Developing a Scalable, AI-Enhanced VR Platform for Aviation Training: Commercial Aircraft Case Studies

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ABSTRACT

The need for resilient and adaptable training solutions in the aviation industry requires innovation beyond traditional methods. Virtual Reality (VR) provides immersive simulation, while Artificial Intelligence (AI) enables greater personalization and interaction. This paper presents the development of an evolving self-designed VR platform for aviation training, outlining a scalable design process and its progression from baseline applications to AI-augmented functionality using commercial aircraft (Airbus A320) case studies. The proposed method establishes the principles for the development of the core VR platform to ensure scalability, applicability, and efficiency across related projects. Progressive development is illustrated through case studies ranging from VR-based landing-gear maintenance to VR/AI-integrated aircraft walkaround procedures. Early feedback indicates positive perceptions of the platform among trainees, even within short pilot interventions. The combination of VR environments and AI-powered extensions, supported by an extensible architecture, offers a promising path toward more customized, effective, and intelligent training, with the potential for operational efficiency for aviation stakeholders.

Keywords-Virtual Reality (VR); Artificial Intelligence (AI); scalable architecture; aviation training; commercial aircraft

I. INTRODUCTION

The airline industry operates in an environment where safety, reliability, accuracy, and efficiency are paramount. As a result, high-quality and efficient training solutions for staff, especially in maintenance and operational processes, are of crucial importance. Human factors remain a key aspect of aviation safety, as maintenance errors can cause severe financial loss and, more seriously, threaten safety [1]. Standard training methods, with typical classroom set-up and accompanying tools such as 2D drawings/schemas, or more recently supplemented by video demonstration, generally have limited capacity to provide adequately immersive, interactive, and engaging learning experiences, especially for complex procedural activities such as aircraft maintenance or walk-around inspections that play a central role in pre-flight airworthiness assurance [2]. Virtual Reality (VR)-based technology is an innovative solution to such training challenges, increasingly deployed across education, from art to engineering [3-8]. By enabling realistic and interactive three-dimensional environments, VR provides an efficient medium for experiential learning, such that fidelity simulations of difficult-to-train complex aircraft systems and airlines' procedures can be interactively experienced without dangers or logistical constraints of training on real aircraft. The application of VR-based solutions to aircraft maintenance training has demonstrated strong potential to increase engagement and learning of technical skills [9, 10]. Building upon what is already known about the strengths of VR, its future in related training lies in integrating Artificial Intelligence (AI) to create even more interactive and adaptive learning environments. AI-enabled functionalities can extend and build upon the core VR experience [11-13]. Large Language Models (LLMs), such as ChatGPT [14], provide the potential to bring intelligent tutoring, automated content generation, and interactive knowledge support to such virtual worlds. These can be adapted to an individual learner's needs, provide immediate feedback through responses, and make significant amounts of technical knowledge instantly accessible and reliable.

Although there are studies showing VR applications in aviation [9, 12], a gap remains in industry-compliant training solutions that involve commercial aircraft maintenance or operation. Since limited published work focuses on OEM-based processes with enough regulatory compliance information, it is difficult to estimate how useful such solutions are in the real-world. This work is distinct in that it documents a scalable development methodology and architecture that directly meets this need while fully adhering to the approved aircraft manufacturer procedural manuals (Airbus A320). The architecture allows for incremental incorporation of AI abilities into constructed advanced commercial aircraft training VR-modules such that it fulfills the operational requirement of educationally integrated and verifiable training solutions.

This paper presents an evolving methodology in developing VR-based training solutions, as exemplified through case studies on commercial airliners' airplanes. With ground principles, it demonstrates the progression from an initial VR application that was originally developed to support landing gear maintenance-related procedures to ongoing work on developing an Airbus A320 walk-around procedure application. Specifically, this new development cycle incorporates an explicit AI-augmented extensional capability, employing ChatGPT to develop a dynamic quiz generator from procedural knowledge and an interactive bot to take advantage of relevant technical aircraft documentation. These case studies demonstrate the real-world production and deployment of these emerging technologies, highlighting their importance for regulatory-compliance aviation training.

II. METHODOLOGY

A. *Scalable Platform Design and Process*

The development process for VR training applications is based on a common set of consistent principles so that scalability, relevance, and efficiency (e.g., development time) can be realized across a number of projects, including the Airbus A320 landing gear associated systems and walk-around procedure case studies included in this study. The VR platform system is designed according to four looping stages: Analysis, Design, Development, and Test & Feedback (Figure 1). Each of them has a set of connected tasks that are adequately addressed in a balanced manner, aligned with the particular objectives of the projects. The first stage, Analysis, requires a deep examination of the selected procedures and technical manuals. The second step is the design of the information system, i.e., determining simulation flow, designing the User Interface (UI) and User Experience (UX) in the virtual world. The third step, Development, implements design ideas and creates VR applications, from 3D object modeling through CAD applications to programming and integration on chosen VR devices (e.g., Oculus Quest 2/3). The fourth step, Test & Feedback, comprises exercises administered by certified aircraft engineers to verify that the VR application is adequately developed and simulates reality (e.g., specifications of real full-scale aircraft systems and parts and conformity to airlines' approved procedures). This last production step is pivotal to the success of such VR-based applied studies, ensuring strict conformity to industry requirements.

This development process is a modular container-based architecture designed for scalability. Figure 2 illustrates this architecture, which decouples platform services (authentication, aircraft/system selection) from procedure modules, enabling easy extension. Learners are routed into specific simulation tracks, for example, on-aircraft operations (Parking module) or off-aircraft workshop tasks (Workshop module), with "pass" gates providing embedded checks and progression control. Since each workflow is encapsulated as a container, new applications can be added without altering the core of the platform, and modules can be enabled or disabled as training needs dictate. This modularity makes the platform efficiently scalable across aircraft systems and types, allowing procedure-specific customization, including enhanced functions (e.g., AI integrations), while preserving common foundational design elements.

B. *Integrating AI/LLM as Extensional Functions*

The modular architecture is leveraged to integrate AI and LLMs as extensional features that enrich the core VR experience. The platform is designed to be LLM-agnostic, supporting interfaces with various models (e.g., ChatGPT, Gemini). For this initial implementation, the GPT-4o Mini model was utilized via OpenAI's API, selected because it provides a good compromise between fair conversational capability, response time suitable for achieving a feeling of presence (targeting a 2 to 5-second latency per response), and affordable cost. Architectural flexibility is desirable because scaling to a large user base would make API expenses prohibitive, so a strategic approach to wider deployment will be necessary.

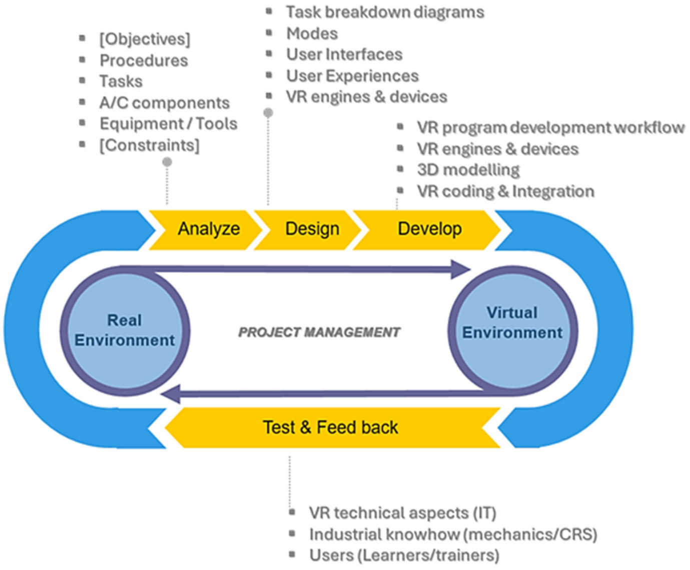


Fig. 1. Production stages of VR applications.

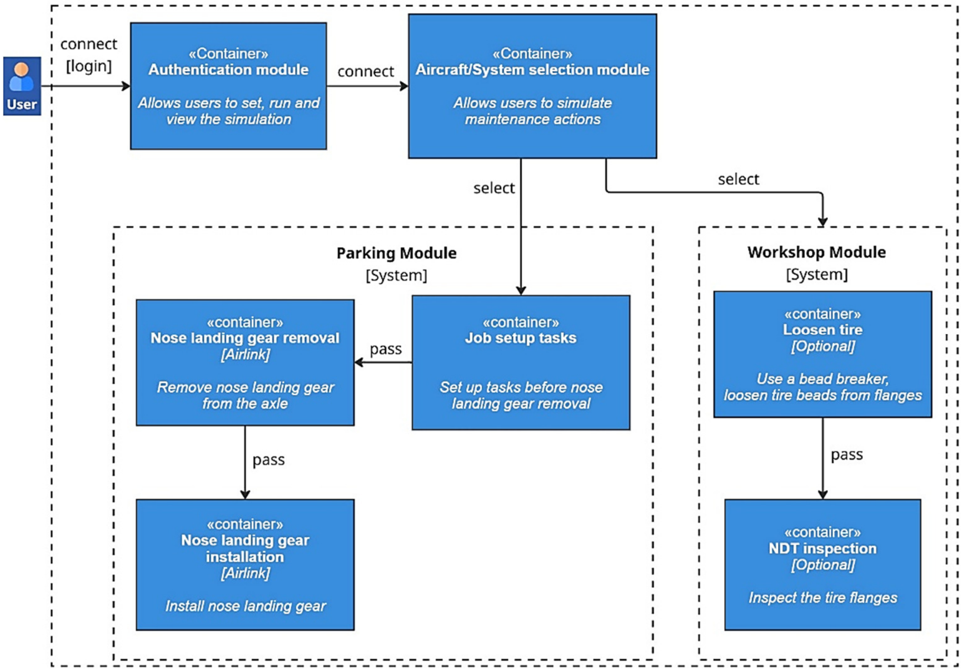


Fig. 2. Container-based architecture of the VR training platform.

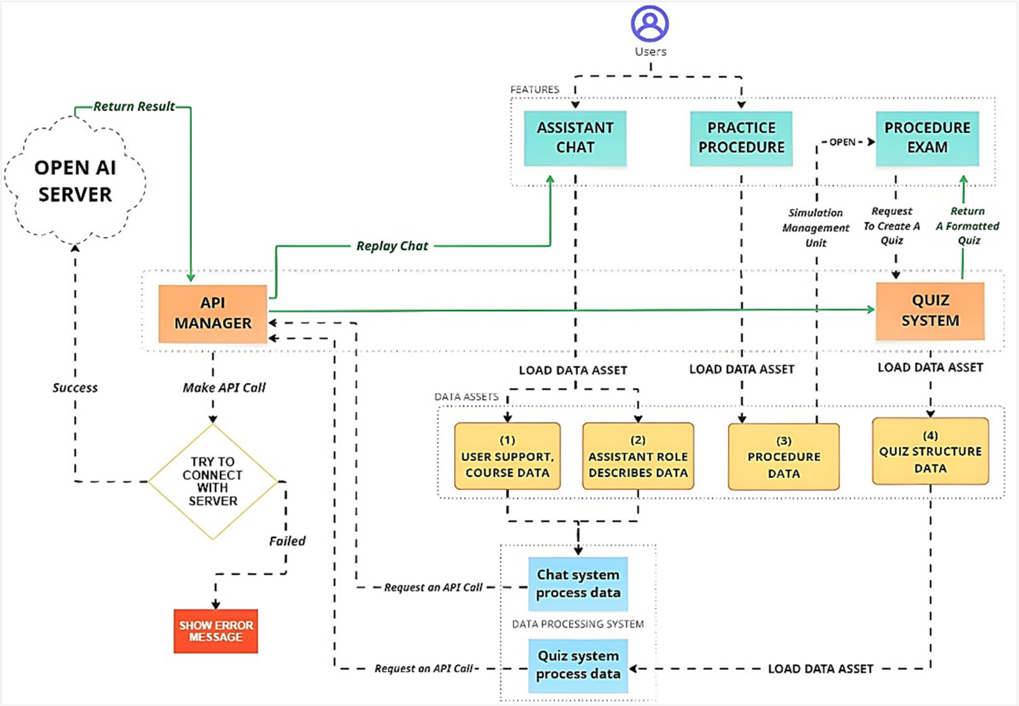


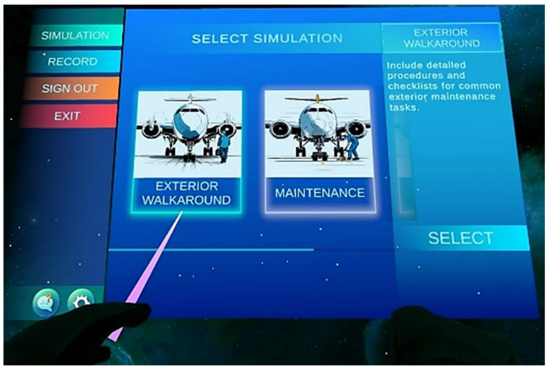
Fig. 3. System design for AI-enhanced VR training applications.

As shown in Figure 3, AI-enhanced functions are designed to be incorporated into the VR applications. Figure 3 describes a closed, safety-constrained process: the Assistant Chat, Practice Procedure, and Procedure Exam functions communicate through the API Manager, which loads vetted data assets: (i) user-support/course data, (ii) assistant-role constraints/descriptions, (iii) procedure data, and (iv) quiz structure data. When a user submits a query, the API Manager performs a retrieval against an indexed, version-locked corpus of approved aircraft manuals (e.g., Airbus A320 AMM/FCOM) and forwards only the matched results to the LLM (e.g., GPT) to compose a reply. To ensure compliance with aircraft technical documentation, the data is preprocessed and validated by the Data Processing System (chat/quiz pipelines) before being passed to the LLM. The LLM synthesizes a response strictly from the provided data. If no authoritative data match is found, the system refuses to answer rather than speculate. The same constraint principle applies to the Procedure Exam, where quiz items are generated only from validated procedure datasets and quiz templates/structures, thereby preventing unverified content.

III. RESULTS AND DISCUSSION

Following the four-stage (Analyze, Design, Develop, Test & Feedback) strategy described, this section presents the progressive case studies. Before detailing them, the application's "overall flow" from a user's perspective is as follows: The user first logs in via the Authentication module and selects a simulation from the main interface (Figure 4). The user then proceeds through the guided procedural steps (Figure 10 provides an example of sequential practicing actions). After completion of the practice, the user can opt to take the AI-generated Procedure Exam (Figure 3), which concludes with a results screen.

Figure 4 shows the interface of the developed VR-based platform, where different application modules appear as tiles (e.g., Maintenance - Case study 1 and Exterior Walkaround for Case study 2 are detailed in the following subsections), routing the learner into a self-contained workflow.



Include detailed procedures and checklists for common exterior maintenance tasks.

Fig. 4. The VR platform interface.

A. *Case Study 1: A320 Nose Landing Gear Wheel Removal and Installation Procedures*

Maintenance operations on the Airbus A320, one of the most widely operated narrow-body aircraft types worldwide, were selected for the simulation. Among the daily responsibilities of certified aircraft engineers, the removal and installation of landing gear system components, such as wheels and tires, are routine but safety-critical tasks. For this case, the Airbus A320 Aircraft Maintenance Manual (AMM) procedures [15], specifically references 32-41-12-000-001-A and 32-41-12-400-001-A covering the removal and installation of the Nose Landing Gear (NLG) wheel-tire system, were adopted. Using these AMM references ensures that the simulation follows OEM-approved documents, complies with regulatory expectations, and reflects procedures directly transferable to real-world aircraft maintenance contexts.

As illustrated in Figure 5, full-scale three-dimensional Airbus A320 models, together with associated components, tools, equipment, and accessories relevant to the selected tasks, were developed using CAD software (such as SolidWorks) and further refined (for texture) with applications (such as Blender). The modeling process relied on real geometric and dimensional data extracted from OEM technical manuals to preserve fidelity to the actual aircraft systems. In addition, the virtual environment was carefully built to replicate the operational setting, including the parking apron and cockpit, so that the VR application provides both technical accuracy and contextual realism.

Figure 6 presents a side-by-side comparison of VR simulation scenes with their real-world counterparts, illustrating the platform's high fidelity. A similar comparison (with slightly different viewing angles in the VR platform) was reported in [10]. The close alignment between practice and the virtual environment underscores the potential of the VR application to deliver immersive, reliable, and instructionally valuable training to aircraft maintenance personnel. A video demonstration of a portion of the simulated maintenance process (presented in time-lapse format) is provided as supplementary material on [16].

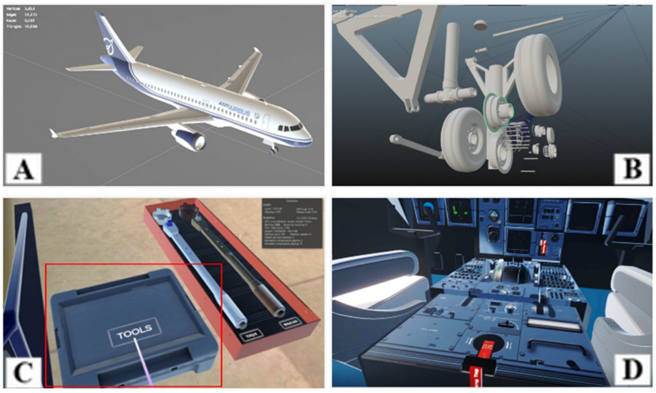


Fig. 5. 3D full-scale CAD models: (A) Aircraft A320; (B) Nose landing gear wheel and tire; (C) Dedicated tools; (D) Aircraft cockpit.

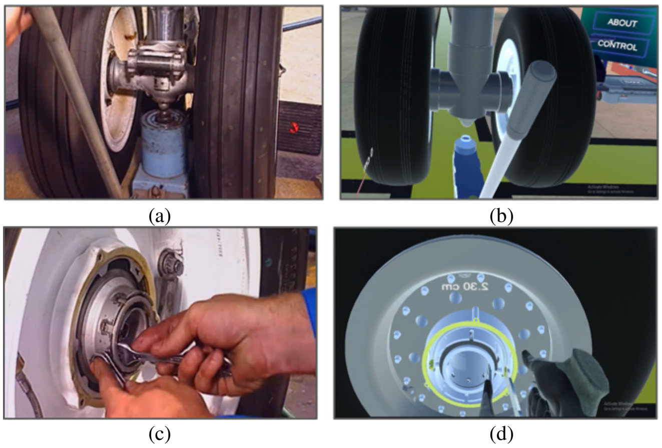


Fig. 6. Comparison of VR simulation scenes with their real-world counterparts: Landing gear nose jacking (a) vs (b); Removal of locking nuts (c) vs (d).

The following performance metrics are used, recorded throughout the development stages of Case Study 1, to provide objective technological evidence on the performance of the platform. The application was developed utilizing Unity (C# scripting) for the standalone Oculus Quest 2 environment, using a Qualcomm Snapdragon XR2 processor with 6 GB of RAM and 90 Hz refresh rates, with a comparison made to a standard PC environment. Some principal performance metrics recorded throughout the stages of software application development (from the early development versions v1 and v2 to the latest versions v3, v4, and v5) include average Frames Per Second (FPS), hardware temperature, and memory usage (Tables I, II, and III, respectively). FPS improved from 20 to 30 (Table I), thermal indicators remained fairly low and stable across versions (Table II), and Quest 2 memory usage increased and then stabilized at approximately 460 MB RAM in later versions, largely within the device's 6 GB RAM capacity (Table III). The results show that, although there was a stabilization impact through incremental improvement, such as 3D model optimization (v3-v5), the performance level obtained in the standalone environment still lags behind that of the PC environment, such as the level of FPS performance (Table I), and could be improved in future refined versions.

TABLE I. CASE STUDY 1 – FPS PERFORMANCE ACROSS VERSIONS (OCULUS QUEST 2 VS PC)

Version	v1	v2	v3	v4	v5
Oculus Quest 2 (Average FPS)	20	20	30	30	30
PC (Average FPS)	115	130	165	170	175

TABLE II. CASE STUDY 1 – TEMPERATURE INDICATORS (°C) ACROSS VERSIONS (OCULUS QUEST 2 VS PC)

Version	v1	v2	v3	v4	v5
Oculus Quest 2	42	43	40	40	40
PC (CPU)	62	63	61	61	61
PC (GPU)	67	67	64	65	65

TABLE III. CASE STUDY 1 – MEMORY USAGE EVOLUTION ACROSS VERSIONS (OCULUS QUEST 2)

Version	v1	v2	v3	v4	v5
Memory cost (MB RAM)	120	300	450	460	460

B. *Case Study 2: A320 Walk-Around Procedure with AI-Enhanced Extensional Capabilities*

The VR platform was extended to an additional application, that of the walk-around inspection operation of an Airbus A320 [15, 17]. This is a must-do pre-flight operation required by aviation authorities to confirm the airworthy external condition of an aircraft and thus provide critical safety to each flight of any airline. Figure 7 provides extracted moments from the VR application. Some critical details of the application are summarized below:

1. Comprehensive details of external A320 aircraft systems and components, equivalent to approximately 150 objects, were modeled. This allows users to explore and gain a detailed understanding of the selected commercial aircraft systems, combining 3D visual objects with explanatory content.
2. The complete procedure, including 21 checkpoints required by the formally approved documents [15, 17], was simulated on the VR platform. Each checkpoint integrates several features to perform the inspection activity, so that trainees must complete an activity before moving to the next (in training mode). The platform accommodates visual recognition so that trainees can find and identify aircraft parts in an interactive 3D context. To supplement this, contextual information is provided on demand within the VR space. In addition, interactive functions are included, such as the CHECK option, which allows users to accept or reject an inspection activity for a specific aircraft system/component, according to the approved technical documentation. During training, guided learning is facilitated through design elements such as highlighting, along with information panels that direct the trainee's attention and provide required information in the location of need. This interactive learning process may be further supplemented by the built-in AI Assistant to allow for more subtle questions and inquiries.
3. The application is also supplemented with AI-powered functionalities, namely the Assistant Chat and Quiz System. As detailed in the methodology (Figure 3), the Assistant Chat (Figure 8) is designed to explain the functionalities of the application and answer questions about training steps, with its knowledge locked into User Support and Assistant Role data assets. The Quiz System (Figure 8) allows the real-time construction of quiz content within the immersive VR environment, but is strictly locked to the approved Procedure Data and Quiz Structure Data assets to ensure that all content remains relevant and compliant.

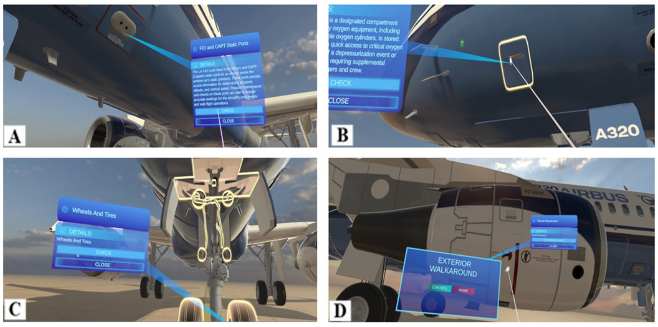
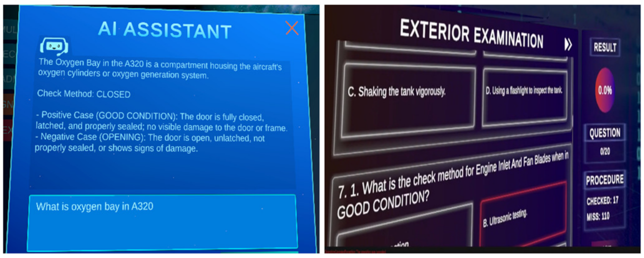


Fig. 7. Extracted scenes illustrating various inspection positions from the Exterior walkaround VR application.



The Oxygen Bay in the A320 is a compartment housing the aircraft's oxygen cylinders or oxygen generation system.

Check Method: CLOSED

- Positive Case (GOOD CONDITION): The door is fully closed, latched, and properly sealed; no visible damage to the door or frame.
- Negative Case (OPENING): The door is open, unlatched, not properly sealed, or shows signs of damage.

What is oxygen bay in A320

C. Shaking the tank vigorously.

D. Using a flashlight to inspect the tank.

7. 1. What is the check method for Engine Inlet And Fan Blades when in GOOD CONDITION?

B. Ultrasonic testing.

Fig. 8. User interfaces for the AI-powered assistant and examination.

Fig. 9. Students practicing aircraft maintenance using the VR platform.

C. Initial Learner Feedback

This section describes the results obtained using two pilot training sessions (see Figure 9) based on Case Study 1 (Removal of nose landing gear wheel-tire system), conducted with an identical procedure consisting of five steps lasting around three hours. These training sessions commenced with (i) an anonymous pre-test survey to obtain basic learner characteristics (e.g., age, gender, year of study), followed by (ii) a conventional traditional lecture to briefly introduce the target Airbus AMM procedure. Next was (iii) an explanation of basic VR principles and the use of the Oculus Quest 2 or 3 headset. Then came (iv), where groups consisting of four to seven participants per group, who shared headsets due to availability constraints, practiced using VR. The practice phase of these training sessions (4th step) was set at around two hours. It is noted that while individual practice time was planned for ~20 minutes each, actual exposure was sometimes uneven (as some highly motivated participants exceeded their allotted time, reducing others' within the set duration). These training sessions ended with (v) an anonymous post-test survey.

Figure 10 shows the step-by-step procedure for practicing nose landing gear wheel-tire removal on the VR system, from initial to final steps. This figure illustrates a set of images (numbered 01–24) obtained from a standard simulation. These proceed sequentially from user log-in (image 01), access to the target maintenance module (image 02), to the Parking scene (images 03–04). Next, the user has to prepare the basic safety procedure. This includes installing safety devices on the landing gear (image 05), transitioning to the aircraft cockpit to apply warning tags to the free-fall and landing gear control handles (images 06–08), followed by the proper application of the relevant circuit breakers (e.g., CB-M33) (image 09), and subsequently setting aircraft braking on (image 10). After moving back to the apron scene (image 11), the user needs to move all wheel chocks away from the tires (image 12) and then correctly position the hydraulic jack at the landing gear jacking point (image 13) to lift the nose landing gear. After completion of the lifting, deflation begins using the designated tool (image 14). Using tools selected from the toolbox (image 15), the user sequentially removes screws and hubcap (images 16–17), locking nuts and bolts (image 18), and the axial casing (image 19). Next, the user selects the specialized torque wrench and adaptor (image 20) and removes the axial nut (image 21). The user then installs the protector tool (image 22) before removing the tire (image 23) and placing it on a support dolly (image 24). Note that these static image scenes, extracted at specific moments in a simulation, are intended only to provide a basic understanding of the procedural sequence. In actual VR practice, users must perform much more complex interactive manipulations within a 3D immersive, realistic-like working environment, as demonstrated in [16].

Fig. 10. Procedural flow of the NLG wheel removal simulation.

The first workshop at the Vietnam Aviation Academy (VAA) involved Aeronautical Engineering/Maintenance undergraduates (AEM; n=24); the second at the Singapore Institute of Technology (SIT) involved Air Transport Management undergraduates (ATM; n=36) [10]. To obtain quick, comparable indicators from these brief interventions, learners answered four single-item questions (Table IV) on 1–5 Likert scales about the VR application for the A320 landing-gear wheel-tire procedure. Because the instrument, protocol, and learner population were comparable, the central tendency can be summarized both by cohort (Figure 11) and pooled across cohorts (AEM+ATM; N=60) using n-weighted means. Likert responses were treated as approximate intervals for mean/Confidence Interval (CI) estimation, and given the single-item design, the results are interpreted cautiously. As shown in Figure 11, the pooled overall index was 4.26 (95% CI 3.95–4.56). By construct, pooled means were Engagement 4.37 (95% CI 4.03–4.70), Interest 4.30 (95% CI 3.94–4.66), Practical 4.20 (95% CI 3.82–4.58), and Understanding 4.17 (95% CI 3.78–4.56), indicating consistently favorable early perceptions, with Engagement most prominent.

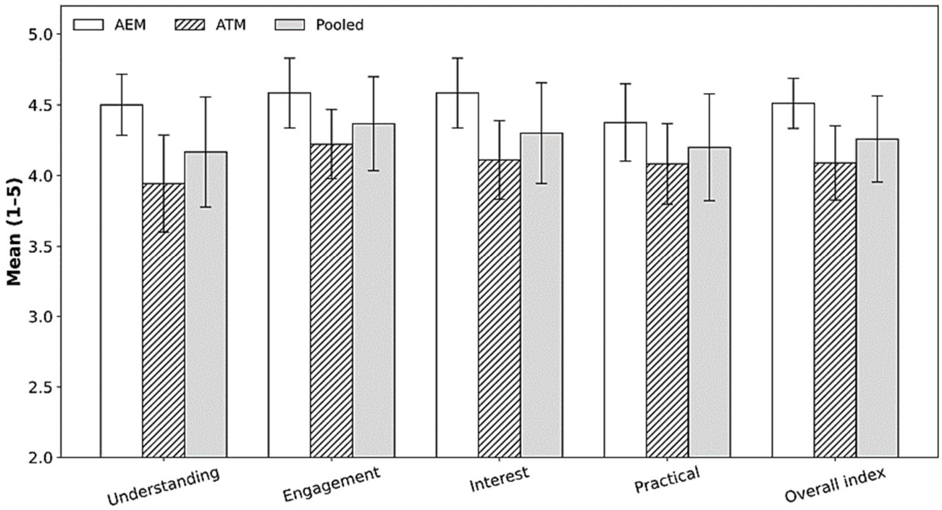


Fig. 11. VR training perceptions by cohort and pooled (Means ± 95% CI).

TABLE IV. SURVEY CONSTRUCTS AND QUESTIONS FOR VR TRAINING

Construct	Definition	Question
Understanding	Perceived help of VR in understanding complex aircraft maintenance procedures	To what extent do you agree with the following statement: "VR technology helps in understanding complex aircraft maintenance procedures"? *(1: Strongly disagree; 2: Disagree; 3: Neutral; 4: Agree; 5: Strongly agree)*
Engagement	Relative effectiveness of VR in enhancing engagement compared to traditional methods	Compared to traditional learning methods, how effective do you find VR in enhancing your engagement with the aircraft maintenance curriculum? *(1: Much less effective; 2: Somewhat less effective; 3: About the same; 4: Somewhat more effective; 5: Much more effective)*
Interest	Change in interest in aircraft maintenance due to VR use	Has the use of VR in your studies increased your interest in aircraft maintenance? *(1: Significantly decreased; 2: Somewhat decreased; 3: No change; 4: Somewhat increased; 5: Significantly increased)*
Practical	Perceived contribution of VR to improving practical aircraft maintenance skills	Do you believe VR experiences contribute to improving your practical skills in aircraft maintenance? *(1: Strongly disagree; 2: Disagree ; 3: Neutral ; 4: Agree; 5: Strongly agree)*

The cohort summaries show AEM at 4.51 (95% CI 4.33–4.69; n = 24) and ATM at 4.09 (95% CI 3.83–4.35; n = 36) on the overall index. These results suggest that integrating VR into aircraft-maintenance training would enhance the learner experience, particularly by increasing engagement while maintaining strong perceptions of understanding, interest, and practical skill development. Given that these pilots are underpowered for between-group inference and rely on single-item measures, this study refrained from hypothesis testing and effect-size reporting. Multi-item validation and powered inferential analyses are planned for future work.

In addition, to obtain preliminary data on the challenges encountered, an analysis of free-response data was conducted based on a post-survey question: "Have you faced any challenges or barriers while using VR in your aircraft maintenance education? If so, please describe." In analyzing data for themes using these 44 responses among both groups, it was found that five participants had reported adverse reactions. (~11.4%), including four for dizziness and one for headache. There was no reference to nausea or cybersickness. Other reported barriers included lack of experience with devices or operating them (*n*=7, 15.9%), access- or time-related barriers (*n*=3, 6.8%), or issues related to device fitting or comfort (*n*=2, 4.5%). No serious or protracted adverse reactions were reported. Due to the relatively small group sizes participating and a free-response format, these data are best treated as preliminary.

D. Training Operational Efficiency and Platform Positioning

In instructor-supervised pilots (VAA, SIT; ~3-hour protocol), trainees completed all AMM-compliant steps in classroom sessions using stand-alone headsets (Oculus Quest 2/3) without reserving a real aircraft. This VR-based setting demonstrates a substitution pathway in which selected hands-on practice, such as repetitions of A320 NLG wheel/tire tasks, can shift from on-aircraft sessions to VR rehearsal conducted directly in traditional classrooms. This approach can reduce aircraft booking hours, hangar occupancy, and the need for specialized tools and materials, while easing logistics-related constraints and potentially shortening the time required on real equipment. As contextual industry evidence, reports from FL Technics (a recognized MRO provider) [12], developed in collaboration with Boeing, describe early deployments of VR maintenance modules that reduced training duration. These industry reports align with the potential for operational training efficiency observed in this work.

In addition to this first level of feasibility, the platform showed operational viability through its integration into the formal course curriculum in both programs (VAA and SIT). From an engineering development perspective, the entire development process took around 2,500 man-hours, with approximately two-thirds related to the first sub-procedure simulation (Case Study 1: A320 NLG wheel removal) and the remaining associated with the second sub-procedure simulation (Case Study 1: A320 NLG Wheel Installation). Although these indicators serve as quantifiable evidence relevant to efficiency and scalability, the process of carrying out a serious cost-benefit analysis (such as the cost per trainee in the context of VR-based training compared to aircraft-based) is beyond the immediate focus and would be addressed in follow-up work.

Compared to other works in the literature, such as [9], this study, at the platform level, underscores the importance of: (i) modular integration following strict guidelines from the aircraft manufacturer for maintenance procedures as defined by AMMs, (ii) extensional AI-powered functions using approved technical references, and (iii) successful classroom-level deployment at multiple universities (VAA and SIT). Table V summarizes a feature-level positioning against some current practices found in the literature, and Tables I-III report system indicators (FPS/memory/temperature) for Case Study 1.

TABLE V. FEATURE-LEVEL POSITIONING OF THE PROPOSED PLATFORM (STRUCTURAL COMPARISON)

Dimension	Current literature (e.g.,[9])	This work
Structural design	Scenario-specific; typically, scalability is not evidenced.	Scalable, Container-based Architecture.
Hardware & deployment	Often PC-tethered or restricted to laboratory settings.	Optimized standalone VR; verified via multi-institutional classroom deployment.
Procedural enforcement	Checklist-based activities; regulatory compliance logic is often not clearly reported.	AMM-aligned gating logic; enforces task sequences and safety actions as per approved documents.
AI integration	Generally absent	AI Extensions, governed by approved technical documentation.
Evaluation evidence	Primarily restricted to user perception or usability surveys.	Analytical benchmarking, including objective system indicators (FPS/temperature/memory) and operational metrics (budget/capacity).

IV. CONCLUSION

This work outlines the step-by-step development of a scalable VR-based training platform under the stringent compliance requirements in aviation, using commercial aircraft case studies and Airbus A320 approved procedures to demonstrate feasibility and efficiency, documenting the path from an initial VR module focused on landing-gear–related maintenance procedures (Case Study 1) to a complete A320-aircraft walk-around inspection simulation (Case Study 2). The proposed system incorporated large-scale aircraft data from OEMs into the platform, increased the fidelity of 3D models representing real systems, components, and operating environments, and optimized the software so that heavy datasets still run smoothly on standalone headsets such as the Oculus Quest 2 and 3. It is important to emphasize that one of the core contributions is, through an extendable VR-platform architecture, the introduction of AI-augmented extensional features, which provide safe and compliance-controlled access to technical documentation and real-time quiz generation and interaction, effectively increasing immersion and procedural support. Collectively, the case studies show that this design and development architecture is efficient as well as intrinsically scalable, delivering efficiencies in VR product development and potential operational efficiency, a significant consideration in academic environments that need industry-grade cutting-edge training tools under limited resources.

In the first case study, a VR application for an aircraft maintenance procedure, early user feedback from sampled higher-education settings was generally positive across two short pilots, suggesting initial inter-program acceptance of the VR method, especially in contexts where procedural and regulatory fidelity are critical. The response pattern indicates that VR stimulates engagement while maintaining strong perceived understanding, interest, and support for hands-on skills. Given the short exposure and single-item measures, these findings are presented descriptively. Subsequent studies will administer more holistic instruments, incorporating literature-established validated measures (e.g., VRSUQ, SUS) [18, 19], to better structure and benchmark findings, quantify user acceptance, and identify opportunities to improve comfort and usability in this evolving VR platform.

In the second case study, an extension of the same platform that simulates a preflight aircraft inspection, the gradual integration of AI components further highlights the platform's potential to deliver more responsive, informative, and interactive learning experiences. The AI-augmented VR training approach is viewed as a promising avenue towards more efficient, personalized, and intelligent training for aviation personnel and learners. Plans involve extending AI capabilities (e.g., AI-powered anomaly scenarios) and addressing user feedback by conducting larger and more comprehensive studies. These studies will be designed not only to assess learning outcomes and knowledge retention, but also to specifically investigate if VR-AI-enhanced training is more effective than traditional methods in preventing procedural mistakes, thus addressing the critical issue of human error in aviation.

A key challenge in scaling is acknowledged. Although the modular architecture and AI framework are highly scalable, the creation of type-specific content remains a labor-intensive constraint. Significant resource advantages exist when scaling within the same aircraft type. For example, when developing a new A320 module (e.g., a different maintenance procedure related to Main Landing Gear systems rather than Nose Landing Gear), the major high-cost assets, such as the full-scale 3D aircraft model and cockpit, can be reused. In contrast, adapting the system to a different aircraft type (e.g., Boeing 737) would still require a resource-intensive modeling effort to replicate type-dependent components, parts, and specialized tools, including their 3D geometry, textures, and interactions. This distinction clarifies the difference between the scalability of the software framework and the workload of the content-creation pipeline. Although this distinction underscores the practical limits of scaling across aircraft types, mainly in terms of labor-related resources, it also highlights the platform's flexibility for expansion within the same framework, due to its scalable AI-enhanced design.

Building on this foundation, future work will apply the same development approach to additional aircraft systems, operational processes, and different commercial aircraft types, thus broadening the platform's generalizability and impact within the wider aviation training community.

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