simulator phase instruction.
- Type C: Provide instructions on both phases.

Type A instructors were directed to the section regarding only the line phase. Type B instructors were directed to a section concerning only the simulator phase. Type C instructors were required to answer questions about both phases.

Of the responses, 67.9% came from Type A instructors, 21.4% from Type C instructors, and 10.7% from Type B instructors. Figure 8 displays the experience of the A320 instructors.

Figure 8

Experience as an instructor of the A320



Concerning the competencies, 95.5% of the instructors reported manual flight as deficient. 68.8% also reported decision-making as a common deficiency, and 67.9% reported communication as a deficiency.

Instructors type B and C reported that most pilots begin the simulator phase with enough knowledge about aircraft systems, are familiar with the cockpit layout, and are capable of locating effectively the switches to control the various systems. 50% of these instructors reported that the pilots are unfamiliar with the aircraft's flight management and guidance system (FMGS) and do not know how to handle the electronic centralized aircraft monitoring (ECAM). Regarding memory items, standard operating procedures (SOP), flow patterns, and callouts, there is no agreement among these instructors, which indicates that it can be improved. A point of concern is the frequency with which instructors must allocate additional training time due to students' lack of preparedness. While 8.3% said they "rarely" needed to do so, 55.6% indicated they sometimes had to.

Instructor types A and C reported that most of the pilots begin the line instruction with enough knowledge about aircraft systems, are familiar with the cockpit layout, and are capable of locating effectively the switches to control the various systems. 50% of these instructors reported that most pilots are familiar with the flow patterns, SOP, and callouts, indicating that the deficiencies are addressed in the simulator phase. Among these instructors, 34.7% are confident in the pilots' understanding of FMGS operation, while 37.8% express concerns about the pilots' insufficient knowledge in this area. Regarding the exterior walkaround, the largest share of these instructors (49%) reported that the pilots began the line instruction phase without enough knowledge to perform the procedure. Only 18% of these instructors believe that the pilots communicate with the ATC clearly, objectively, and using standard phraseology.

The survey shows that the most deficient competency is manual flight, which makes sense, given the pilots' previous experience. Communication is also a need for improvement, especially communication with the ATC. Automation management, knowledge, and decision-making are also competencies that must be improved.

Interview with Subject Matter Expert

An online recorded transcripted interview was performed with the SME explained above in the text. The session was conducted on October 20th using Google Meet software with screen recordings activated and lasted 72 minutes.

There were two research participants, one being the interviewer and the other an observer taking notes. The questions formulated to be addressed with the SME are available in Appendix C.

The SME was sharing the camera and his/her screen while showing the images produced by a flight simulation software as well as interacting with it using a META Quest 3 headset goggles. It showed an Airbus A320 cockpit in detail parked at Viracopos International Airport. The level of detail was surprising to the interviewer, who has been an A320 type rated Captain for 20 years.

During the whole interview, the SME shared impressions and practical examples of interaction through VR in a cockpit and procedure training environment. The instructor pointed out that training the scan flows and procedures is a positive outcome of VR. The interviewee justified that it creates a very positive challenge and response philosophy among students. The interviewee stated that it can monitor each step and interaction with the cockpit and understand if pilots are performing checklists only after performing all necessary tasks. The device can provide feedback if items are missing and correct the student if something was not performed or done out of order. The SME stated that "the device can identify missing items in procedures and lets the pilot know if they ask for the checklist without having completed the tasks".

When asked about the applications of the VR goggles technology in training, the SME mentioned that has had information that Portugal's TAP Airlines and Air Canada are seeking possibilities to implement it. The interviewee also pointed out an example of LOFT Dynamics (formerly VRM Switzerland) that has been able to achieve FTD level 3 certification in the European Union Aviation Safety Agency (EASA) environment with an FSTD device for the Airbus H125 helicopter, which combines both physical equipment and use of VR goggles.

Regarding costs, the SME mentioned that creating an immersive experience for training is a challenge even for Full Flight Simulators. FFSs are big and expensive equipment that needs to have a set of lenses and mirrors shaped with a vacuum to create an individual collimated viewing perspective for each pilot. The headset goggles in VR can create it at about US$ 500,00 a piece with brighter images since there is no light loss without mirrors. Still, in comparison with FFS the SME stated that the visual graphics quality and experience take longer to be updated and improved than those on personal computer flight simulator softwares nowadays.

If equipped with headphones, the headset can also create a more immersive experience with individual audio. The SME also highlighted that the audio functionality can be used as means to train communications and phraseology. The student can interact with the instructor, a program in the goggles, and get answers from a person or artificial intelligence. Communication skills are one of the top gaps identified by the A320 instructors during training.

When asked about the necessary improvements, the SME pointed out that using some rotary switches can be challenging. The technology still cannot understand pinch gestures, and therefore, it needs to use touch and push or pull movements instead of turning hands. Although it has been under review by developers, the muscle memory process in these interactions is not representative of real movements in the cockpits yet.

During the interview, the SME provided some general comments that were considered relevant to the research topics. The interviewee stated that the VR experience is better and more natural for students than touchscreens. The muscle memory it allows to create is also very important to training, and the technology creates a virtual environment that feels the same as the sizes and movement dimensions as in the real cockpit.

The SME mentioned that VR goggles can offer a wide field of view, allowing a good perception of depth in landing training. The interviewee stated that during the flare, it is possible to see the runway surface approaching within the "eyes' corners", just as it is in the airplane. According to META's technical specifications for the Quest 3, their goggles allow a field of view of 110 degrees horizontally and 96 vertically. Again, the SME highlighted that considering that touchscreen VPTs do not provide images with the sight out of the cabin, VR can generate more immersion. Compared to FFS's 180-degree screens, VR is not a match. But since headset goggles can simulate the head movements in any direction, they can provide side views out the window in angles the present FFS does not have projections for. The SME also explained VR can generate images for the pilot simulating a walk-around outside the airplane, which a fixed FSTD cockpit cannot.

When asked about the alternatives for implementation of VR in initial training programs curriculums, the SME objectively answered, “it is not it (VR) that will make them (the student) fail”. The interviewee later explained that in his/her experience, it could be an adequate substitute for even an FTD level 5 regarding cockpit procedures training.

The SME stated that some pilots undergo training at an internationally recognized company in the United States of America. When returning to the airline, they have not yet learned how to perform an external inspection of the airplane because of using FTD simulators. The interviewee stated that the airline is developing training in VR for it, so students will be able to start their flying training missions better prepared than today with the third party's FTD simulators.

Regarding instructors who are colleagues of the SME in the same airline, they have expressed that the VR devices allow better preparation of the students. The interviewee said the instructors stated that students are not “raw when coming to training anymore”. Another claim from the instructors was, “if I had it before...”. Meaning they wish they had their initial training with the VR goggles as well. In the SME’s words, the other instructors also consider it much more natural to training in the virtual environment than touchscreen VPTs. A final thought the SME shared was, “receiving an airplane dashboard in paper for training? We are in 2023...”.

In summary, the statements provided by the Subject Matter Expert established an understanding of the resources, applications, and outcomes of VR when used in an airline for pilots’ initial training. The key aspects explained by the SME relate to the gaps identified in the training survey, addressing each of the main opportunities with possible beneficial use of VR. By mentioning the depth perception for landings, muscle memory experience, and movement range within the cockpit, we may understand that the VR goggles can be positive for students' manual flight skills. The goggles' headphones and microphones being enabled and coupled with an instructor or radio simulation software can be positive for students' communication skills with ATC. The procedure training lessons with mistake reviews can help students acquire solid knowledge about the airplane's scan flows, procedures, and checklists. Finally, according to the SME, since VR can generate any virtual environment scenario right before the student's eyes, it may provide examples of aeronautical decision-making in normal, abnormal, and emergency operations.

Limitations

This study is based on the instructors' perceptions and, although the instructors received the Companys' standardization course, it may be influenced by their own standards. No pilot was actually assessed during this study. The competencies assessment could be influenced by the aircraft type, given the complexity of the A320 systems.

No device was assessed, our conclusions were based on previous studies' findings.

Project outcomes

The manual flight deficiency perceived by the instructors is mostly related to the lack of experience of the recently hired pilots. Given the Brazilian market model, only a few pilots go from flight training school to a regional airline or a business jet to build flight experience. Usually, the pilots get their commercial pilot license, obtain their flight instructor license, and build their flight experience as flight instructors in light single-engine piston aircraft such as the Cessna 152. It may lead to a lack of experience in handling complex aircraft.

Using VR goggles to develop manual flight competence without additional hardware that replicates the actual aircraft controls and provides force feedback may not result in improvement. It will increase costs and may be less effective than using an FFS. In this sense, substituting traditional VPT devices with VR goggles may not directly improve this competency.

As suggested by Embry-Riddle Aeronautical University, communication between pilots and ATC can be improved using VR devices. The industry already has software integrated with VR goggles that helps students practice radio calls at their own pace, focusing on repetitive listening and speaking accuracy with simulated ATC (ERAU, 2022). The software generates a dynamic, AI-powered setting populated with various aircraft and air traffic controllers. This enhances the authenticity of flight training and offers a comprehensive ATC and traffic experience both in-flight and on the tarmac. By eliminating the need for instructor-guided role-playing, the software presents authentic communication scenarios, boosts the value of the training, and cuts down on related costs (ASTi, n.d.). Although this software can be integrated with an FTD or VPT, the availability of these devices can be limited due to the high associated cost as well as the need for instructors. In this way, it becomes more viable to use VR devices.

Regarding overall knowledge, both tools appear to be effective. According to Guthridge and Clinton (2023), pilots who received training using VR devices performed similarly to pilots who received training in traditional PC-based simulators. However, pilots prefer to train on VR devices (Khenak et al., 2023), which may increase the study time if the device is available for them. Based on the theory of situated learning (Lave & Wenger, 1991), it is possible to infer that VR devices can improve knowledge about exterior walkaround procedures since the devices' fully immersive and interactive environment can transfer knowledge more efficiently than a video. Similarly, decision-making can also benefit from using VR once it can be more immersive and provides more possible training scenarios than VPTs without additional hardware (e.g., fire in the cabin, smoke removal procedure, flight crew incapacitation).

Regarding automation management, it is unclear if VR instead of VPT devices can improve this competency. Pilots prefer interacting with cockpit electronic systems in traditional simulators (Oh, 2020). However, it may be the case where the VPT device has additional hardware that replicates some of the components that control the automation system on the A320, especially the multipurpose control and display unit (MCDU) and the flight control unit (FCU). How pilots would react to a touchscreen only VPT versus a VR goggle is uncertain.

Conclusion

Based on the presented literature and on the information retrieved during the SME interview we can conclude that the immersive nature of VR enables it as a versatile and cost-effective training tool, allowing normal and abnormal procedures training without additional hardware besides the goggles. Moreover, VR devices have been suggested as advantageous in enhancing pilot-ATC communication. While VR goggles alone might not significantly improve manual flight skills compared to traditional methods, this technology can potentially improve other skills. This leaves more FFS time available to develop aircraft handling skills. Also, the tangible feel of traditional simulators seems preferable for automation management training.

Being a cost-effective solution, the potential of VR in flight training is evident and indeed can be integrated as a training tool in the training program of a complex aircraft, such as the A320. Also, as the lessons do not depend on a human instructor and the content is prepared in advance, all pilots will have the same exact lesson for each topic. This leads to a higher degree of standardization, which can result in a safer operating scenario. However, it is necessary to have more evidence to ensure its effectiveness when replacing traditional VPT devices or even FTD devices. Further studies are needed to understand the effectiveness of using VR goggles to replace traditional VPT for CPT. These studies could serve as the basis for a change in regulations that will allow VR devices to be certified, transforming the flight training industry.

References

Aerosim. (2017, October 16). *Aerospace Technology*. Aerospace Technology. Retrieved September 30, 2023, from https://www.aerospace-technology.com/contractors/training/aerosim/attachment/aerosim1/

Airbus. (2022, November 10). *Airbus Virtual Procedure Trainer offers an innovative way for pilots to learn procedures using Virtual Reality - Lufthansa Group becomes launch customer* [Press release]. https://aircraft.airbus.com/en/newsroom/press-releases/2022-11-airbus-virtual-procedure-trainer-offers-an-innovative-way-for

Agência Nacional de Aviação Civil [ANAC]. (2023, February 24). *Instrução Suplementar 141-007C*. ANAC. https://www.anac.gov.br/assuntos/legislacao/legislacao-1/iac-e-is/is/is-141-007c

ASTi. (n.d.). *SERA: Simulated Environment for Realistic ATC*. https://seraatc.com/

Azuma, R. (1997). A survey of augmented reality. *Presence: Teleoperators & Virtual Environments*, *6*(4), 355–385. https://doi.org/10.1162/pres.1997.6.4.355

Bolter, J. D. (2014). Augmented Reality. In M. Ryan, L. Emerson, & B. Robertson (Authors), The Johns Hopkins Guide to Digital Media. Johns Hopkins University Press. https://search.credoreference.com/pt/articles/Qm9va0FydGljbGU6NDYwMzM1?aid=96099.

CPaT Global. (n.d.). *CPat* [Software]. https://cpat.com

De Paolis, L. T., & Bourdot, P. (2020). *Augmented reality, virtual reality, and computer graphics: 7th International Conference, AVR 2020, Lecce, Italy, September 7–10, 2020, Proceedings, Part I*. Springer.

Dictionary.com. (n.d.). Goggle. In *Dictionary.com*. https://www.dictionary.com/browse/goggles

Embry-Riddle Aeronautical University [ERAU]. (2022, January 21). *Improved Pilot-Training program yields promising results* (G. Pinholster, Interviewer). Embry-Riddle Aeronautical University. https://news.erau.edu/headlines/improved-pilot-training-program-yields-promising-results

Federal Aviation Administration [FAA]. (1992). *Airplane Flight Training Device Qualification*. https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_120-45A.pdf

Flightvectors. (2022). *Flight Deck Cockpit Procedure Trainers : Original Model Cockpit Trainer & Carrels*. Retrieved September 30, 2023, from https://www.flightvectors.com/Products/OTD/

Guthridge, R., & Clinton, V. (2023). Evaluating the efficacy of virtual reality (VR) training devices for pilot training. Journal of Aviation Technology and Engineering, 12(2). https://doi.org/10.7771/2159-6670.1286

JETPUBS. (2023, August 7). *Training materials*. JETPUBS Inc. https://www.jetpubs.com/training-materials/#tab-713493ce-83c1-2

Khenak, N., Bach, C., Drouot, S., & Buratto, F. (2023). Evaluation of Virtual Reality Training: Effectiveness on pilots' learning. IHM'23-34e Conférence Internationale Francophone sur l'Interaction Humain-Machine. Université de Technologie de Troyes, Troyes, France. https://hal.science/hal-04046414

Lagasse, P., & Columbia University. (2018). Virtual reality. In The Columbia Encyclopedia. Columbia University Press. https://search.credoreference.com/pt/articles/Qm9va0FydGljbGU6NjI1NDUx?aid=96099

Lave, J., & Wenger, E. (1991). Situated Learning: Legitimate Peripheral Participation (Learning in Doing: Social, Cognitive and Computational Perspectives). Cambridge: Cambridge University Press. doi:10.1017/CBO9780511815355

Marques, E., Carim Junior, G., Campbell, C., & Lohmann, G. (2023). Ab Initio Flight Training: A Systematic Literature Review. *The International Journal of Aerospace Psychology*, *33*(2), 99–119. https://www-tandfonline-com.ezproxy.libproxy.db.erau.edu/doi/full/10.1080/24721840.2022.2162405?scroll=top&needAccess=true&role=tab

META. (2023). *META Quest 3*. META Quest 3. https://www.meta.com/quest/quest-3/

Moisejenko, K. (2023, June 2). *How much does it cost to become a pilot?* BAA Training. https://baatraining.com/blog/how-much-does-it-cost-to-become-a-pilot/

Oh, C. (2020). Pros and Cons of A VR-based Flight Training Simulator; Empirical Evaluations by Student and Instructor Pilots. *Proceedings of the Human Factors and Ergonomics Society. Annual Meeting*, *64*(1), 193–197. https://doi.org/10.1177/1071181320641047

PICO. (n.d.). *PICO Neo3 Link Standalone VR Headset | PICO Global*. https://www.picoxr.com/global/products/neo3-link

Popov, O., Tretyakov, A., Barcz, A., & Piela, P. (2004). Some Problems of Design of Computer-Based Training Systems for Civil Aviation Pilots, Methods of their Solving. IFAC Proceedings Volumes, 37(6), 511–515. https://doi.org/10.1016/S1474-6670(17)32226-7

SKYBrary Aviation Safety. (n.d.). *Full Flight Simulator (FFS)* |. SKYBrary. https://skybrary.aero/articles/full-flight-simulator-ffs

Statista. (June 26, 2023). Volume of the VR headsets market worldwide from 2018 to 2028 (in millions) [Graph]. In Statista. Retrieved October 06, 2023, from https://www-statista-com.ezproxy.libproxy.db.erau.edu/forecasts/1331896/vr-headset-sales-volume-worldwide

Title 14, Chapter I Subchapter D Part 1 # C.F.R. § 1.1 (2023). Retrieved October 21, 2023, from https://www.ecfr.gov/current/title-14/part-1

Title 14, Chapter I Subchapter D Part 60 # C.F.R. § 60.1 (2023). Retrieved October 21, 2023, fromhttps://www.ecfr.gov/current/title-14/chapter-I/subchapter-D/part-60

Visionary Training Resources [VTR]. (n.d.). *The Case For VR: Training Pilots Using VR Changes Everything*. Visionary Training Resources. https://www.vtrvr.com/the-case-for-vr

Appendix A

List of Acronyms

- AATD – Advanced Aviation Training Device
- ANAC - National Civil Aviation Agency (Brazil)
- AR - Augmented Reality
- ATC - Air Traffic Control
- ATD – Advanced Training Device
- BATD – Basic Aviation Training Device
- CAA - Civil Aviation Authority
- CBT - Computer Based Training
- CFR – Code of Federal Regulations
- CPT - Cockpit Procedure Trainer
- EASA - European Union Aviation Safety Agency
- ECAM - Electronic Centralized Aircraft Monitoring
- FAA – Federal Aviation Administration (U.S.)
- FBS – Fixed Base Simulator
- FCU - Flight Control Unit
- FFS – Full Flight Simulator
- FMGS - Flight Management and Guidance System
- FSTD – Flight Simulation Training Devices
- FTD – Flight Training Device
- IATA – International Air Transportation Association
- ICAO – International Civil Aviation Organization

- IFR – Instrument Flight Rules
- MCDU - Multipurpose Control and Display Unit
- PCTD – Personal Computer Training Device
- QPS - Qualification Performance Standards
- QTG – Qualification Test Guide
- RBAC - Brazilian Civil Aviation Regulations
- SERA - Simulated Environment for Realistic ATC
- SME - Subject Matter Expert
- SOP – Standard Operating Procedures
- VFR – Visual Flight Rules
- VPT - Virtual Procedures Trainers
- VR - Virtual Reality

Appendix B

Online survey questions.

Header

Students' level of preparedness for instruction.

This research aims to identify the perception of A32F instructors and examiners regarding the quality with which students are being prepared for the initial simulator and route instruction phases.

This survey is anonymous. The data collected will be used for academic purposes.

Section 1, instructors' demographic and general data

How many years have you been an A320 instructor?

- Less than 1 year
- 1 to 5 years
- 6 to 10 years
- 11 to 15 years old
- Over 16 years old

In which phase of instruction do you work?

- Line Instruction Only
- Simulator Instruction Only
- Line and Simulator Instruction

In your opinion, which phase of training is the most stressful for students?

- CPT
- FTD
- FFS

- Line

If you wish, comment on your previous answer (Open-text answer).

Section 2, Student Preparation Level – Simulator

This section was not available for line instructors only.

Students begin the simulator instruction phase with sufficient knowledge of the aircraft systems.

- 1 - Totally Disagree
- 2 - I disagree
- 3 - I neither agree nor disagree
- 4 - I agree
- 5 - Totally Agree

Students enter the simulator instruction phase familiar with the cockpit layout and are able to effectively locate the switches that control the aircraft's different systems.

- 1 - Totally Disagree
- 2 - I disagree
- 3 - I neither agree nor disagree
- 4 - I agree
- 5 - Totally Agree

Students begin the instruction phase in a simulator familiar with the Flow Pattern (scan flow), task sharing and callouts in accordance with the aircraft's SOP.

- 1 - Totally Disagree
- 2 - I disagree

- 3 - I neither agree nor disagree
- 4 - I agree
- 5 - Totally Agree

Students begin the instruction phase knowing how to handle ECAM correctly and effectively.

- 1 - Totally Disagree
- 2 - I disagree
- 3 - I neither agree nor disagree
- 4 - I agree
- 5 - Totally Agree

The students begin the instruction phase with satisfactory knowledge about the Memory Items (Actions and Callouts).

- 1 - Totally Disagree
- 2 - I disagree
- 3 - I neither agree nor disagree
- 4 - I agree
- 5 - Totally Agree

The students begin the simulator instruction phase familiar with the operation and functioning of the FMGS. Consider the students' interactions with all components of the FMGS, i.e., FMGC, MCDU, FCU, FMA, AP, A/THR, FD, etc.

- 1 - Totally Disagree
- 2 - I disagree
- 3 - I neither agree nor disagree
- 4 - I agree

- 5 - Totally Agree

How often do you need to dedicate session time to teach topics not planned in the training phase due to students' lack of preparation?

- 1 - Always
- 2 - Frequently
- 3 - Sometimes
- 4 - Rarely
- 5 – Never

What are the most common deficiencies you observe in students at the start of training? (Select all that apply)

- Lack of technical knowledge (systems, regulations, charters, etc.)
- ATC Communication
- Lack of knowledge of procedures (SOP, memory items, etc.)
- Low flight proficiency (handling)
- Little ability to make decisions
- Other: (open-text)

In addition to simulator instruction, do you also provide route instruction?

- Yes
- No

This last question was only used to apply the correct logic to the form.

Section 3, Students' proficiency level in route instruction.

This section was not available for simulator instructors only.

Students begin the route instruction familiar with the schematic and all items that must be checked during the EXTERIOR WALKAROUND.

- 1 - Totally Disagree
- 2 - I disagree
- 3 - I neither agree nor disagree
- 4 - I agree
- 5 - Totally Agree

Students begin the line instruction phase familiar with the cockpit layout and are effectively able to locate the switches that control the various aircraft systems.

- 1 - Totally Disagree
- 2 - I disagree
- 3 - I neither agree nor disagree
- 4 - I agree
- 5 - Totally Agree

Students begin the line instruction phase familiar with the Flow Pattern (scan flow), task sharing, and callouts according to the aircraft's SOP.

- 1 - Totally Disagree
- 2 - I disagree
- 3 - I neither agree nor disagree
- 4 - I agree
- 5 - Totally Agree

Students begin the line instruction phase with satisfactory knowledge about the operation of the FMGS (FMGC, MCDU, FCU, AP, A/THR, FD, FMA, etc.). Consider satisfactory if the student can operate the system effectively without the need for instructor intervention.

- 1 - Totally Disagree
- 2 - I disagree
- 3 - I neither agree nor disagree
- 4 - I agree
- 5 - Totally Agree

Students communicate with ATC clearly, concisely, and using standard phraseology.

- 1 - Totally Disagree
- 2 - I disagree
- 3 - I neither agree nor disagree
- 4 - I agree
- 5 - Totally Agree

What are the most common deficiencies you observe in students at the start of training? (Select all that apply)

- Lack of technical knowledge (systems, regulations, charters, etc.)
- ATC Communication
- Lack of knowledge of procedures (SOP, memory items, etc.)
- Low flight proficiency (handling)
- Little ability to make decisions
- Other: (open-text)

Appendix C

SME interview questions.

1 - In your opinion, what are the main advantages of using virtual reality goggles in pilot training compared to traditional methods?

2 - Are skills like scan flows, checklists, and other skills in applying normal and abnormal procedures trained with VR devices?

3- Communication between the students and the ATC improved after implementing the VR training.

4 - Regarding the number of failures in the training phases, is it possible to say that there was a reduction in the number of pilots who failed in their training or that the average grade in the evaluations underwent positive changes?

5 - Briefly, can you describe the impacts on the quality of training after implementing the VR training program? Were there any challenges or limitations you encountered when using virtual reality goggles in training, such as students getting tired more than usual, nausea or motion sickness, technical problems during training or with the quality of the image?

6 - Were any negative aspects mentioned by instructors or students in the VR training program?

7 - Do you believe that virtual reality goggles can replace some training devices, such as CBT, CPT or VPT?

8 - How do you rate the effectiveness of virtual reality goggles in training?

9 - Would you recommend the use of virtual reality goggles for pilot training?