Safety & Defense 11(2) (2025)
DOI https://doi.org/10.37105/sd.274

Transforming Aviation Education through the Integration of Digital Technologies: Artificial Intelligence (AI) and Virtual Reality (VR)

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Received: 17 October 2025 | Revised: 11 November 2025
Accepted: 11 November 2025 | Available online: 30 December 2025

Abstract

This article explores the transformation of aviation education through the integration of digital technologies, particularly Virtual Reality (VR) and Artificial Intelligence (AI). Traditional teaching methods, such as lectures and classroom exercises, are increasingly complemented by interactive and remote learning tools. The COVID-19 pandemic accelerated this shift, highlighting the need for inclusive and flexible teaching models. E-learning, game-based learning, and flipped classroom approaches allow for individualized learning, immediate feedback, and greater accessibility. AI systems enhance learning by adapting content to user performance and providing detailed analytics, though concerns about data privacy remain. VR technology enables realistic simulations of aircraft maintenance environments, providing students with hands-on experience in a safe environment. This article presents a case study of a virtual hangar developed for PART-147 technical training, using Unity and Oculus VR. Key components like engines and hydraulic presses were modeled in 3D, allowing students to interact with equipment and complete tasks. The system supports repeated practice and scenario-based learning, improving engagement and skill acquisition. Challenges include the need for powerful hardware, time-intensive development, and ensuring educational value over entertainment. The project demonstrates the potential of immersive technologies to enhance aviation training and recommends further integration with curricula and collaboration with industry partners to prepare students for real-world technical roles.

Keywords: artificial intelligence, aviation training, safety in aviation training, virtual reality

1. Introduction

Modern aviation education is based on hands-on training, both in real conditions and in a simulated environment. On the other hand, teaching theoretical content is still often based on the traditional form, i.e., lectures or exercises in lecture halls. However, the COVID-19 pandemic has caused unprecedented disruption to higher education, accelerating the transition from traditional

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to digital learning (Purushottam, 2025). Various systems are being developed to support the education of aircraft mechanics. One such system is SkyMaintain. A paper written by another author (Onilede, 2024) presents a solution that uses artificial intelligence to predict faults in aircraft systems and support technicians in performing maintenance in accordance with regulations. By analyzing historical data and current operating parameters, the system significantly increases the efficiency of technical service, shortens repair time and improves operational safety. An article by (Moghadasniana, 2024) presents the impact of artificial intelligence on the modernization of aircraft maintenance processes. The use of AI has been shown to significantly improve predictive maintenance efficiency, operational safety and sustainability, while also pointing to the need for further research and standardization in this area. Current technologies allow for the construction of integrated condition monitoring systems that use artificial intelligence, blockchain technology, and advanced data analytics (Kabashkin, 2024). More importantly, such models enable the detection of both visible and hidden faults, supporting the transition from a reactive to a predictive and prescriptive approach in aircraft technical health management. Due to the increasing number of such systems in industry, it is necessary that such technologies be considered in aviation education. In other papers (Dela Peña, 2025), he provides an overview of the applications of virtual reality (VR) and augmented reality (AR) technologies in aircraft maintenance training and operations, demonstrating their effectiveness in reducing training time by 30–50% and reducing procedural errors by 20–45%. This shows how important it is to implement new methods and technologies at every stage of flight training. However, in this article, the author also states that despite high user satisfaction, the implementation of these technologies faces challenges related to cost, equipment ergonomics and the lack of certification regulations.

Virtually all educational institutions that are related to flight training have implemented distance learning methods and increased the number of classes on simulators. Such education is more adaptable by combining digital innovation with inclusive pedagogical strategies. However, it should be noted that the implementation of new teaching systems not only requires a different approach from students but also requires different preparation from teachers themselves. Another article (Ziakkasa, 2023) presents one of the concepts for implementing AI in aviation education at the academic level, based on an approach from simple to complex issues. The article presents a model and research on integrating AI into pilot training programs, considering aspects of human systems engineering, professional competencies, and the needs of the aviation industry in the context of modern technologies and global training standards, demonstrating its usefulness and complexity in equal measure. Another example of the application of new technologies in teaching is presented in an article (Jevčáka, 2024), which analyzes the use of immersive technologies such as virtual reality (VR), augmented reality (AR) and mixed (MR) in aviation education at the university level, highlighting their potential in increasing teaching effectiveness, student engagement and training safety. The authors of this article also point to the challenges of cost, technical and health requirements, as well as highlighting the growing role of artificial intelligence in the personalization and optimization of educational processes.

In emerging modern systems, we have three levels that are constantly changing. One aspect is hardware combined with software, where creators are required to reproduce real-world conditions with greater fidelity, as well as to individualize training. On the other hand, it is necessary to educate teachers and develop appropriate IT tools. Additionally, the entire system must be properly adapted to the students' requirements and needs. Each of these elements requires a separate understanding and approach, and not forgetting the most important fact: a change in one requires verification in the other two. However, it should be noted that research by Mittelstaedt (2024) conducted in a realistic aircraft cabin simulator shows that short-term use of VR glasses can sometimes cause severe symptoms of cybersickness, and symptoms such as nausea and dizziness intensify during turbulence, especially with dynamic visual content. The aim of this article is to present the process of developing a computer model of a selected aircraft maintenance station in VR technology.

2. Modern teaching methods

Current teaching is mostly carried out through a combination of traditional methods, i.e., lectures, exercises, projects, or seminars, enriched with information technologies. It can include presentations of films, slides, and animations, as well as work on simulators, desktops, or touchscreens. It is a group of interactive methods in which the teacher takes an active part in the learning process. Such methods include e-learning, game-based learning, problem-based learning, and the flipped classroom model. With these methods, it is possible to individualize the learning process, select the right dates for the learner, and provide support at any time, e.g., by answering the most frequently asked questions. E-learning methods rely on remote teaching via educational platforms. Teachers send previously developed educational materials so that each student has access to them and can become acquainted with them. Modern platforms allow not only the content itself, but also the preparation of quizzes, projects or tasks to be solved. Constantly updated systems make it possible not only to provide a yes-or-no answer, but also, in the event of failure, to indicate which element is incorrect, e.g., during mathematical calculations. This type of teaching can be used mainly during the transfer of knowledge. The thematic scope can be presented across a wider range, supported by appropriate examples, in both multimedia

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and written forms, and the student could take a test to verify the degree of knowledge acquisition. An important factor here is the opportunity to revise the content that the person had problems with at a later time. However, such methods are not very useful in practical teaching, where students are required to acquire competence, e.g., in the use of digital meters. Another approach is to use game-based models. In such an arrangement, students earn points (badges) as they complete tasks, and there is an element of competition with other participants in the group. The task format is also adjusted accordingly, e.g., to meet a certain number of tasks per day or to achieve the required number of points. Such methods work well for teaching foreign languages and regularity, and students acquire social competences in the spirit of healthy competition. However, such an approach will not work when imparting knowledge, because students may often focus on earning points (badges) rather than acquiring knowledge. In addition, in this approach, there is an excess of stimuli, such as graphics or sound effects, which is not conducive to the acquisition of theoretical concepts.

A different approach from the other two methods is the inverted class model. It consists in providing the content that the student is to get acquainted with and the effects that are expected after the end of the class. On the one hand, such a form seems to be a new approach at the secondary school level, but in academic teaching, in the case of laboratories, it has long been necessary to familiarize yourself with the material in advance, because without it, it was impossible to complete the intended tasks. However, modern technology not only enables theoretical knowledge but also practical preparation for classes through interactive elements, such as using a phone as a control panel for an aircraft air-conditioning system simulator. All the methods presented have a few common features, which include:

- individualization of classes,
- getting quick answers to basic questions, without the need to involve a teacher,
- the possibility to adjust the place and time of classes,
- the ability to complete tasks multiple times and return only to parts that are incomprehensible to the listener.

3. Teaching support tools

Progress in the field of computerization is taking place on an ongoing basis. New technologies are released every year, and software updates are performed on average every quarter. Therefore, technologies that until recently seemed unattainable to use due to costs and difficult accessibility are now possible to implement. Such methods may include learning using artificial intelligence (AI) and VR technology. In the case of methods based on artificial intelligence, they support the repeated learning of content with which the user has problems, but in this case the mechanism recognizes the given user and suggests areas for improvement, as well as changing how information or tasks are presented so that they are more accessible. In such systems, users not only receive feedback in the form of an evaluation but also detailed information about the areas in which they performed best and the topics with which they had problems. Constantly improving technology already allows such an analysis to be carried out not only on the final test results but also on the time or number of additional classes in a given department. What is more important, many of these procedures take place without the need for user intervention, e.g., when the system detects an increased number of occurrences or errors at a given stage, adjusts the number of practical tasks, or presents the content in more detail. Another element is also information for the user about the need for breaks in teaching, but not only on the basis of time itself, but also based on the results / number of errors obtained, or in newer systems also based on the number of blinks of the eye (suggesting fatigue), an increase in heart rate or a decrease in blood oxygen coefficient. Within such systems, it is also possible to automatically assess whether the environment during task implementation is appropriate. This can be done on a visual basis, but also on an audio basis. In addition, the systems, learning together with the user, make it possible to make changes in the subsequent stages of learning, paying attention from the beginning to the elements with which there were previously problems.

However, it should be remembered that, in addition to the positive elements resulting from the use of AI-assisted learning systems, there are also negative aspects. These systems, especially in the initial phase, are unreliable. They need time to start functioning properly. In addition, from the user's perspective, these systems collect accurate data on the time and location of logins, the time spent learning, and the grades (percentage points) obtained from the relevant departments. This creates significant mistrust among users, who fear that this data will be used against them, which can lead to the end of flight training or a delay in it. An example of this is the use of priority when planning training flights or simulator exercises. It should be remembered that data from such a system is not made public, and users themselves may not be aware of its importance.

A separate technical department that is increasingly supporting teaching, especially for aviation personnel, is VR (Virtual Reality) technology. This technology allows for accurate reproduction of reality anywhere, if you have the right device (glasses) and software. Currently, the hardware itself is easily accessible. It has the appropriate parameters to reproduce the real image and sound. Still, the problem lies with the software, specifically the proper preparation of the virtual workspace. This factor significantly limits the use of this technology, but it is also where the greatest potential for improvement lies. The problems arise not

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in the image reproduction itself, but in the development of interactive technologies, the adaptation of joysticks and buttons and their meaning. However, when this is achieved, the user can "experience" in a specific role, seeing and hearing the same as in normal environmental conditions. Faithful reproduction allows users to familiarize themselves with the work environment before physically completing tasks. Students who carry out the internship have contact with this technology right at the beginning of the internship, i.e., during OHS training, where they can easily familiarize themselves with the hazards and risks at the workplace, in safe conditions. It is worth noting that they are not just passive observers, but implement scenarios that include, for example, approaching a first aid kit or a collection point and finding emergency buttons. It should also be kept in mind that the obstacle in this technology itself can be human. Users must be familiar with the operation, as well as have appropriate health parameters, e.g., no significant vision defects, no neurological disorders, which is unheard of in the case of people training to become pilots. However, in the case of people studying to be ground handlers or aircraft mechanics, it can cause difficulties.

The support tools described can occur together, be complementary, or occur separately. It should be remembered that the more advanced the system, the more powerful the computer hardware required to operate it. Therefore, when considering the ability of systems to support VR technology and artificial intelligence modules simultaneously, it is necessary to anticipate the need for substantial IT equipment resources. This, in turn, not only generates additional costs but also requires additional time for maintenance work, such as cleaning VR glasses or installing software updates.

4. Development of a Virtual Workstation Model

To streamline the learning process during exercises for students studying at the PART-147 Technical Mechanics Training Center, an initial virtual image of the hangar was developed. Visualization of the hangar is of great importance because the training program requires performing appropriate activities during aircraft operation. When training more than 50 people, the most significant limitation is access to infrastructure and instructors. Therefore, if it were possible to create a virtual model that reproduces the work in the hangar, it would at least partially familiarize students with the activities performed earlier. On the other hand, the lack of availability of equipment and instructors makes it impossible to repeat exercises, e.g., those with which the student had problems, and the use of Virtual Reality technology would solve this problem.

During model development, it was assumed that the reproduction would include the hangar in Gliwice where AT-3 training aircraft are serviced. The key elements of the station include tool trolleys, storage racks, an electric compressor, a worktop, a hydraulic press, waste containers, workshop lamps on tripods, aircraft components, and workshop supports. Figure 1 shows a general view of the hangar and the individual elements that have undergone the virtualization process. The entire project was carried out on the Unity engine for Google Oculus 2. In addition, it was necessary to use the Open XR add-on to communicate with the virtual reality platform and the high-level XR Interaction Toolkit. In the initial phase, it was necessary to properly configure the height of the camera as well as the controllers responsible for the motor skills of the left and right hands. Example configuration screens are shown in Figure 1.

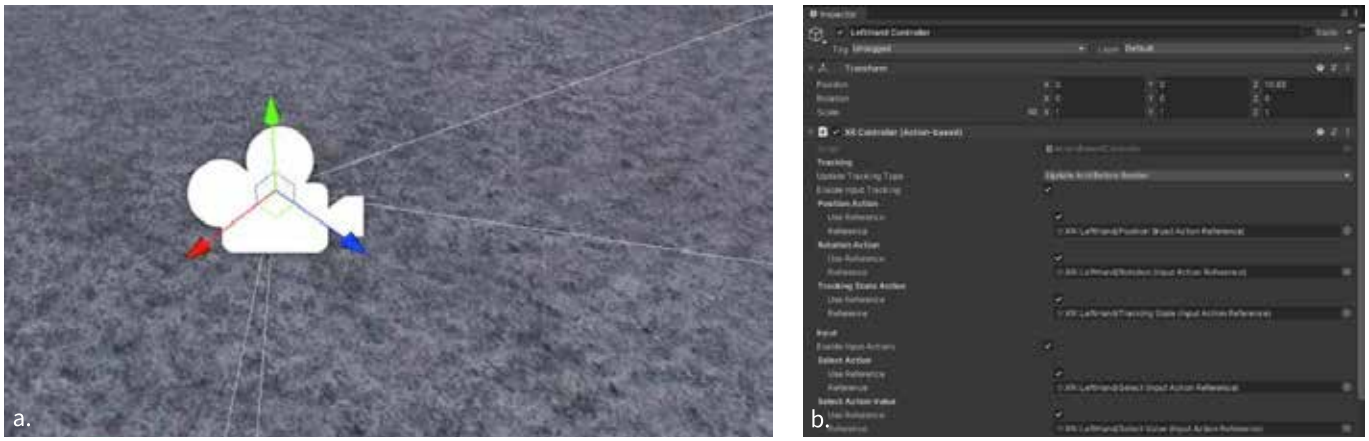

Figure 1. Examples of configuration screens: a. camera, b. controller. Source: the authors' own work.

In this step, it was also necessary to set the character's movement system. The system of "teleporting" to the indicated location was abandoned, as it does not reflect the visualization's realism, which is why the Continuous Move Provider and Continuous Turn Provider scripts were introduced. These scripts allow you to move smoothly in the horizontal plane and rotate around your own axis.

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The whole thing has been configured so that the Joysticks located under the thumbs of both controllers are responsible for movements. In the right hand, it is possible to rotate around its own axis, while in the left hand, it is possible to move on a horizontal plane. The project was educational, so it was assumed that, before using this system, a short training session would be conducted to demonstrate the rules of movement or to perform activities. The initial training screen that the student can complete before the start of the actual tasks is shown in Figure 2.

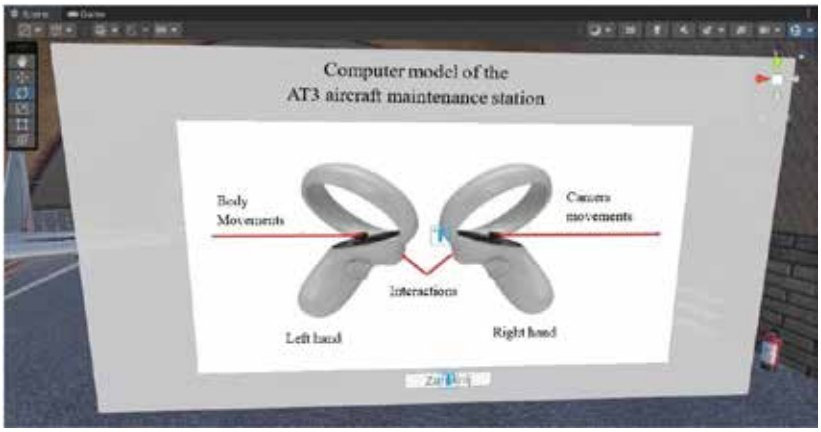

Figure 2. Controller Principal Screen. Source: the authors' own work.

In the next step, the hangar was mapped in a virtual reality system. The whole project was introductory, so they did not aim to reproduce the rooms' appearance or colors as accurately as possible, but instead focused on interactive elements and a general scheme of movement around the facility. Figure 3 on the left shows the jack on which the engine is installed in hangar conditions, while Figure 3 on the right shows an example of an information panel that opens in front of the user when getting acquainted with the parameters of the Rotax engine.

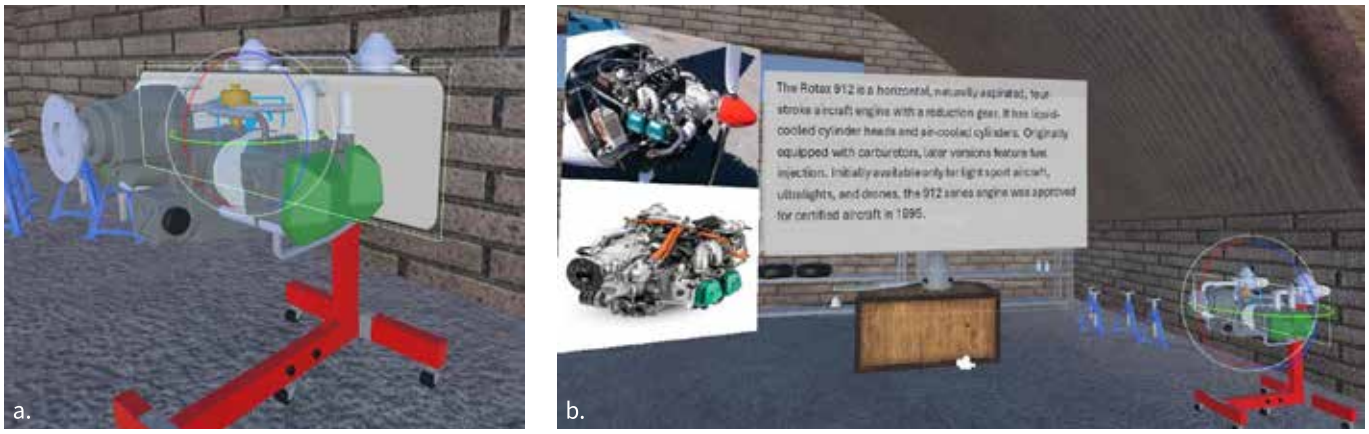

Figure 3. View from VR goggles for aircraft engine maintenance station. Source: the authors' own work.

At this stage of the project, the user can move around the hangar and obtain information about individual elements. The engine shown in the picture includes not only text and photos but also the ability to play an animation that shows its structure. The same applies to the other components that have been implemented in the system. At this point, however, it should be noted that the general construction of the hangar and the rough mapping of individual elements is the easiest task. The most time-consuming and difficult aspect is accurately reproducing parts with complex shapes, followed by making a stop-motion animation at the beginning. Figure 4 shows the hydraulic press as an object in a virtual system. It shows how many individual parts need to be reproduced to achieve a realistic look. In addition, such an object must be mapped in a 3D view so that it can be properly positioned relative to the walls and accurately reflect the object's perspective and size. In materials commonly available on the Internet, there are ready-made 3D models, but due to the specific nature of aviation, only a small number can be implemented directly in this system.

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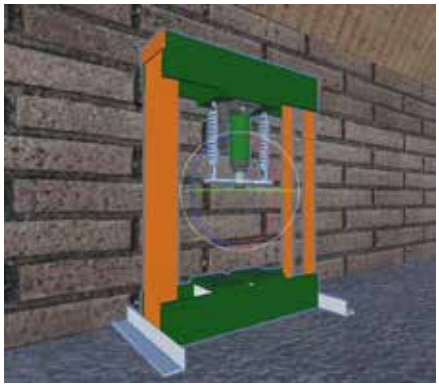

Figure 4. View of the hydraulic press illustrated in 3D technology. Source: the authors' own work.

The project was completed at the stage where the hangar room was remapped and the main elements were placed. Separate 3D models were created for selected parts, such as the engine, hydraulic press, or racks containing hazardous materials. Further, it is planned to increase the number of 3D models, improve the visualization of the hangar's appearance, and add more interactive elements. In addition, work will be carried out in the direction of interactivity of the entire system, i.e. execution of commands displayed at given workstations, as well as the introduction of a specific type of game, in which students will be obliged to move around in the hangar, find tasks, and indicate elements set in violation of the regulations.

In the future, the entire development of the system is to complement the training for aircraft mechanics, which also means the need to adapt to the training programs. The system is intended to be useful for learning and expanding knowledge, so the introduction of multimedia elements or games must be carefully considered to avoid the effect of pure fun (a game). Another problem is to guarantee adequate space to perform tasks. Approximately 4 m² is needed for each workstation so the user can use the system without any problems. This means that six workstations can be installed in laboratory rooms, with a total area of 45 m² on average, after accounting for the proximity of walls and ensuring user safety (e.g., so they do not bump into each other). This number also seems optimal, even with one teacher, because with a larger number of employees, it might not be possible to instruct students, and the time spent on breaks during task implementation would increase excessively.

5. Conclusions

The implementation of a virtual environment representing an aircraft maintenance hangar for the training of aircraft mechanics has generated increased interest not only among instructors, but most importantly among students, indicating a clear need for further development and continuation of the project. The presented preliminary version, although still in the testing phase, is fully functional and enables users to become familiar with this technology. More importantly, creating the entire environment from the beginning and within the center allows for the free introduction of changes and improvements. However, here too, there is a drawback: the high cost of time required for implementing this project. One anticipated element is the purchase of individual 3D models prepared by external units. Another way to improve the creation of a virtual environment is to use 3D scanners, which will allow for faithful reproduction of the selected part. More importantly, this technology will allow scanning not only small objects, but also the entire hangar.

During implementation, Google VR, Oculus 2, and computer hardware were used, along with the software described in the article. The whole set was estimated at EUR 3,000, which is not an exorbitant cost considering that many people can use this position. An important element is that the same system can be applied to several positions, thereby increasing the number of people who can participate in training at a time. Another element was the ability to analyze the time spent on individual tasks by specific users. Even with such a simple system, you could see the differences. People who had not had contact with this type of system so far immediately became apparent, as they fully used the introductory system, and the initial movement and equipment-finding elements were longer than for people who skipped initial training, i.e., de facto had already had contact with this type of system. In addition, users had the opportunity to devote as much time as they wanted to the elements of the equipment they chose. Here, too, the differences became apparent: some people spent more time on the aircraft engine components, while others spent more time on the hydraulic press. This information shows the potential of this type of system and the need for expansion. In a broader context, such systems not only enhance teaching effectiveness but also prepare students for real professional challenges. An important recommendation is to integrate the VR system into training programs and to collaborate with educational institutions or aviation industry companies.

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DOI https://doi.org/10.37105/sd.274

Declaration of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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