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Metaverse in the Aviation Industry – A Challenge to be Addressed

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***Abstract*—The Metaverse represents a rapidly developing digital platform that opens up new possibilities for innovation across various industries.The aviation industry, as one of the most technologically demanding and regulated sectors, is beginning to take an active interest in the potential of using metaverse in areas such as personnel training and certification, optimizing flight operations, aircraft maintenance, and improving customer experience.This paper aims to identify key areas where the metaverse can bring added value to the aviation sector, provides an overview of the use of the metaverse in the aviation industry, discusses the technological prerequisites for its implementation, and the challenges associated with integrating these new solutions into the existing infrastructure and regulatory framework.**

Keywords—aviation, metaverse, digitalization, virtual reality, augmented reality

I. Introduction

The aviation industry is currently facing rapid technological advances that are fundamentally changing the way airlines, airports, and the entire air transport ecosystem operate. These changes are reflected not only in increased operational efficiency and safety, but also in an enhanced passenger experience and more efficient internal processes. The dynamic development of digital technologies and the emergence of the Metaverse concept are bringing new opportunities for optimizing and digitizing processes in aviation. Virtual and augmented environments enable airlines and airport operators to link real-world operations with digital simulations and interactive platforms. This allows companies in the aviation industry to increase the efficiency of their services, improve the customer experience, and optimize internal processes such as employee training, operations planning, aircraft maintenance, and customer communication.

Metaverse technologies, combined with artificial intelligence, virtual reality (VR), and augmented reality (AR), enable the creation of digital twins that simulate the real infrastructure of airports, aircraft, or logistics operations. These solutions contribute to reducing costs, streamline work processes, and increase the safety and reliability of operations, according to the Capgemini Research Institute in 2022 [1]. The Metaverse in aviation is thus ceasing to be just a marketing concept and becoming a practical tool for improving and streamlining business processes and innovation. This article provides an overview of the most important companies in the aviation industry that are making the best and most effective use of these technologies and identifies the most significant areas for process efficiency through the application of Metaverse technologies based on the materials obtained and personal interviews.

II. Overview of the Use of Metaverse in the Aviation Industry

Virtual Reality (VR) and Augmented Reality (AR) technologies began to gain popularity in the 1990s, primarily in the gaming and entertainment industries. One of the first companies to explore their potential in the aviation industry was Boeing. In the 1990s, Boeing began experimenting with AR to improve the manufacturing process, with technicians using AR glasses to assemble electrical cables in aircraft. A significant pioneer in the field of VR simulation and training was the Canadian company CAE Inc., founded in 1947, which specialises in the development of flight simulators. In the 2000s, CAE began integrating VR into its simulators, creating a more realistic and interactive training environment for pilots [2].

Airlines have begun to recognize the potential of Metaverse technologies to improve customer service and training. One of the first was Lufthansa's Lufthansa Aviation Training (LAT) division, which implemented VR simulators for pilot training. This initiative was motivated by the need to reduce the costs of traditional simulators and provide more flexible training options [3].

As reported by the International Journal of Aviation, Aeronautics, and Aerospace [4], key players in the early stages of the concept included Boeing, which is one of the most important companies that has contributed to the integration of metaverse technologies in the aviation industry. Their implementation of AR to streamline manufacturing and maintenance processes has brought significant improvements in accuracy and efficiency. Boeing has also announced plans to develop a "digital factory" in the metaverse, where engineers from around the world will design aircraft in a single shared 3D environment using XR tools and AI. This supports global collaboration without the need for physical presence [5].

Airbus has also played a key role in adopting metaverse technologies. Their "Smart Glasses" application uses AR to provide digital manuals and visualizations to technicians, reducing errors and increasing maintenance efficiency [6].

Lufthansa Aviation Training (LAT) has been a pioneer in integrating VR into pilot training. Their use of VR simulators allows pilots to train in a realistic environment without the need for a physical simulator, significantly reducing the costs and logistical challenges associated with traditional training methods (Table I) [4].

TABLE I. VR SIMULATION COMPONENTS FOR CREW TRAINING

Component	Usage
VR Headset	It provides an immersive visual and audio environment for realistic simulation.
Simulated pressure/smoke	Some advanced VR simulators use physical effects (e.g., smoke walls).
Scoring System	Training sessions are evaluated based on speed, accuracy, and consistency of responses.
Replay/Analysis	Training sessions can be replayed and analyzed to review decisions and procedures.

The Federal Aviation Administration (FAA) uses VR to train air traffic controllers, improving their reaction times and decision-making in challenging situations. This initiative contributes to increased flight safety and improved controller performance [7].

In aviation, blockchain can be used to secure data on an aircraft's technical history or maintenance records. Using NFTs (Non-Fungible Tokens), it is possible to uniquely identify aircraft parts (components) or verify a digital certificate of ownership. For example, GE Aviation is testing blockchain to track the history of aircraft components for maintenance purposes [8].

The development, implementation, and streamlining of Metaverse technologies in the aviation industry are supported by numerous expert studies and research. A significant study published in the Journal of Air Transport Management [6] examines the impact of VR simulators on pilot training and identifies key benefits such as improved emergency preparedness and reduced training costs. The idea of using the Metaverse in the aviation industry arose in response to the need to increase efficiency, safety, and service quality. Key players such as Boeing, Airbus, Lufthansa Aviation Training, and the FAA have played an important role in adopting and implementing these technologies to streamline processes through the Metaverse in aviation [9].

According to a study by Accenture, the metaverse in aviation also makes it possible to create digital twins of aircraft and airports, simulate flight situations, and build virtual workplaces for employees, leading to increased efficiency and safety [10]. Rolls-Royce uses digital twins of its engines, which track thousands of data points during flight and provide information on component wear, enabling predictive maintenance.

Fig. 1. Roll Royce UltraFan Jet Engine (Source: ROLLS-ROYCE. Digital Twin [online]. [cit. 2025-03-02]. Available at: https://www.rolls-royce.com/innovation/digital/digital-twin.aspx)

The picture above (Fig.1) shows the UltraFan engine, which is equipped with digital twin technology. Each fan blade has its own digital twin that stores data from real-world tests. This technology allows engineers to predict engine performance during operation and optimize maintenance [11].

TABLE II. AIRLINES AND THEIR USE OF METAVERSE TECHNOLOGIES IN AVIATION

Company	Technology	Metaverse Use	Year of Implementation
Emirates Group	Emirates Metaverse, NFT collection	Virtual check-in, board tour, NFT products	2022
Lufthansa Group	Innovation Runway, VR Training	VR staff training, AR for ground services	2022 – 2023
Qatar Airways	QVerse – Metahuman Cabin Crew	3D aircraft tour with an avatar in VR	2022
Singapore Airlines	Digital Twin Technology	Airport and maintenance simulations in digital twins	2023
Accenture	Metaverse Strategy for Travel	Consulting services, virtual customer experiences	since 2022
Microsoft	Microsoft Mesh Platform	Virtual workspaces, VR training	since 2021

Table II provide an overview of the Metaverse usage in aviation and the year of their implementation. Expert studies and research confirm the benefits of the Metaverse for the aviation industry and provide valuable insights for further development and innovation. In other words, based on the above information, we can say that Metaverse components are positively transforming the aviation industry, from training and maintenance to customer service and engineering. Their implementation leads to greater efficiency, safety and innovation in aircraft operation and development. Despite challenges such as cost, technology standardisation and data security, the Metaverse in aviation is opening the door to a new era of digital aviation.

III. KEY AREAS FOR PROCESS EFFICIENCY IMPROVEMENTS USING METAVERSE IN THE AVIATION INDUSTRY

This section focuses on an overview of key areas where Metaverse technology is most commonly used to streamline processes in the aerospace industry. From training and simulations to maintenance and technical support to design and customer service, Metaverse delivers innovative solutions that transform established practices and contribute to greater efficiency and safety across the industry.

A. *Crew and Employee Training*

Lufthansa Aviation Training (LAT) has developed a VR program for training cabin crew, which was the first of its kind to be approved by the German Aviation Authority. Since its introduction in 2019, approximately 20,000 flight attendants have completed the program. VR training enables realistic simulations that increase efficiency and reduce the costs associated with traditional training methods. Lufthansa Aviation Training (LAT) has achieved increased efficiency and cost savings in cabin crew training by implementing virtual reality (VR) based on several key factors:

- Reduced need for physical simulators
- Increased training capacity
- Increased training efficiency
- Reduced training costs[12]

B. *Technical maintenance and predictive diagnostics*

Lufthansa Technik has achieved significant improvements in technical maintenance and predictive diagnostics by implementing augmented reality (AR) and virtual reality (VR) technologies. These technologies have enabled more efficient training of mechanics, more accurate diagnostics, and faster repairs, leading to increased efficiency and reduced costs. Since 2021, Lufthansa Technik has been testing various XR technologies for maintenance, training, and marketing applications. The use of AR allows mechanics to obtain an "X-ray" view of engine components, improving the accuracy and speed of repairs. VR is used to train mechanics in areas such as engine component identification and endoscopic inspections, e.g.:

- XR training in MRO (maintenance, repair, overhaul),
- XR (augmented reality, virtual reality, mixed reality) demonstration applications designed for training mechanics in the field of MRO in cooperation with Lufthansa, Technical Training: AR training in cockpit procedures (Cockpit Procedure Training), VR training in the localization and identification of engine components and VR training in engine endoscopy — visualization of all engine surfaces in a 360-degree view.

C. *Customer support and onboarding*

In this area of process improvement, Emirates is again a good example, having developed a virtual reality (VR) platform called MIRA (Mixed Reality Training) for training cabin crew. This platform allows crew members to interact with a virtual environment and improve their skills in realistic scenarios (Fig. 2). MIRA offers self-guided, multi-user training modules that allow staff to virtually practice operations such as door handling and firefighting in realistic cabin environments.

Key features of the MIRA platform:

- Realistic simulations: MIRA provides a highly realistic audio-visual environment that allows the crew to practice various scenarios, such as door handling, firefighting, and cabin evacuation.
- Multi-user training modules: The platform supports simultaneous training of multiple crew members who interact via avatars in a shared virtual space.
- Self-paced training: Crew members can complete training at their own pace, which increases flexibility and contributes to more effective learning. Emirates plans to train approximately 23,000 cabin crew members using the MIRA platform, including training for the Airbus A380, Boeing 777, and Airbus A350 aircraft. The implementation of VR training enables faster and more efficient crew training, leading to better preparedness for emergency situations and reducing the need for physical simulators. MIRA enables crew training without the need for physical presence at a training center, reducing logistics costs and enabling remote training.

Fig. 2. Simulation of Emirates crew training using avatars in virtual space (Source: EMIRATES. Emirates cabin crew to step into the virtual world for safety training [online]. [cit. 2025-01-16]. Available at: https://www.emirates.com/media-centre/emirates-cabin-crew-to-step-into-the-virtual-world-for-safety-training/)

D. *Logistics and supply chain management*

Boeing has implemented digital twin technology to optimize its manufacturing processes and supply chains. This technology enables the creation of virtual models of aircraft and production lines, leading to more efficient planning, reduced costs, and improved quality.

One example is the use of digital twins in the T-7A Red Hawk program, where Boeing achieved an 80% reduction in assembly time through model engineering and 3D design. Similarly, in the production of the MQ-25 aircraft, engineers use digital models to verify compliance with technical specifications, which increases the accuracy and quality of production [13].

In the area of supply chains, Boeing uses digital twins to simulate and optimize logistics processes, enabling better prediction of problems and more efficient inventory management. This technology provides a comprehensive view of the entire chain, increasing transparency and enabling faster decision-making [14].

E. *Flight simulation and cabin design*

Singapore Airlines (SIA) has implemented virtual reality (VR) technology as part of its KrisLab digital innovation lab to improve aircraft cabin design and customer experience. This initiative allows designers to test and modify cabin concepts more efficiently, leading to an optimized design process and improved passenger comfort. Opened in 2019, KrisLab serves as a collaborative space for SIA employees to develop innovative ideas and collaborate with external partners. One of the main projects is the use of VR technology, which allows designers to virtually enter the aircraft interior and interactively change design elements in real time. This approach simplifies the design process and allows potential problems to be identified and resolved more quickly.

The benefits of implementing Metaverse virtual technologies are mainly reflected in:

- *Increased training efficiency:* Mechanics can train in a realistic virtual environment, which increases their preparedness for real-life situations.
- *Reduced training costs:* VR training reduces the need for physical models and equipment, thereby reducing the costs associated with traditional training methods.
- *Improved repair accuracy:* AR technologies provide mechanics with accurate visual instructions, reducing the risk of errors during repairs.
- *Faster repairs:* The use of AR and VR technologies reduces the time needed for diagnosis and repair, resulting in faster return of aircraft to service.
- *Accelerated design process*: The implementation of VR has enabled designers to test and modify designs more quickly, resulting in a reduction in the time needed to develop new designs.
- *Improved customer experience:* The ability to simulate and evaluate from the passengers' perspective before physical implementation allows for the optimization of interior comfort and functionality, contributing to higher customer satisfaction.
- *More effective collaboration:* Support for collaboration between employees and external partners, including startups and research institutions, leading to faster development and implementation of innovations.

IV. Quantifying the Benefits of Metaverse in the Aviation Industry

The introduction of Metaverse technologies into the aviation industry brings significant changes in the way processes are managed, quality is improved, and costs are optimized. The following section focuses on a quantitative assessment of the impact of these technologies in key areas of airline operations. The data obtained presents the specific benefits that have been achieved through the implementation of virtual and augmented reality, digital twins, and other Metaverse tools.

By comparing indicators such as cost savings, time reduction, and quality improvement, it is possible to better understand the processes in which these innovations have the greatest effect. Visualizing these results in the form of a graph provides a clear overview of how the Metaverse can contribute to streamlining aviation operations and achieving greater customer satisfaction and more efficient operations based on the information obtained (Fig. 3).

The highest efficiency in terms of cost reduction (40%) and time reduction (55%) was achieved through crew and employee training, with the quality of training also increasing to 90%. Technical maintenance and diagnostics saw 25% cost savings and 30% time efficiency, with work quality increasing to 85%. In the area of customer support and onboarding, costs were reduced by 15%, processes were accelerated by 25%, and the customer experience was improved by 80%. Logistics and supply chain management delivered 20% cost savings and the same time efficiency, while process quality increased by 75%. Flight simulation and planning enabled a 30% reduction in costs, a 35% reduction in time, and an 85% increase in design quality. These results demonstrate the significant potential of the Metaverse in optimizing operational, training, and customer processes in the aviation industry.

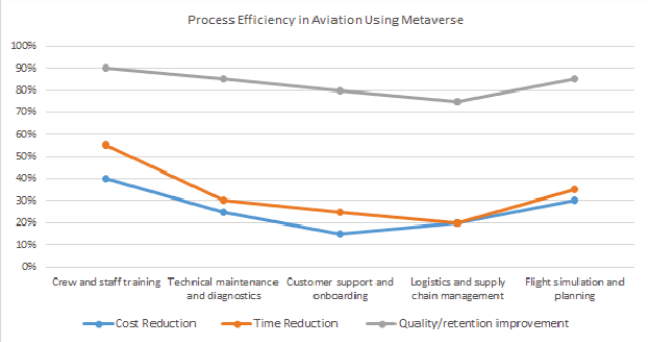

Fig. 3. Process Efficiency in Aviation Using Metaverse (Source: Grami, L. Metaverse v leteckom priemysle. 2025. Košice)

The graph clearly demonstrates that Metaverse has the greatest effect in terms of improving quality and sustainability in crew training (90%) and flight planning and simulation (85%). The most significant time savings (55%) and cost savings (40%) were achieved in staff training, confirming that education is the most quickly monetizable part of Metaverse implementation in aviation. Areas such as technical maintenance and logistics management achieved very solid results, particularly in reducing errors and speeding up work, which has a long-term positive impact on the safety and reliability of airline operations. These results support the recommendation that airlines should start with training, maintenance, and customer experience for successful Metaverse implementation.

V. Challenges and Limitations in the Use of the Metaverse in the Aviation Industry

The implementation of Metaverse technologies in the aviation industry represents a revolutionary step in the digitization of processes, training, maintenance, flight planning, and customer support. As practical examples from companies such as Lufthansa Group, Emirates Airlines, Boeing, and Singapore Airlines show, the use of virtual and augmented reality, digital twins, and artificial intelligence brings demonstrable benefits in the form of reduced costs, shorter process times, and improved service quality. Despite these benefits, airlines face a number of specific challenges and limitations when applying Metaverse technologies, which can complicate, slow down, or increase the cost of the implementation process.

One of the most significant obstacles to the deployment of Metaverse technologies in the aviation sector is the high initial investment costs. Given the complexity of these solutions – from the development of software platforms, through the purchase of specialised hardware, to staff training – this is an extremely capital-intensive process. Deploying Metaverse requires not only investment in computing technology and infrastructure (e.g. 5G, data servers, VR/AR devices), but also a long-term digital transformation strategy. For smaller airlines and regional airports, the introduction of Metaverse technologies poses a significant challenge, particularly from a financial and technological perspective. Implementing Metaverse solutions on a smaller scale may not

bring the same return on investment as it does for large companies. Another negative factor may be the technological unpreparedness of infrastructure, which requires additional modernization costs. Another barrier is the lack of qualified personnel to manage these systems and the risk that the investment will not bring the expected results due to a limited customer base [15].

The deployment of Metaverse technologies in aviation is closely linked to the level of technical sophistication of the infrastructure, which must ensure stable and high-capacity real-time data processing. A key prerequisite for the smooth functioning of virtual and augmented environments is the availability of high-speed connectivity (e.g., 5G), robust server capacities, and specialized hardware such as VR and AR devices. Airlines and airports are therefore facing the need for a major upgrade of their IT systems, including the renewal of data centers, the strengthening of network infrastructure, and the expansion of digital service support. Effective use of the Metaverse in aviation therefore requires not only investment in cutting-edge hardware, but also a strategic approach to building a sustainable and secure technological infrastructure [15].

In addition to innovative opportunities in customer service and process efficiency, Metaverse technologies place high demands on secure data processing. Virtual and augmented realities, digital twins, and blockchain solutions generate vast amounts of sensitive information, from passenger personal data, booking details, and payment transactions to loyalty program data. Every interaction in the digital environment is therefore a potential target for cyber threats. One of the biggest risks is the possibility of unauthorized access or data leaks, which can lead to a loss of customer trust and significant damage to the reputation of airlines. In this context, privacy protection and data security play a key role. Given the growing risks associated with digital technologies, it is clear that ensuring data integrity and protecting privacy will be one of the most important areas of development in the deployment of the Metaverse in aviation. It is therefore essential for companies that want to remain competitive and maintain customer trust to address these challenges proactively and strategically.

The implementation of the Metaverse in the aviation industry brings with it a fundamental transformation not only of technological systems, but also of the working environment and the way employees perform their tasks. One of the main obstacles airlines face is the low level of acceptance of new technologies among employees, especially those with many years of experience with traditional practices. Resistance to change may stem from a fear of losing certainty in established processes, concerns about technological complexity, and a lack of confidence in the effectiveness of new solutions. Another problem is insufficient digital literacy, which makes it difficult to adapt quickly to new systems. For many employees, especially those in operational positions, working with VR or AR technologies is completely new, requiring extensive and often costly training. Complex user interfaces can lead to frustration and reduced motivation to complete training, thereby reducing the effectiveness of Metaverse implementation.

Except technological and organizational challenges, the deployment of VR and AR technologies in the aviation industry have to face complex legal and regulatory frameworks that companies must strictly adhere to. Given the high safety standards in aviation, any use of new technologies is subject to thorough certification and approval processes by the relevant regulatory authorities. One of the biggest challenges is the need for new VR training, simulation systems, and digital tools to meet official aviation standards and be recognized as equivalent to traditional methodologies.

Another aspect is international regulation, as the aviation industry is regulated by global standards set by organizations such as ICAO (International Civil Aviation Organization) or EASA (European Aviation Safety Agency). Any technological innovation that affects flight safety, crew training, or aircraft maintenance must comply with international regulations. This significantly increases the time required to implement new solutions and raises the costs associated with certification processes. For airlines and aircraft manufacturers, this means that, in addition to technical readiness, they must also invest in legal advice, safety audits, and regulatory cooperation to ensure that their digital transformations are fully compliant with applicable legislation. These legal and regulatory requirements can act as a brake on innovation, but at the same time they are an essential tool for protecting safety and confidence in the global aviation system.

VI. Conclusion

The main objective of this study was to highlight the potential of using Metaverse technology in aviation to increase the efficiency of several processes in air transport. The findings confirm that its application can streamline staff training and education, support aircraft maintenance, and improve planning and simulations, ultimately contributing to greater safety and productivity. At the same time, it has been shown that the successful adaptation of these technologies requires appropriate organizational approaches and the gradual development of digital skills within airlines.

Despite optimistic results and practical examples, there are also significant obstacles that could slow down the wider introduction of the metaverse in aviation. One of these is the high initial investment in hardware, such as professional VR headsets and content creation, which not all entities can afford to the same extent. Furthermore, there is a lack of uniform standards and methodologies – from technical platforms to safety and training standards. Regulatory authorities are proceeding cautiously and are only gradually approving the use of VR, for example in pilot training, which means that flight schools and airlines must combine new procedures with traditional ones for the time being. Another challenge is the adaptation of staff to the new working environment, where it is necessary to provide training for employees and address potential problems such as fatigue or nausea during prolonged use of VR. At the same time, if the Metaverse were to offer a full-fledged alternative to some forms of business travel in the future, such as virtual conferences, this could also mean a certain decline in demand for traditional flying for the aviation industry, according to IATA. Last but not least, attention must be paid to cybersecurity and the protection of sensitive data within virtual worlds. The integration of real flight operations with Metaverse platforms will require robust security against attacks and data leaks.

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