How can Extended Reality (XR) enhance Aviation Personnel Training: A Literature Review

Astrid Klotz[1] and Karen Stendal[2]

[1] University of South-Eastern Norway, Norway
astrid.klotz@usn.no
[2] University of South-Eastern Norway, Norway
karen.stendal@usn.no

Abstract. The implementation of extended reality (XR) technology into training and education methods is not a new emerging trend. In fact, it has caught researchers' attention for decades. However, technology has become more accessible to a larger population group, resulting in an increased interest in XR learning. Various industries have investigated how technology can train their personnel with lower costs and increased efficiency; the commercial aviation sector is no exception. This review examines how XR technology can be implemented for training commercial aviation personnel. The aim is to provide an overview of the latest cutting-edge applications within the aviation industry. Using a grounded theory approach, this review has developed themes and categorized various XR applications addressing different areas within aviation training.

Keywords: extended reality (XR), virtual reality (VR), mixed reality (MR), augmented reality (AR), aerospace, commercial aviation, training

1 Introduction

Extended reality (XR) technology has a promising future ahead as the Metaverse is emerging and XR plays an important role in enhancing the Metaverse experience [1]. XR enables our overall society to be more innovative, and the evolution of education and training approaches are affected. However, the inclusion of XR technology to develop novel training methods and applications is not a new concept. In fact, it has caught researchers' attention for decades [2, 3]. Nevertheless, training and education will experience disruptions due to the technology [4].

The aerospace industry has noticed the superiority of XR technology-based training methods and plan future increase in use [5, 6]. In the industry, private companies such as PaleBlue [9], have created their own gamification training systems available to the market. Hence, immersive training has become more commercialized with extended varieties and different focuses.

Despite the acknowledged importance of XR technology in aviation training methods, not many studies have been carried out in the research area. The literature in aviation personnel training is dispersed, leading that there is not a clear overview of the current XR aviation training applications and concepts. In spite that the research area is still in its infancy, it would be beneficial for both scholars and practitioners to have an overview of the current trends in XR aviation training. This would contribute to their understanding of the current developments in XR aviation training and enhances the outlook of future research in the area. Therefore, this research aims to provide a thematized overview of the current landscape of XR technology training possibilities within various areas of the aviation industry. We address the following research question:

"How can various XR technologies be applied and integrated in aviation personnel training methods?"

This research question is tackled by following the steps of the grounded theory approach [10]. This study provide an overview of various XR training possibilities for five different areas within the aviation industry: flight crew, maintenance, cabin crew, ground operations, and air traffic control. Notably, most analyzed concepts unanimously agree that XR training elements cannot substitute all traditional training methods but complement these valuably.

The literature endorsed that XR training provides at least a corresponding performance level compared to traditional methods. Nevertheless, its numerous benefits (such as safety, cost, and implementing changes), makes it overall more valuable [7]. These technologies offer aerospace organizations to reduce costs associated with expensive training (e.g., pilot training). XR transforms a training environment into a 'real' environment which immerses the user, resulting in better received training as the trainee gains and improves muscle memory in this 'real' environment. XR systems can simulate hazardous, or not yet existing environments, which is ideal for the aerospace industry. In addition, the technology is flexible regarding the modification and reconfiguration of training scenarios as digital content can be created or modified efficiently [6, 7]. Lastly, inclusion of gamification effect [8] also enhances the engagement and perceived training, making it a positive experience for trainees. Overall, it can be concluded that XR can strengthen students' ability to learn efficiently and effectively. Consequently, the aviation industry may become better, safer, and more efficient [5].

The next section will explain the concepts of XR (i.e., virtual reality, augmented reality, and mixed reality) based on the virtuality continuum [11]. Afterwards, the methodology including queries, databases, criteria, and analysis are outlined. Furthermore, the literature including findings and discussion with implications for future work are discussed, followed by a conclusion.

2 Concepts

Extended Reality (XR) is an umbrella term for virtual reality (VR), augmented reality (AR), and mixed reality (MR) [12]. XR technology unites these reality categories, and the virtuality continuum illustrates this precisely (Figure 1) [11]. On one end of the continuum (far-left), the complete physical world is placed, and on the other end (far-right), the complete virtual world (i.e., VR). The realities in between of the spectrum are MR technologies. This framework is sustainable and allows researchers to expand the range of realities, resulting in unlimited future opportunities for XR.

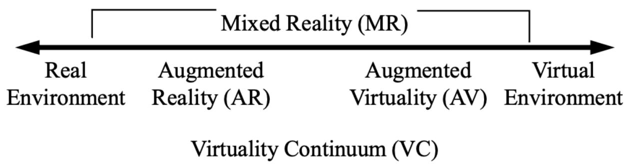

Figure 1: Simplified representation of the virtuality continuum [11]

Extended Reality Training has been defined as: "a purposely designed, immersive learning experience, which takes advantage of the appropriate technologies. These technologies engage and support employees when acquiring the knowledge and skills needed to drive the behaviors that impact specific business outcomes, which are aligned with organizational goals." [12].

Gamification is defined as the inclusion of game components in non-gaming contexts. The term can be extended as the design process of services, systems and actions to enhance user-engagement and positive user-experience [12]. Users undergo a faster learning process through XR gamification, also referred to as "gamification effect" [8].

High user immersion training addresses new, multisensory approaches [12]. Consequently, the learner is more exposed to "muscle-memory", which stimulates learners. Additionally, XR training enables tailored and self-paced learning leading to more beneficial learning outcomes as each individual learner's needs can be addressed [7].

Aviation Personnel are addressed as staff carrying out operational tasks that are directly associated with aircrafts and/or passengers. E.g., Pilots, cabin crew, aircraft maintenance engineers, air traffic controllers, ground operators (i.e., fueling, luggage handling, taxing fleet, etc.).

3 Methodology

This section describes the research method of this literature review. The keywords for this review are: 'Extended Reality (XR)', 'Virtual Reality (VR)', 'Augmented Reality (AR)', 'Mixed Reality (MR)', 'aviation', 'aerospace', and 'training'. A combination of these search strings has been utilised with the Boolean 'OR' and 'AND' operators. The search was conducted between September and October 2022, and the range of the articles was between 2017 and 2022. Notably, most papers were ranging between 2020 and 2022.

Journal articles and conference papers have been collected from the databases Scopus, Web of Science, and Google Scholar. To select the corresponding literature for this review, inclusion criteria have been established:

1. The article must contain XR concepts (including VR, AR, and/or MR).
2. The XR technology is applied to an area within the commercial aviation sector for training purposes.
3. The article must explain the purpose of the XR technology within the aviation training field.

Besides having these three inclusion criteria, exclusion criteria have been added. These encapsulate that books and theses will not be included in the selected literature. As the purpose of this study is to provide the current applications, books do not always comply, since by the time they are published, the technology can be already outdated. Non-reviewed theses are also excluded as this review aims to provide quality. Peer-reviewed research articles guarantee the validity of the research.

During the first phase of the literature review, all abstracts have been read in order to assure the relevance to the review. A total of 16 papers were selected during these phases of the literature review process. After a conducting a backward search, 6 additional papers were included, resulting in a total of 22 selected research articles.

Data analysis. The aim of this review is to provide an overview of the current available XR training methods within the civil aviation industry. Therefore, the grounded theory approach [10] was adopted to analyze the selected literature and classify them using open, axial, and selective coding. Open codes have been derived from keywords, abstracts, and the article's bodies (table 1). The content will be presented using a 'concept-centric' approach (cf. 'author-centric' presentation) to elevate the readability and highlight the concepts [13, 14].

Table 1 Extract of Grounded Theory of the Literature

Article	Open coding	Axial coding	Selective coding
Torrence & Dressel (2022)	AR step-by-step textual information for technician, AR checklist procedure for aircraft power unit, AR training content, tutorials, and virtual demonstrations of safety equipment on board, MR to support visualisation and management of air traffic	AR aircraft unit detection, AR checklist, AR emergency procedure training, Holographic MR system (ATC)	Maintenance, Cabin crew, Air Traffic Control
Cross, Boag-Hodgson, Ryley, Mavin & Potter (2021)	VR, flight simulator, cockpit familiarisation, procedure training (PT), AR, assist pilot's decision-making process, improve situation awareness	VRFS, VRPT, AR pilot guidance	Flight crew
Neretin, Kolokolnikov & Mitrofanov (2021)	AR, VR, aviation personnel training, mobile applications, VR for training maintenance specialists, step-by-step assembly and disassembly of unit structure, VR model cabin, technical training tool for stewards	AMVR, VR cabin crew safety training	Maintenance, Cabin crew
Siyaev & Jo (2021)	MR, aircraft maintenance, education, speech interaction, deep learning, digital twin, step-by-step instruction	AMMR	Maintenance

Limitations. This review aims to provide a list of novel cutting-edge research contributions. Nevertheless, by the time a training tool is designed, implemented, and sufficiently tested, it can be already outdated [7]. Additionally, in some circumstances it takes time to peer-review and publish a paper, which dilutes the newness.

The selected articles (N = 22) range from a publication year between 2017 and 2022. Most articles are conference papers. All research articles were peer-reviewed and were published in outlets such as IEEE, Springer, Sage, ACM, and JATIT. 16 papers (around 73%) are empirical studies. This paper does not elaborate on the technical aspects of XR set-ups but focuses on the utility of XR within training methods. Applications including the reflection upon benefits and challenges are addressed.

4 Findings

Based on the existing literature, five themes (i.e., area focus) could have been derived: (1) flight crew, (2) maintenance, (3) cabin crew, (4) ground operations, and (5) air traffic control. 11 papers (50%) addressed VR, 8 (36%) AR, and 2 (9%) MR, only one paper included all three realities. According to the literature, XR technology is proven to be an effective training tool [7]. It is transforming aviation training by enhancing user engagement and retention with interactive content. The immersive learning involved, bridges the gap between the classroom and simulation environment [15].

4.1 Flight crew

Physical flight simulators (PFS) are crucial for pilot education. However, fully equipped PFS cost between $6 to $8 million, with an additional $400-500 hourly operation rate, tremendously increasing the expense to train a pilot. Additionally, PFS are inflexible since they only simulate one type of aircraft, are physically situation at a particular location, and involves additional staff to train the flight crew [16]. Applying XR technologies can hence be more efficient and cost-effective. Therefore, the European Union Aviation Safety Agency (EASA) approved the first virtual reality flight simulator (VRFS) in 2021 [17]. Pilots who trained in simulators first, learned faster during in-flight training as users were already exposed to certain situations. Additionally, it enabled immediate feedback resulting in more efficient training [7].

XR training for flight crew is prominent. Hence, most papers address this topic.

Virtual Reality Flight Simulator (VRFS) simulates the PFS in a virtual environment. It can be used for the same training purposes e.g., cockpit familiarization training (CFT) as the VRFS mimics the interactions with physical PFS switches. Off-the-shelf hardware and software can be used for this purpose [16]. Sensors included in the VRFS can also report valuable information regarding cognitive processes from the user. Researchers can take this information to improve flight training [18].

Virtual Reality Procedure Training (VRPT) is a virtual cockpit [19]. In this module, a list of tasks is displayed. The user can interact with the list and retrieve more information. The checklist also indicates whenever a task has been completed [20].

Virtual Reality Aviation Illusion Trainer (VRAIT) targets runway width illusion. Pilots may become disoriented during a flight when one or more of the information systems on board are displaying conflictive information. This disorientation may result in the pilot landing the plane in an undesired state. The VRAIT leverages the awareness of aviation illusions by assisting the pilot in a safe training setting. The flight scenario is simulated and offers the flight crew the opportunity to visualize what the aviation illusion looks like, preparing them to take the right action. Pilots that tested this application, classified the VRAIT as a valuable training tool [21].

AR Pilot Guidance has the potential to navigate the flight crew on different occasions. For instance, the “AR cockpit guidance” is developed to display information (i.e., symbols, guidance, and obstacle representations) to lead pilots during flight phases (i.e., taxi, enroute, approach) with challenging vision [22]. “AR Navigation” is another sub-application within this area. With AR Navigation, virtual navigation cues are exhibited in the real environment, allowing pilots to better understand what is going on around them. This application was considered as very promising among pilots [23].

AR checklist is an interactive 3D model in which the user can engage with the components. The user follows a checklist procedure to start the aircraft’s APU (i.e., a self-contained gas turbine power unit). The checklist tasks must be completed in sequential order to safely start the engine. The digital AR content indicates via a light which system switch must be activated. Additionally, it features an interactive arrow leading to the right switch control. The user also sees the APU checklist displayed [24].

AR-based ab initio pilot training aims to implement AR as an assistance tool throughout the full pilot training process (i.e., ab initio). As pilot students consider approach and landing contents as the hardest parts of their training, AR can assist them by providing additional information. Visual cues can be augmented to facilitate their navigation during an approach. AR can also be useful for abnormal and emergency procedures (e.g., engine failure, forced landings). AR technology can simulate these conditions, teaching the pilots how to react accordingly. Other challenging elements mentioned during the ab initio training were turns, climbing, descending, straight and level flight with speed changes and stalls. AR can provide visual cues so that pilots look outside to the horizon to make the right calculations during the flight on when to turn, etc. Lastly, AR can be applied for en-route procedures (e.g., navigation and map reading, flight instrument use, radio navigation aids), and flight management (e.g., checks, systems, icing, etc.) [25].

AR digital twin can be applied for type rating (TR) training. A TR authorizes a pilot to fly with certain types of aircrafts as certain aircrafts belong under a particular category. Pilots agree that AR technology can be applied for both the theoretical and practical content. The AR digital twin was considered particularly helpful for learning the aircraft structure, and equipment and flight preparations. AR technology allows users to have richer asynchronous interactions during training e.g., video recordings of a practice session, guidance videos with holographs, etc. Nevertheless, it should be noted that regardless many similarities, there are gender-specific preferences for this type of training [17].

MR take-off module. This training model for take-off procedures is designed to operate with HoloLens. Its interactivity, such as hand gestures and voice command, makes the user more engaged during the training module. The take-off module is tutorial based and features each step sequentially. The module allows users to return to a preceding step, start over, or proceed to the next step. As the training is self-paced, only one step is shown in the head-up device (HUD) and remains until the user makes a command to proceed to the next step [26].

4.2 Maintenance

Aircraft maintenance receives research attention as researchers acknowledge the potential to implement XR technology within this area. Five different applications have been found, most of them were classified as AR technology.

Aircraft Maintenance Virtual Reality (AMVR), a 3D model of an aircraft is developed in a virtual environment. Users can perform walk-around inspections, fuel system observations, and use a horizontal elevator. All actions include an information screen displayed in the environment to guide the user [27]. The software encompasses aircraft units for disassembly and reassembly procedures. Step-by-step processes were designed, and each step involves the selection of appropriate units and tools to perform the maintenance action [28, 29]. AMVR allows users to disassemble and assemble parts as many times they wish to do. Additionally, each unit can be examined in detail and analyzed in the context of the entire aircraft. AMVR is also more inclusive than traditional training methods as factories cannot supply sufficient units for every student. VR technology on the contrary is more accessible [30].

AR aircraft unit detection, an AR marker-based application is designed to assist maintenance trainees. The AR application detects physical aircraft power units, using artificial intelligence (AI). This application is ran on a mobile device and provides the technician a step-by-step manual and animations on the screen [31]. Maintenance trainees will detect more rapidly aircraft units and learn what actions to take.

AR checklist can be used for maintenance workers to check the engine for air bleed or other malfunctions [24].

Aircraft Maintenance Augmented Reality (AMAR) uses the same principles as AR aircraft unit detection. However, it also incorporates HUD devices. AMAR is an aviation equipment inspection system that adopts AI detection to support standard operation procedure (SOP) maintenance training. The system indicates the location of a unit and detects errors on the aircraft. After detecting the error, the corresponding manual is displayed. Currently the application is used on turbofans and landing gear units. AMAR has the opportunity to replace authentic manual training as users detect more rapidly the units and less time is spent to read tedious SOP manuals [32].

Aircraft Maintenance Mixed Reality (AMMR) upgrades AMAR by including interaction with virtual airplanes (i.e., real-scale digital twin) that transfer a relatively real industry experience. AMMR is enriched with a custom deep learning speech interaction module, enabling users to make voice commands while working with both hands. The MR application is situated in the metaverse, hence maintenance solutions, and virtual aircrafts can be updated, manipulated, downloaded, and shared conveniently. The 3D twin aircraft is supplemented with maintenance tools. The MR application displays manuals, instructions, visualizations, and tutorials throughout the maintenance procedure tasks. Moreover, as it is a metaverse application, it allows interactive learning and collaboration among maintenance workers and trainees around the world [33].

4.3 Cabin crew

VR cabin crew safety training. The interior of an aircraft is translated into a virtual environment in which the user can walk around and interact with the aid of VR. Certain particles, such as smoke and fire can be displayed [29]. This application allows cabin crew to experience conditions they could otherwise not during training. Also, the development of emergency handling is enhanced.

AR emergency procedure training is designed to improve motivation and user-engagement in onboard emergency procedure training. The mobile application applies image recognition to overlay digital content. The digital content consists of virtual buttons, videos, and tutorials. Generally, users perceived the application to be effective due to its user-friendliness and complementary information overlay, enhancing the overall experience [34].

4.4 Ground Operations

VR ground operation training involves the aircraft being duplicated within a virtual environment. Pre-flight checks are incorporated, in which personnel can virtually walk around the aircraft, ensuring it is free of malfunctions or issues. Other ground handling can also be performed in the VR simulation. This is effective for the new employee to familiarize themselves with the new terminal environment. Direct exposure to an aircraft is hazardous, and the noise and traffic going on the tarmac might be distracting and involve a high risk. VR training in a safer environment is hence beneficial as employees can get used to it and practice handlings such as refueling, de-icing, water replenishment, and cargo handling. The VR environment also allows the instructor to introduce scenarios that can occur e.g., encountering an unidentified baggage. Additionally, unusual situations can be simulated, such as sudden harsh weather conditions, system failures, and other operational conditions that would otherwise be too dangerous to perform on physical aircrafts [35].

4.5 Air Traffic Control

VR eye-tracking assistance examines the visual scanning behavior, aimed to enhance expert tower controller training. Controllers must develop systematic scanning behavior to collect all cues, ensuring safe air traffic (out-the-window view, runways and operating areas on the airport, and airspace surrounding the airport). By designing a VR tower cab, less physical space is needed, and the device allows evaluation of the trainee's scanning in real time. The VR application should include surveillance displays, flight progress steps, and out-the-window view. Additionally, the VR simulation enhances the creation of off-nominal air traffic events, and train controllers for such scenarios. VR eye tracking gives researchers the opportunity to better understand controllers scanning behavior, improving the development of controller training tools [36].

Holographic MR system. A four dimensional (i.e., 3D including time) holographic MR system supports the visualization and management of air traffic. The controllers can easily switch and navigate among multiple displays using visual and voice commands [31]. This training tool facilitates the familiarization of the dynamic airport environment and air space (e.g., many flights taking-off, landing, and in the air, sudden weather changes affecting flight routes, etc.).

4.6 Benefits and Challenges of XR aviation training

A prominent advantage of XR aviation training is the simulation of scenarios that are otherwise impossible to reproduce in traditional aviation training. XR enables users to carry out tasks in a safe and controlled environment, while providing real-time feedback. [22, 31]. Moreover, XR aviation training offers elevated user-engegement [34]. This results in an improved content retention [19] and a lower occurrence of errors [16, 28, 30]. Additionally, XR allows personalized training as modules are self-paced and the user decides when to proceed to the next module. Therefore, users perceive less stress throughout the training process [26]. Lastly, the gamification effect motivated some users to explore certain content more thoroughly [24].

Overall, users enjoyed the XR learning experience and acknowledge its superiority [20, 30, 34]. The inclusion of XR technology in aviation training would enhance skills such as decision-making, situation awareness, problem solving, and teamwork [19, 25, 27].

As XR is still in development within aviation training, there are challenges. The first and foremost limitation of technology is the field of view (FOV). The limited view in XR devices could result in information being placed outside the view range, hence, users must move their heads into unnatural positions to spot the relevant displays. Therefore, the FOV should be increased to perform better aviation training, and all information should be located within this range to optimize training processes [19, 26, 31]. Another challenge relates the increase of overall operation time compared to traditional methods [28, 30]. As the difficulty level of a task increased, so did the operation time in an XR environment, making the training less efficient [16]. Users are still unfamiliar with the devices and need time to understand how to use the commands for training purposes [24]. Moreover, current HMD and HUD devices have been perceived as heavy, encumbering the movements of users over time. [16].

XR training could cause cyber sickness (i.e., simulator sickness). Simulator sickness is nothing new to the aviation industry as many personnel trains in simulators. However, it has been reported that more users experience cyber sickness with XR applications rather than in traditional simulator environments [16, 31]. Aditionally, the number of XR devices is a challenge as every user should have access to it. During training, supervision is required considering the technology is still in its infancy and the users' reactions have to be monitored. Therefore XR aviation training is dependent on the availability of personnel and the number of participants has to be limited. Lastly, due to health precautions, time spent with XR technology, especially with HMDs and HUDs, cannot be extensive, resulting in shorter training sessions [20].

5 Discussion and Implications for Future Work

The aim of this review was to answer the question '*How can various XR technologies be applied and integrated in aviation personnel training methods?*'. Therefore, an overview of the current cutting-edge XR aviation training applications and concepts is determined. Table 3 depicts all XR application per aviation area. The XR training is categorized into VR, AR, and MR.

Table 2 XR Applications per Aviation Area

Personnel	XR Type	Application
Flight crew	VR	VRFS
		VRPT
		VRAIT
	AR	AR pilot guidance
		AR checklist
		AR-based ab initio pilot training
		AR digital twin
	MR	MR take-off module
Maintenance	VR	AMVR
	AR	AR aircraft unit detection
		AR checklist
		AMAR
	MR	AMMR
Cabin crew	VR	VR cabin crew safety training
	AR	AR emergency procedure training
Ground Operations	VR	VR ground operation training
Air Traffic Control	VR	VR eye-tracking assistance
	MR	Holographic MR System

Having this overview provides a baseline for both the industry and researchers to be aware of what has already been conducted and what requires more investigation. Our research offers a synopsis of the most prominent XR application per area, including a focus for future research. To date, VR is existent in every aviation domain and the most known application. Nevertheless, this technology still has room for improvement to fit better the industry's needs. Interestingly, MR is the least recorded application as it is the newest subset of XR. However, MR technology in training purposes have shown great potential [33], hence it is recommended to look further into this application.

Based on the literature review, future research should investigate the following areas to develop sustainable XR aviation training methods.

XR aviation training inclusiveness. According to the literature, most papers addressed XR training for flight crew and maintenance workers. Few studies were conducted on cabin crew, ground operations, and air traffic controllers. Future research should focus on including these groups as XR training may be beneficial. Regarding cabin services, XR technology can also be adopted to train employees in interaction with passengers and carry out security tasks on board on top of the existing emergency training applications. Ground operations XR training can be extended profoundly as passenger service agents and other airport staff (e.g., airport security) can also be trained. Passenger service agents learn theoretical procedures and the check-in, and boarding of flights demands technical skills while in the meantime dealing with passengers. These multitasking skills can also be learned via XR training before entering the industry.

Tailored XR aviation training. XR training has the advantage of being highly flexible, hence it can be personally tailored to the user's needs. Further research can hence take advantage of the technology's adaptability. It has been shown there are minor differences in training preferences among pilots [23, 25], this can also be applicable for other aviation areas. Therefore, focusing on gender-based preferences for XR training will make the concept more sustainable. Additionally, experienced and non-experienced personnel have different needs in XR environments [18]. Ensuring these criteria are more thoroughly examined and met, XR training will become more inclusive and learner-centric, resulting in sustainable training practices.

XR aviation training collaboration. With the emergence of the metaverse, XR training will become more socially interactive. In the synthesized literature, social interaction only occurred when users where unsure about how to use certain functions [34]. Nevertheless, collaboration with other aerospace personnel and experts in the field is beneficial for the industry. When a training is taken into the metaverse, users from over the world can interact, solve problems, share models, etc. to improve training and make it more realistic [33]. MR metaverse applications already exists in the maintenance field and has proven promising results. Further research can consider this concept and dive deeper into the functionalities for training practices in aerospace.

XR aviation training providers. Despite the fact the existing literature consists of empirical work, research addressing specific application designs is scarce and dispersed. Some studies developed theoretical models for possible applications. However these are not available yet, confirming XR training is still in its infancy. It is notable that the application designs from the analyzed literature consist of small research groups, whereas it would be more beneficial to collaborate with different teams to pursue improved XR aviation training models. Current commercial providers have a market advantage since there are not many players in the market, giving them market power and resources to develop applications [17]. Collaboration with such players and sharing knowledge in the research community will enhance the development of new XR training methods.

Future XR aviation training integration. Most studies confirm that XR aviation training should serve as a supplement instead of a replacement [16]. XR technology has the ability to enhance theoretical training and simulation experiences, resulting in promising learning outcomes [19]. Therefore, future research can focus on the effective integration of XR technology into traditional aviation training methods.

Implications for practice. Our suggestion stems that players in the aviation industry will have to invest in optimizing training methods by implementing XR training sessions, in areas where students need further assistance in, before entering the industy. Considering that XR can be personalized, it offers the possibility to fill in knowledge gaps and let the user experience certain scenarios. For instance, aviation students could first practice in the XR space with a virtual twin before performing actual tasks. If these students still feel the need to practice certain procedures, XR training will allow them to repeat these procedures. Hence, aviation players will benefit from adopting a mix between traditional methods complemented with XR training as it allows their personnel to become more experienced and skilled by offering tailored training sessions. Of course, there is no single prescription for the right mix or the right number of XR training sessions. The use will depend per focus area and other factors, such as personal learning, personal preferences, level of difficulty of the task etc. Therefore, aviation players should be prepared to be flexible once they utilize XR technology for training purposes. Additional resource management (for the available XR equipment) and flexible training schedules on an individual level have to be considered for an optimal outcome. Moreover, technology changes rapidly. Hence, aviation players should consider following up the trends in XR training. It is essential to be aware of the latest updates, to integrate potential new methods, and improve current methods for enhancing the training quality.

6 Conclusion

This literature review encapsulates and provides an overview of the latest cutting-edge XR applications applied in the aviation industry. Five major aviation areas were identified in which XR technology could improve training methods: flight crew, maintenance, cabin crew, ground operations, and air traffic control. In all areas, VR was predominantly suggested as XR technology, followed by AR. MR is the least explored technology in aviation training due to its novelty.

The application of XR technology in aviation training has several benefits. Especially for the aerospace industry, it is very effective that users can train in safe and control environments to gain enhanced experience. Nevertheless, the greatest challenge the technology is facing is its limited field of view, which is crucial for optimal training practices. Considering the current state of the technology, aviation players can implement XR training to complement their traditional training methods. Players in the aviation undustry can utilize XR technology to address gaps in traditional training settings and also use the technology first before personnel enters practical training sessions. This review has made suggestions for future research possibilities to ensure XR training will become more sustainable.

7 References

[1] Xi, N., et al., *The challenges of entering the metaverse: An experiment on the effect of extended reality on workload.* Information Systems Frontiers, 2022.
[2] Caudell, T.P. and D.W. Mizell. *Augmented reality: an application of heads-up display technology to manual manufacturing processes*. in *Proceedings of the Twenty-Fifth Hawaii International Conference on System Sciences*. 1992. IEEE.
[3] Hoffman, H. and D. Vu, *Virtual reality: teaching tool of the twenty-first century?* Academic Medicine, 1997. **72**(12): p. 1076-81.
[4] LLP, P.C., *2020 Augmented and Virtual Reality Survey Report: Industry insights into the future of immersive technology*. 2020, Perkins Coie LLP.
[5] Boeing. *Boeing: Commercial Pilot, Civil Pilot, Aviation Technician & Cabin Crew Demand Outlook*. Boeing 2022 2022.

[6] Gupta, S. *Extended Reality (Augmented Reality, Virtual Reality, Mixed Reality, and Hybrid Reality) | NASA SBIR & STTR Program Homepage*. NASA SBIR & STTR program 2022 01/04/2022.
[7] Kaplan, A.D., et al., *The Effects of Virtual Reality, Augmented Reality, and Mixed Reality as Training Enhancement Methods: A Meta-Analysis.* Human Factors: The Journal of the Human Factors and Ergonomics Society, 2021. **63**(4): p. 706-726.
[8] Dichev, C. and D. Dicheva, *Gamifying education: what is known, what is believed and what remains uncertain: a critical review.* International Journal of Educational Technology in Higher Education, 2017. **14**(1): p. 9.
[9] PaleBlue. *PaleBlue | Immersive Employee Training for the Enterprise*. PaleBlue.
[10] Wolfswinkel, J.F., E. Furtmueller, and C.P. Wilderom, *Using grounded theory as a method for rigorously reviewing literature.* European journal of information systems, 2013. **22**(1): p. 45-55.
[11] Milgram, P. and F. Kishino, *A Taxonomy of Mixed Reality Visual Displays.* IEICE TRANSACTIONS on Information and Systems, 1994. **Vol.E77-D**(No.12): p. pp.1321-1329.
[12] Palmas, F. and G. Klinker. *Defining Extended Reality Training: A Long-Term Definition for All Industries*. in *2020 IEEE 20th International Conference on Advanced Learning Technologies (ICALT)*. 2020. IEEE.
[13] Webster, J. and R.T. Watson, *Analyzing the past to prepare for the future: Writing a literature review.* Management Information Systems Quarterly, 2002. **26**(2): p. 3.
[14] Oates, B.J., M. Griffiths, and R. McLean, *Researching information systems and computing*. 2022: Sage.
[15] Brown, L., *The next generation classroom: Transforming aviation training with augmented reality.* 2017.
[16] Auer, S., et al. *Comparison Between Virtual Reality and Physical Flight Simulators for Cockpit Familiarization*. in *MuC '21: Mensch und Computer 2021*. 2021. ACM.
[17] Moesl, B., et al., *Towards a More Socially Sustainable Advanced Pilot Training by Integrating Wearable Augmented Reality Devices.* Sustainability, 2022. **14**(4): p. 2220.
[18] Weelden, E.v., et al. *Advancing the Adoption of Virtual Reality and Neurotechnology to Improve Flight Training*. in *2021 IEEE 2nd International Conference on Human-Machine Systems (ICHMS)*. 2021. IEEE.
[19] Cross, J.I., et al., *Using Extended Reality in Flight Simulators: A Literature Review.* IEEE Transactions on Visualization and Computer Graphics, 2022: p. 1-1.
[20] Dymora, P., et al., *The effects of Virtual Reality technology application in the aircraft pilot training process.* IOP Conference Series: Materials Science and Engineering, 2021. **1024**(1): p. 012099.
[21] Thomas, R.L., et al., *Usability of the Virtual Reality Aviation Trainer for Runway-Width Illusions.* Collegiate Aviation Review International, 2021. **39**(2).
[22] Brown, C., et al., *The Use of Augmented Reality and Virtual Reality in Ergonomic Applications for Education, Aviation, and Maintenance.* Ergonomics

in Design: The Quarterly of Human Factors Applications, 2021: p. 106480462110034.
[23] Schaffernak, H., et al., *Potential Augmented Reality Application Areas for Pilot Education: An Exploratory Study.* Education Sciences, 2020. **10**(4): p. 86.
[24] Borgen, K.B., T.D. Ropp, and W.T. Weldon, *Assessment of Augmented Reality Technology's Impact on Speed of Learning and Task Performance in Aeronautical Engineering Technology Education.* The International Journal of Aerospace Psychology, 2021. **31**(3): p. 219-229.
[25] Moesl, B., et al., *A Research Agenda for Implementing Augmented Reality in Ab Initio Pilot Training.* Aviation Psychology and Applied Human Factors, 2021. **11**(2): p. 118-126.
[26] Safi, M. and J. Chung, *Use of Augmented and Virtual Reality for Enhancement of Aerospace Cabin and Cockpit Experience*, in *XR Case Studies*, T. Jung and J. Dalton, Editors. 2021, Springer International Publishing: Cham. p. 43-50.
[27] Wu, W.-C. and V.-H. Vu, *Application of Virtual Reality Method in Aircraft Maintenance Service—Taking Dornier 228 as an Example.* Applied Sciences, 2022. **12**(14): p. 7283.
[28] Bailey, S.K.T., et al. *Using Virtual Reality for Training Maintenance Procedures*. in *Proceedings of the Interservice/Industry Training, Simulation, and Education Conference*. 2017.
[29] Neretin, E.S., P.A. Kolokolnikov, and S.Y. Mitrofanov, *Prospect for the application of augmented and virtual reality technologies in the design, production, operation of aircraft and training of aviation personnel.* Journal of Physics: Conference Series, 2021. **1958**(1): p. 012030.
[30] Pirmanov, I., et al., *HARDWARE-SOFTWARE COMPLEX OF INTERACTIVE TRAINING PROGRAMS ON AIRCRAFT REPAIR PROCESSES BASED ON 3D AND VR.* . Vol., 2022(4): p. 10.
[31] Torrence, B. and J. Dressel. *Critical Review of Extended Reality Applications in Aviation*. 2022. Springer International Publishing.
[32] Peng, C.-C., A.-C. Chang, and Y.-L. Chu. *Application of Augmented Reality for Aviation Equipment Inspection and Maintenance Training*. in *2022 8th International Conference on Applied System Innovation (ICASI)*. 2022. IEEE.
[33] Siyaev, A. and G.-S. Jo, *Towards Aircraft Maintenance Metaverse Using Speech Interactions with Virtual Objects in Mixed Reality.* Sensors, 2021. **21**(6): p. 2066.
[34] Gangabissoon, T., G. Bekaroo, and W. Moedeen. *Application of augmented reality in aviation: improving engagement of cabin crew during emergency procedures training*. in *ICONIC: 2020 International Conference on Intelligent and Innovative Computing Applications*. 2020. ACM.
[35] Zmigrodzka, M. and K. Kostur-Balcerzak. *Virtual Reality in Aviation Training*. in *Proceedings of 22nd International Scientific Conference Transport Means 2018*. 2018. Kaunas University of Technology.
[36] Crutchfield, J., et al. *Identification of Expert Tower Controller Visual Scanning Patterns in Support of the Development of Automated Training Tools*. 2022. Springer International Publishing.