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Development of a virtual cockpit system using Web 3D/360 technology for CASA C-295 aircraft

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ABSTRACT

Virtual Reality and Web 3D/360 technologies are experiencing rapid development and are increasingly applied in military training systems to enhance training effectiveness and minimize operational risks. This paper presents the research and development process of a virtual cockpit simulation system for the CASA C-295 aircraft based on Web 3D/360 technology. The system is designed with a layered architecture, integrating 360-degree panoramic environments, interactive 3D models, technical documentation, and multimedia content, enabling flexible deployment across various devices, including web browsers and VR headsets. The system construction involves capturing real cockpit panoramas, processing images, creating 3D models, and linking content through a metadata framework. The system was piloted at the 918th Air Regiment and received positive feedback, with high satisfaction levels reported by both training experts and trainees. Results indicate that the system has significant potential to support technical training, improve spatial awareness, and foster self-paced learning among trainees, while also serving as a cost-effective and efficient solution in the process of digital transformation in military education and training.

Keywords: virtual reality, Web 3D/360, immersive training, virtual cockpit, CASA C-295, military simulation

1. INTRODUCTION

Training military personnel on modern aircraft systems is often constrained by safety, cost, and availability of physical equipment. These limitations hinder the ability of engineers and pilots to gain necessary hands-on experience, especially in high-risk or resource-constrained environments. The rise of virtual reality (VR) and Web 3D/360 technologies enables the simulation of realistic environments that can mitigate these constraints. This research focuses on the development of a virtual cockpit training software system for the CASA C-295 aircraft using Web 3D/360 technologies, aiming to bridge the gap between theory and practical experience.

2. RELATED WORK AND TECHNOLOGICAL BACKGROUND

Multiple military-grade training systems, such as Viettel's VOTO and CIC's TecknoSim, have showcased high-fidelity flight simulation solutions. However, such systems are typically high-cost and require complex setup, limiting deployment across widespread units. Meanwhile, WebGL and HTML5-based platforms have demonstrated the potential for developing lightweight, browser-based simulations.

Recent scholarly efforts have explored the integration

of VR and 3D technologies in military and aviation contexts. Wang et al. (2022) provide a comprehensive review of VR-based military training systems, emphasizing usability, immersion, and training efficiency [1]. Similarly, Li et al. (2021) propose deep learning-based panoramic image stitching to enhance the realism of virtual training environments [2].

Gao et al. (2019) focus on improved image stitching techniques using SIFT and RANSAC algorithms, which are essential in creating seamless panoramic cockpit views [3]. Furthermore, Chen et al. (2021) present an AI-driven panoramic image processing framework that has been shown to improve both user orientation and interaction fidelity in virtual environments [4].

In the domain of web-based simulation platforms, WebGL has emerged as a dominant technology, allowing integration of real-time 3D graphics into standard browsers. Open-source libraries like Three.js and A-Frame, built on top of WebGL, facilitate rapid development of interactive 3D and 360-degree content without requiring specialized hardware.

Despite these advances, there remains a lack of cost-effective and scalable systems tailored specifically

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for localized military units with limited access to physical training equipment. Our proposed system addresses this gap by providing a web-based, modular, and immersive training environment specifically designed for the CASA C-295 aircraft.

3. SYSTEM DESIGN AND ARCHITECTURE

3.1. System overview

The proposed virtual cockpit system includes two core modules:

- Interactive Virtual Cockpit Environment (360 View & 3D Models).
- Technical Data Management System (documents, images, 3D parts).

The architecture allows data to be displayed both on standard screens and VR headsets (e.g., Oculus Quest 2), enabling full 360-degree interaction with spatial navigation, zoom, and component-level access.

3.2. System architecture diagram

The system is built using a layered architecture that separates the user interface, data management, and rendering layers.

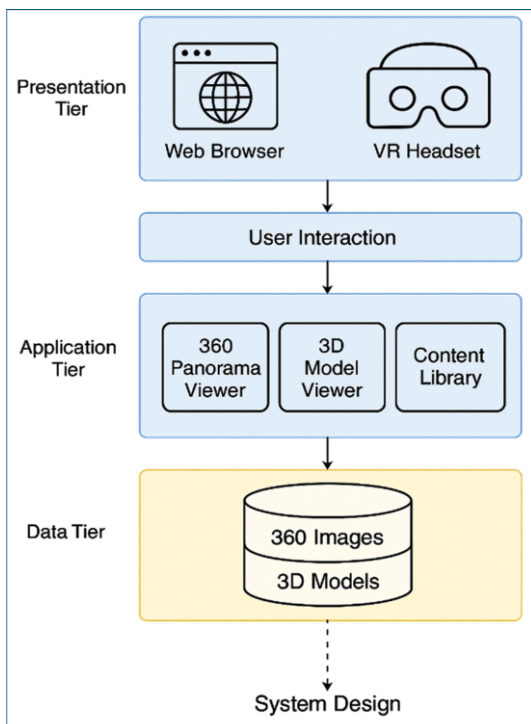


Figure 1. System architecture diagram

A three-tier architecture governs the software's internal logic and deployment:

- **Presentation layer:** Utilizes A-Frame and WebGL to render immersive 3D scenes and user interfaces. It supports traditional mouse-keyboard setups and VR hardware through WebXR APIs.
- **Application layer:** Acts as the control logic mediator.

It interprets user interactions, manages navigation states, triggers content loading, and synchronizes visual elements with associated metadata.

- **Data layer:** Stores and delivers structured content including 3D models, high-resolution panoramic scenes, and technical documentation (PDFs, JSON metadata, video assets). This layer interfaces with a Node.js server and CDN infrastructure to ensure fast delivery and maintain modularity.

This tiered approach separates concerns, simplifies debugging, and allows for independent development and scaling of each system component.

3.3. Immersive module production workflow

Building the virtual cockpit required a multi-phase content generation workflow:

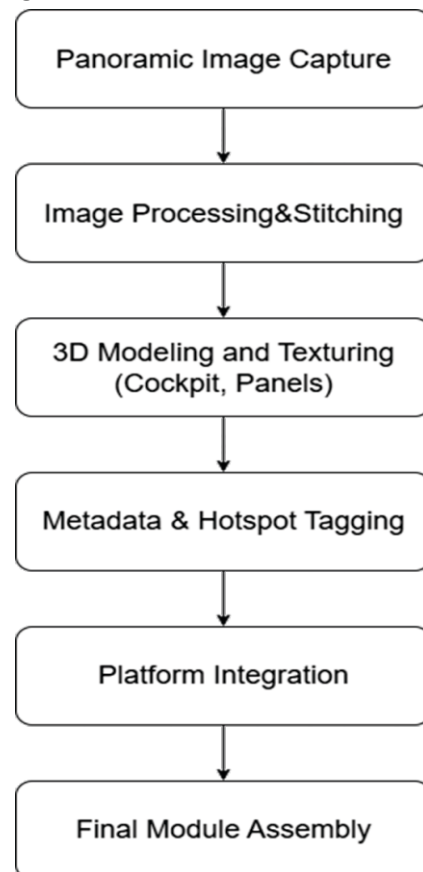


Figure 2. Immersive module production workflow

- **Capture and acquisition:** High-overlap photographic sequences and 360-degree images were captured from the real CASA C-295 cockpit using a combination of handheld DSLR cameras and Ricoh Theta Z1 devices.
- **Image stitching and processing:** Source images were processed using SIFT and RANSAC algorithms via OpenCV, followed by blending and stitching to produce high-resolution panoramic scenes.

- 3D Modeling and texturing: CAD-based modeling was carried out using Blender, with GLB exports optimized for runtime rendering. Textures, materials, and component hierarchies were configured to reflect functional realism.
- Metadata & hotspot tagging: Technical manuals, annotations, and visual callouts were indexed and hyperlinked to corresponding hotspots and 3D elements through JSON descriptors.
- Platform integration: The generated panoramic scenes, models, and metadata were integrated into a modular Web 3D/360 framework, supporting cross-device delivery via browsers and VR headsets.
- Final module assembly: All components were packaged as a cohesive training module, optimized for responsive interaction, immersive learning, and independent content updates.

This pipeline ensures a tightly coupled yet loosely integrated content structure where updates in visuals or documentation can propagate independently.

3.4. Interaction design and user experience

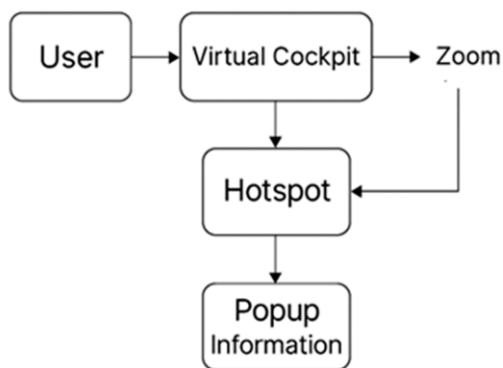


Figure 3. Interaction design and user experience

Interaction paradigms in the system were guided by usability principles tailored to technical learners. The interface design emphasizes clarity, spatial awareness, and responsiveness:

- Hybrid navigation: Users can switch between panoramic walk-through and detailed object inspection modes. VR support adds head-tracking and controller input.
- Semantic hotspots: Clickable markers embedded in 3D space allow access to documents, part breakdowns, or procedural videos. Visual cues (e.g., pulsing icons) indicate interactive zones.
- Responsive adaptation: Interfaces dynamically adapt to screen sizes and input devices. Progressive enhancement strategies ensure consistent experience across laptops, tablets, and

VR headsets.

These features are aimed at minimizing cognitive load and supporting exploration-based learning.

3.5. Integrated technology stack

To achieve real-time rendering, modular development, and scalable delivery, the following technologies were adopted:

- Frontend: A-Frame and Three.js serve as the core visualization engines, built on top of WebGL. Custom HTML/CSS/JS logic handles UI layering and state transitions.
- Backend: A Node.js server manages RESTful API calls for asset metadata, user actions, and content queries. Express middleware handles routing, while JSON files maintain dynamic scene descriptors.
- Deployment: Content assets (GLB, HDR images, PDFs) are hosted on a cloud CDN. WebXR APIs facilitate VR headset access, ensuring compliance with emerging web-based XR standards.

The system stack includes A-Frame for 3D rendering, integrated with HTML5, WebGL, and external libraries [5].

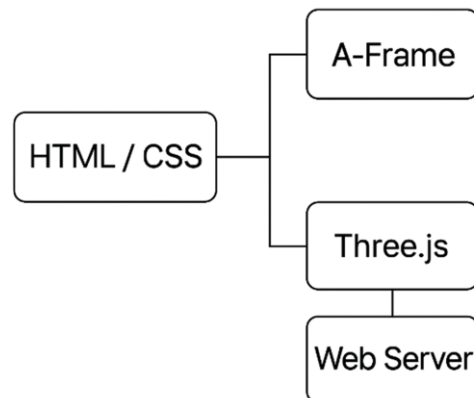


Figure 4. Integrated technology stack

4. IMPLEMENTATION AND FUNCTIONAL MODULES

4.1. Functional integration and software composition

The implementation of the system adopts a micro-modular approach, where each module handles a specific aspect of user experience, content interaction, or data visualization. This separation allows for parallel development, easier testing, and clearer user flows.

- Virtual cockpit explorer (VCE): The heart of the system, this module renders immersive 360° imagery of the CASA C-295 cockpit. Users can navigate spatially, identify control panels, and access interactive hotspots that reveal contextual information or linked assets.



Figure 5. Virtual Cockpit Explorer displaying panoramic cockpit view with interactive hotspots for accessing related documents, 3D models, and videos

- 3D equipment viewer (3DEV): This module enables dynamic inspection of technical parts, rendered in GLB format. Components such as the flight console or navigation systems are annotated and structured hierarchically to allow layered exploration.

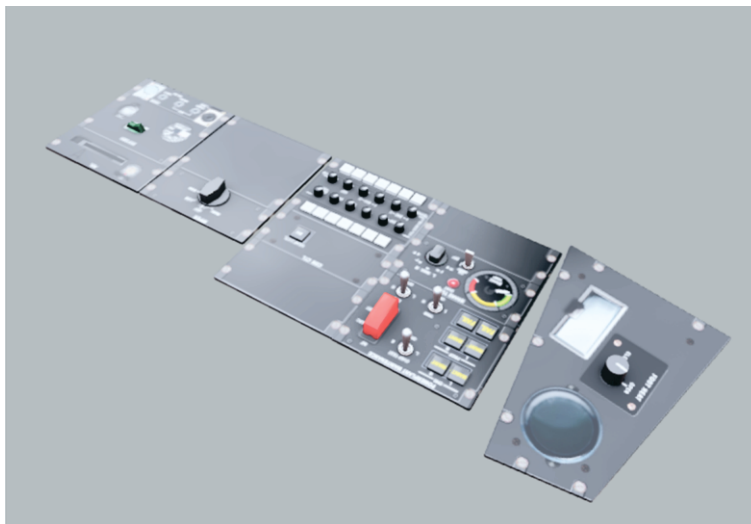


Figure 6. 3D equipment viewer

- TechDoc library module (TDLM): A lightweight document management layer that indexes technical manuals, videos, and schematics. It supports content retrieval based on metadata such as part ID, equipment group, or usage scenario.

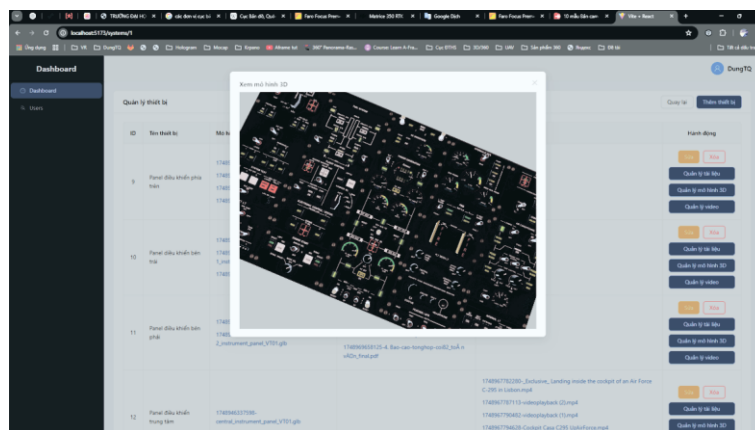


Figure 7. TechDoc library module interface showing indexed documentation linked to specific aircraft components via semantic search and metadata tags

This triad of modules ensures that learning and exploration are deeply intertwined with visual and textual reference materials, replicating hands-on engagement.

4.2. Backend services and integration logic

The backend is built on RESTful principles to allow modular communication between client interfaces and data repositories. Each endpoint delivers metadata and resource paths dynamically, enabling asynchronous loading:

- GET /api/models/:deviceId - Fetches associated 3D models with hierarchy metadata.
- GET /api/documents/:deviceId - Returns technical documentation links for the selected equipment.
- GET /api/scenes/:id - Loads panoramic image paths and spatial mapping information.

State synchronization is maintained through local JSON scene descriptors, which track object-document mappings. This allows the frontend to remain lightweight while adapting to diverse content sets.

4.3. Platform optimization and device interoperability

To ensure responsiveness and cross-device support, several optimization strategies were implemented:

- Lazy asset loading: Large assets (GLB models, panoramic textures) are loaded only when required. This minimizes memory usage and improves first-paint times.
- Adaptive rendering: The rendering engine adjusts resolution, draw distance, and texture fidelity based on hardware capabilities and network

conditions.

- VR and Non-VR modes: For VR headsets (e.g., Oculus Quest 2), the interface leverages WebXR APIs for controller mapping and spatial anchoring. Non-VR users access the same content via click-and-drag interfaces, ensuring universal usability.

These implementation strategies ensure that users across training centers, research units, and remote deployments can access the system reliably, regardless of device constraints.

5. EVALUATION AND USER TESTING

To enhance future evaluations, a comparative study involving a control group using traditional manuals will be considered. This will provide a clearer benchmark for measuring learning effectiveness across different training methods.

5.1. Evaluation design

To assess the usability and effectiveness of the virtual cockpit system, a two-phase evaluation was conducted. The first phase involved expert validation by training instructors, while the second phase included a user study with 30 technical trainees from the 918th Air Regiment. The primary metrics evaluated were usability, learning effectiveness, interaction fidelity, and perceived immersion.

5.2. Survey instrument

Participants responded to a structured questionnaire comprising 12 Likert-scale items (1 = Strongly Disagree, 5 = Strongly Agree). A sample of the survey questions is shown in Table 1:

Table 1. Sample Evaluation Questionnaire

Item No.	Evaluation criterion	Question
Q1	Usability	The interface is intuitive and easy to navigate.
Q4	Learning Support	The system helps me understand cockpit operations better.
Q7	Interaction	The 3D and 360° scenes respond smoothly to my actions.
Q10	Immersion	I feel immersed in the cockpit environment.

In addition to mean scores, standard deviations were computed for each evaluation criterion. For example, Usability (mean: 4.6, SD: 0.42), Learning Effectiveness (mean: 4.5, SD: 0.48).

5.3. Results and analysis

Figure 8 illustrates the average rating per dimension from the user group. All dimensions received mean scores above 4.2/5.0, indicating strong user satisfaction.

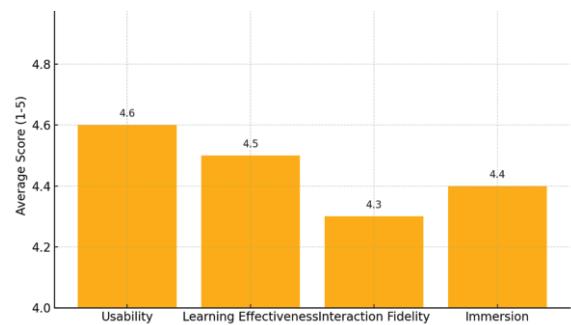


Figure 8. Mean Evaluation Scores Across Criteria (N = 30)

- Usability: 4.6/5.0 - praised for intuitive controls and modular layout.
 - Learning effectiveness: 4.5/5.0 - trainees reported improved spatial memory and part recognition.
 - Interaction fidelity: 4.3/5.0 - minimal lag, high responsiveness noted, especially in VR mode.
 - Immersion: 4.4/5.0 - users felt engaged and "present" inside the aircraft cockpit.
- A detailed breakdown of response percentages has been added in Table 2.

Table 2. Percentage Breakdown of Survey Responses

Evaluation criterion	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Usability	60%	30%	10%	0%	0%
Learning support	55%	35%	10%	0%	0%
Interaction fidelity	50%	40%	10%	0%	0%
Immersion	53%	37%	10%	0%	0%

5.4. Expert Feedback

Instructors highlighted the system's flexibility and readiness for broader application. Suggested improvements included expansion to other aircraft models and deeper integration with real-time simulation data.

The system's modular architecture allows adaptation for other aircraft models or even civilian aviation training scenarios. Future implementations could include platforms like UAV ground control stations or commercial pilot familiarization modules. Such extensions align with recent studies on the use of 3D technologies in broader education and training domains [6].

6. DISCUSSION AND COMPARATIVE ANALYSIS

6.1. Distinct Contributions of the System

The developed virtual cockpit system introduces several novel elements that distinguish it from existing training solutions:

- Web-Native deployment: Unlike traditional VR-based simulators that require proprietary hardware and local installation, this system operates fully in-browser, leveraging WebGL and WebXR for accessibility. This allows rapid scaling

across military units without infrastructure overhead.

- Hybrid visualization environment: The seamless integration of panoramic imagery with 3D models enables dual-context learning-allowing users to first understand spatial layout (macro-level) and then focus on subsystem details (micro-level).
- Document-Linked interaction: The tight coupling of visual interfaces and documentation enhances procedural understanding and supports just-in-time learning. This feature has rarely been implemented holistically in earlier systems.

6.2. Comparison with traditional training systems

The system does not yet support haptic feedback, which may limit realism in tactile-oriented tasks [7]. Some latency was noted during interaction, particularly with entry-level VR headsets. The system also requires stable internet bandwidth for full-resolution multimedia streaming.

Table 3 summarizes key differences between the proposed platform and two categories of training systems: Conventional physical mockups and high-end VR simulators.

Table 3. Comparative Analysis of Training Platforms

Criterion	Physical Mockups	High-End VR Simulators	Proposed Web 3D/360 System
Cost	High	Very High	Low to Moderate
Deployment	Fixed	Semi-mobile	Fully web-based
Realism	High	Very High	Moderate to High
Maintenance	High	Moderate	Low
Scalability	Poor	Moderate	High
Interactivity	Limited	High	High
Technical Documentation Support	External	Partial	Fully Integrated
Cost Range (USD)	\$100,000 - 300,000	\$200,000 - 500,000	~\$10,000 - 15,000

This comparison indicates that while high-end simulators provide superior immersion, their costs

and hardware dependencies limit widespread use. The web-based approach, while not as immersive,

strikes a balance between effectiveness, accessibility, and affordability - particularly suited for foundational training and knowledge reinforcement.

6.3. Reflections on training outcomes

Feedback from both instructors and trainees supports the system's ability to enhance learning retention and orientation within the aircraft environment. Users particularly appreciated the flexibility to train asynchronously and revisit technical procedures as needed. The system also demonstrated value as a supplementary platform for pre-briefings and debriefings.

However, limitations remain in areas such as haptic feedback, motion simulation, and full procedural walkthroughs involving cockpit interaction logic. These are aspects better handled by physical or hybrid VR simulators.

6.4. Potential for integration and future evolution

Given its modular design and adherence to web standards, the platform can evolve in several promising directions:

- Multimodal Integration: Combine the current system with real-time telemetry, voice-based virtual instructors, or AI-driven procedural feedback.
- Asset Expansion: Extend the platform to support other aircraft platforms or even ground vehicle simulations using the same framework.
- Interoperability: Enable API-level integration with logistics systems, maintenance databases, or learning management systems (LMS).

These pathways provide clear avenues to further strengthen the system's role in digital transformation within defense training ecosystems.

7. CONCLUSION AND FUTURE WORK

This study presented the design, development, and deployment of a web-based virtual cockpit training system for the CASA C-295 aircraft. The system combines 360-degree panoramic environments, interactive 3D models, and linked technical documentation to deliver an immersive and modular training platform. Leveraging modern web

technologies such as WebGL and WebXR [8, 9], the solution supports both VR and non-VR access, with optimizations for low-bandwidth environments and scalable deployment across devices.

One of the key achievements of the project is its successful real-world implementation at the 918th Air Regiment, where it has been actively used for technical training and operational familiarization. The positive feedback from both instructors and trainees highlights the system's effectiveness in enhancing spatial awareness, technical understanding, and self-paced learning. Its intuitive interface and low deployment footprint make it suitable not only for formal instruction but also for remote access and refresher sessions.

The platform's modular design and adherence to open standards position it well for further development. Future work will focus on:

- Expanding the content library to include additional aircraft types and technical systems.
- Enhancing interaction fidelity with haptic feedback and simulated cockpit controls.
- Integrating analytics for training assessment and personalized learning paths.
- Exploring AI-driven assistants and procedural guidance within the virtual space [4].

In summary, the system represents a scalable, accessible, and pedagogically grounded approach to modernizing technical training in the defense sector. Its successful deployment underscores the practical value of Web 3D/360 technology in real-world military education environments [1, 2, 10].

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REFERENCES

- [1] Z. Wang, L. Huang and S. Liu, "Virtual Reality-Based Military Training: A Review of Technologies and Applications," *Journal of Defense Modeling and Simulation*, vol. 19, no. 3, pp. 231-245, 2022.
- [2] B. Li, H. Yu, and X. Chen, "Deep Learning for Panoramic Image Stitching in Simulation Systems,"

Multimedia Tools and Applications, vol. 80, no. 4, pp. 6193-6212, 2021.

[3] Y. Gao, X. Zhang and M. Li, "Image Stitching Using Improved SIFT and RANSAC Algorithms," *IEEE Access*, vol. 7, pp. 112892-112901, 2019.

[4] Y. Chen, L. Fang, and D. Hu, "AI-Augmented

Panoramic Visualization for Technical Training Simulations," *Applied Sciences*, vol. 11, no. 22, pp. 10821, 2021.

[5] C. Gan, J. Liang, M. Gong, J. B. Tenenbaum, and A. Torralba, "ThreeDWorld: A platform for interactive multi-modal physical simulation," *arXiv preprint arXiv:2007.04954*, 2020. <https://doi.org/10.48550/arXiv.2007.04954>

[6] S. Münster, "Digital 3D technologies for humanities research and education: An overview," *Applied Sciences*, vol. 12, no. 5, p. 2426, 2022.

[7] F. G. Hamza-Lup and I. Sopin, "Web-based 3D and haptic interactive environments for e-learning,

simulation, and training," *Web Information Systems and Technologies*, vol. 18, pp 349-360, 2019.

[8] Mozilla Foundation, "A-Frame: A web framework for building virtual reality experiences." [Online]. Available: <https://aframe.io/>. [Accessed: Apr. 2025].

[9] Khronos Group, "WebGL - Open Graphics Library for the web." [Online]. Available: <https://www.khronos.org/webgl/>. [Accessed: Apr. 2025].

[10] B. Lee and Y. Park "Hybrid Training Approaches Using VR and Embedded Multimedia for Aircraft Maintenance," *Computers & Education*, vol. 161, Article ID 104060, 2021.

Nghiên cứu và phát triển hệ thống mô phỏng cabin ảo ứng dụng công nghệ Web 3D/360 cho máy bay CASA C-295

Trần Quang Dũng, Nguyễn Huy Liêm, Phạm Hoàng Hưng, Nguyễn Trung Kiên, Hồ Thị Thảo Trang

TÓM TẮT

Công nghệ thực tế ảo (Virtual Reality) và Web 3D/360 đang phát triển mạnh mẽ và ngày càng được ứng dụng rộng rãi trong các hệ thống huấn luyện quân sự nhằm nâng cao hiệu quả đào tạo và giảm thiểu rủi ro vận hành. Bài báo này trình bày quá trình nghiên cứu và phát triển hệ thống mô phỏng buồng lái ảo cho máy bay CASA C-295 dựa trên công nghệ Web 3D/360. Hệ thống được thiết kế với kiến trúc phân lớp, tích hợp môi trường toàn cảnh 360 độ, mô hình 3D tương tác, tài liệu kỹ thuật và nội dung đa phương tiện, cho phép triển khai linh hoạt trên nhiều thiết bị, bao gồm cả trình duyệt web và kính thực tế ảo. Quá trình xây dựng hệ thống bao gồm các bước chụp ảnh toàn cảnh buồng lái thực tế, xử lý ảnh, dựng mô hình 3D, và liên kết nội dung thông qua hệ thống siêu dữ liệu. Hệ thống đã được triển khai thử nghiệm tại Trung đoàn 918 và thu được kết quả tích cực, với mức độ hài lòng cao từ cả chuyên gia huấn luyện và học viên. Kết quả cho thấy hệ thống có tiềm năng lớn trong việc hỗ trợ đào tạo kỹ thuật, nâng cao nhận thức không gian và khả năng tự học của học viên, đồng thời là một giải pháp hiệu quả, tiết kiệm chi phí trong tiến trình chuyển đổi số giáo dục - đào tạo quân sự.

Từ khóa: thực tế ảo, Web 3D/360, huấn luyện nhập vai, buồng lái ảo, CASA C-295, mô phỏng quân sự

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