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The Application of Emerging Technologies in Electric Vertical Take-Off and Landing CBTA Training

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ABSTRACT

Electric Vertical Take-Off and Landing (eVTOL) aircraft are designed to transform Advanced Air Mobility (AAM) by providing effective, efficient, sustainable, and fast transportation options. These aircraft, which use electric propulsion for vertical takeoff and landing, are designed to alleviate urban congestion while offering an eco-friendly and efficient transportation solution. As the market for eVTOLs expands, the need for robust, competency-based training and assessment (CBTA) methods tailored to these new operational environments becomes paramount. In traditional aviation, pilot training has relied on fixed regulatory frameworks emphasizing standard skills and knowledge. However, the unique flight characteristics of eVTOLs, including their reliance on advanced technologies such as fly-by-wire systems and their operation in low-altitude, high-traffic urban areas, require a shift toward CBTA. This training approach focuses on developing key competencies needed for specific operational contexts, emphasizing real-world performance and safety. However, these aircraft's safe and effective operation requires a new approach to pilot training that focuses on Competency-Based Training and Assessment (CBTA). This paper explores the application of emerging technologies, including different aspects of Artificial Intelligence (AI) like Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), and Simulated Air Traffic Control Environment (SATCE) in simulation training focusing on eVTOL CBTA programs. Initially, it compares the regulatory frameworks of the Federal Aviation Administration (FAA) and the European Union Aviation Safety Agency (EASA). The research method follows an Evidence-Based Training approach and examines real-world business case studies from leading eVTOL manufacturers. Using the International Civil Aviation Organisation (ICAO) Analyze, Design, Develop, Implement, and Evaluate (ADDIE) framework, we analyze the integration of International Air Transport Association (IATA's) CBTA competencies in training and present key findings on how these technologies enhance training effectiveness while addressing regulatory challenges. Finally, the paper concludes with recommendations for harmonizing global regulatory approaches and leveraging technology to ensure safe and efficient eVTOL training.

Keywords: Artificial intelligence (AI), Virtual reality (VR), Augmented reality (AR), Mixed reality (MR), Simulated air traffic control environment (SATCE), Competency-based training and assessment (CBTA), Electric vertical take-off and landing (EVTOL) aircraft, Advanced air mobility (AAM)

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INTRODUCTION

The rise of Electric Vertical Take-Off and Landing (eVTOL) aircraft represents a major shift in the aviation landscape, especially in the context of Urban Air Mobility (UAM) / Advanced Air Mobility (AAM), (Airbus, 2023). These aircraft, which can take off and land vertically using electric propulsion, offer rapid, low-emission urban transportation potential. However, introducing eVTOLs also necessitates rethinking pilot training approaches due to these aircraft's novel operational challenges, particularly in dense urban airspaces (Ehang, 2023).

Competency-Based Training and Assessment (CBTA) has emerged as a critical approach for eVTOL training, emphasizing the development of key competencies beyond traditional pilot training frameworks. CBTA ensures that pilots are equipped with the skills and knowledge necessary to operate eVTOLs safely in complex environments. At the same time, emerging technologies such as Virtual Reality (VR), Augmented Reality (AR), Artificial Intelligence (AI), and advanced simulation tools are transforming the way pilots are trained, offering immersive, real-world training experiences that can enhance learning outcomes, minimizing the training cost and time (Table 1).

Table 1. Presentation of CBTA approach in the implementation of CBTA training programs for eVTOL pilots (Ziakkas et al., 2024).

CBTA Competencies	Pilot Competencies
PC 0	Application of Knowledge
PC 1	Application of Procedures
PC 2	Communication
PC 3	Aeroplane Flight Path Management, automation
PC 4	Aeroplane Flight Path Management, manual control
PC 5	Leadership & Teamwork
PC 6	Problem-Solving & Decision Making
PC 7	Situation Awareness and Management of Information
PC 8	Workload Management

This paper applies the ADDIE model (Analyze, Design, Develop, Implement, Evaluate) to explore the development and implementation of CBTA training programs for eVTOL pilots. It also provides a detailed comparison of the Federal Aviation Administration (FAA) and European Union Aviation Safety Agency EASA regulatory approaches and includes real-world business case studies from Joby Aviation, Volocopter, and Lilium to illustrate how these companies are addressing the challenges of eVTOL pilot training (Table 2. Ziakkas et al., 2024).

METHODOLOGY

The current research uses qualitative and quantitative methods to evaluate the impact of developing technologies on electric vertical take-off and landing CBTA training. The interpretivism approach was selected to study Emerging

Technologies and CBTA Training in Advanced Air Mobility. Through an extensive literature review and research with Future Aviation Simulation Technologies Gmbh (FAST) in Berlin, Germany, the Human Factors research team examines how human-centered design and AI affect CBTA training in upcoming electric vertical take-off vehicles (FAST, 2024). Future Aviation Simulation Technologies investigates and develops novel simulation models for eVTOL simulator adaptation, CBTA eVTOL pilot training using machine learning, and realistic winch simulations. The Research Onion approach (Saunders, 2019) is the foundation of the research methodology, as illustrated in Figure 1.

Figure 1: Emerging technologies implementation on electric vertical take-off and landing CBTA training research methodology.

The ADDIE Model

Our interpretivism approach follows the ICAO ADDIE model; ADDIE is a systematic instructional design framework used to develop aviation training programs. Table 2 presents the literature review findings focusing on the selected methodology, research objective, key activities, and examples from eVTOL companies worldwide.

This methodology provides a structured approach for designing and implementing CBTA programs, particularly for the emerging eVTOL market, in the following way:

- **Analyze**: Understanding the specific competencies required for eVTOL pilots based on operational and regulatory demands.
- **Design:** Creating training programs that integrate emerging technologies to address these competencies.
- **Develop**: Building training modules using VR, AI, and simulation tools to provide immersive learning experiences.
- **Implement**: Applying these training modules in real-world pilot training environments.
- **Evaluate**: Continuously assess the effectiveness of the training programs using data analytics and competency assessments.

Table 2. Presentation of the ADDIE model in the implementation of CBTA training programs for eVTOL pilots (Ziakkas et al., 2024).

ADDIE Phase	Objective	Key Activities	Examples from eVTOL Companies
Analyze	Identify training needs for eVTOL operations	1. Assess industry requirements (FAA, EASA standards) 2. Analyze skills gaps and challenges 3. Identify competencies for eVTOL pilots 4. Engage stakeholders	**Volocopter:** Collaborating with EASA for certification standards for urban air mobility pilots. **Joby Aviation:** Working closely with FAA on operational safety standards and SiPO for eVTOL operations.
Design	Create the CBTA training blueprint	1. Define measurable objectives 2. Develop an eVTOL-specific curriculum 3. Integrate emerging tech (wearables, VR, AR) 4. Plan training phases	**Joby:** Incorporating flight simulations and e-learning to teach new operational standards.
Develop	Create training materials and resources	1. Develop e-learning modules, flight scenarios, and evaluation tools 2. Program simulators with real-world eVTOL scenarios 3. Pilot-test training resources	**Volocopter:** Leveraging VR/AR to simulate urban flight paths. **Joby:** Creating simulations of high-density urban airspace.
Implement	Deliver training to eVTOL pilots	1. Launch the CBTA program 2. Conduct training using simulators and VR/AR. 3. Use wearables for performance tracking 4. Provide feedback	**Lilium:** Implementing the training program for the first commercial pilots by 2024. **Volocopter:** Integrating wearable tech in training to monitor real-time,
Evaluate	Assess and improve training effectiveness	1. Gather performance data 2. Collect feedback from trainees and instructors 3. Analyze the achievement of objectives 4. Adjust the program as needed.	**Joby:** Evaluating pilot readiness based on FAA-defined competencies.

ANALYSIS

Emerging technologies such as VR, AR, AI, and advanced simulations play a vital role in enhancing the effectiveness of CBTA programs for eVTOL training (Archer, 2023). Based on the literature review:

- Virtual Reality (VR): Provides immersive simulations of real-world urban environments, allowing pilots to practice navigation and emergency procedures without the risks associated with live flight (Ziakkas et al., 2023).
- Artificial Intelligence (AI): Facilitates personalized training by analyzing pilot performance and adjusting training scenarios based on individual needs (EASA, 2023).
- Simulation Tools: Advanced simulation software can replicate complex flight scenarios, including system failures, weather challenges, and urban airspace congestion.

- Wearable Technologies: Devices such as biometric sensors can track pilot stress levels and other physiological indicators during training, providing insights into a pilot's readiness.

The FAA and EASA have both developed frameworks for regulating eVTOL operations, but their approaches to CBTA training differ in several key areas:

- The FAA emphasizes adapting existing Part 135 and Part 61 regulations to cover eVTOL operations (FAA, 2024). However, the FAA is still in the process of developing specific guidelines for competency-based training in UAM environments.
- The EASA has been more proactive in creating the Special Condition for VTOL aircraft (SC-VTOL), which provides specific UAM and eVTOL pilot training guidelines. EASA's regulations also emphasize the use of emerging technologies in training, particularly for situational awareness and decision-making competencies.

FINDINGS

The development and operation of Electric Vertical Take-Off and Landing (eVTOL) aircraft require significant investments in technology and human capital. Beyond the technical capabilities of eVTOLs, the training infrastructure for pilots plays a key role in the business models of companies and training organizations. This section provides a detailed analysis of the financial aspects, including operating costs, return on investment (ROI), and training costs. We also discuss how established aviation training companies like FAST, CAE, and FlightSafety International are critical in developing training programs tailored to eVTOL operators. The transition towards eVTOL operations is characterized by notable technological and methodological progress. The following areas or domains of new technologies influence the application of CBTA in the AAM-UAM aviation ecosystem:

Operating Costs of eVTOLs and ROI for Operators

Operating Costs

Operating costs for eVTOLs differ from traditional aircraft in several key ways, mainly due to the reliance on electric propulsion and reduced mechanical complexity. However, the relatively novel nature of these aircraft means operators must make significant upfront investments, including training pilots and establishing maintenance infrastructure.

According to various industry estimates, the key components of operating costs include:

Battery and Energy Costs: Electric power consumption for eVTOLs is significantly lower than fuel-based aircraft, but maintaining and replacing batteries remains challenging. It is estimated that battery replacement could account for up to 30% of operating costs over the aircraft's lifespan.

Maintenance Costs: While eVTOLs have fewer moving parts, they require regular maintenance. The reliance on electric propulsion systems and the novelty of urban air mobility introduce additional requirements for specialized maintenance, driving up costs in the initial phases.

Infrastructure Costs: Developing vertiports and charging infrastructure for urban air mobility will be necessary. These costs are factored into the operating expenses for early adopters and will be a crucial element of any business plan.

Pilot Training Costs: The cost of training eVTOL pilots is a significant part of the operational expenditure, as companies need to invest in competency-based training programs and technologies like VR, AI, and simulation tools.

Return on Investment (ROI)

Several studies estimate that early-stage ROI for eVTOL operators will be dependent on key factors, such as:

Urban Air Mobility Demand: With the rise in demand for efficient urban transportation, eVTOL operators stand to gain if cities embrace UAM infrastructure. Some estimates suggest that urban air mobility could become a $1 trillion market by 2040.

Regulatory Approvals: ROI projections depend heavily on the speed at which regulators like the FAA and EASA approve eVTOL operations. Early movers like Joby Aviation and Lilium have already secured substantial investments, betting on the successful rollout of UAM services in the coming years.

Technology Adoption: Adopting advanced training technologies significantly reduces long-term training costs and improves pilot competency, ultimately leading to fewer operational risks and lower insurance costs.

For operators, breaking even on initial investments is projected to take anywhere from five to ten years, depending on the regulatory environment, the efficiency of infrastructure deployment, and the scalability of their services (Ziakkas et al., 2022).

Cost of Training and Training Organizations' Role

Training Costs

Training costs for eVTOL pilots are substantial due to the need for specialized programs that focus on the unique operational and regulatory challenges posed by UAM (Vertical Aerospace, 2023). According to early estimates from companies like FAST, the average cost of training a single eVTOL pilot is between $50,000 to $100,000, depending on the use of advanced technologies like VR and AI.

The identified key training costs include:

- Simulator Development: High-fidelity simulators replicating eVTOL urban operations can cost millions to develop. For example, FAST has invested heavily in full-motion simulators using VR-AR-MR, which provide pilots with an immersive training experience and minimize training costs.
- Virtual Reality (VR) Training Modules: VR training reduces the need for expensive in-air training hours and provides a safe environment for pilots to learn how to handle emergencies (SkyDrive, 2023). VR

systems can cost $200,000 to $500,000 to set up for large-scale training programs.

- Instructor Fees: Using experienced eVTOL instructors, many of whom come from traditional helicopter or fixed-wing backgrounds, adds to the overall cost. On average, flight instructor salaries range from $80,000 to $150,000 per year.

FAST, a global leader in aviation training has already established itself as a key player in the eVTOL space. The company has signed agreements with multiple eVTOL manufacturers to develop tailored pilot training programs that meet both FAA and EASA regulatory requirements.

CAE has partnered with companies like Volocopter to develop specialized training programs using advanced simulation technologies. These programs are designed to align with EASA's eVTOL framework and include scenario-based training that incorporates IATA/CBTA competencies. Furthermore, CAE has invested in cutting-edge full-flight simulators and VR-based training modules that enable pilots to experience complex urban air mobility scenarios. These tools enhance pilots' decision-making, situational awareness, and flight path management skills. CAE projects a significant return on its investment in eVTOL training due to the expected growth of the UAM market. The company plans to scale its training programs across global locations as demand for eVTOL pilots increases (CAE, 2023).

FlightSafety International (FSI) is another major player in the aviation training industry, focusing on providing high-fidelity simulators and advanced pilot training programs (FSI, 2023). FSI plans to create a range of advanced simulators specifically for eVTOL operations. FSI has worked closely with Lilium to ensure its training modules align with the aircraft's specific technical and operational requirements.

Business Case Studies: Joby Aviation, Volocopter, and Lilium

Joby Aviation (USA) aims to integrate VR and AI-driven simulators into its training programs to create immersive and realistic urban air mobility scenarios. The company's training programs are designed to meet FAA guidelines and focus on CBTA principles. Joby has secured over $800 million in funding and has invested substantially in aircraft development and training infrastructure. Joby's ROI projections are based on the assumption that its aircraft will enter service by 2025, with a focus on urban transportation networks in cities like Los Angeles and San Francisco (Joby, 2023).

Volocopter (Germany) has collaborated with CAE to develop its pilot training programs, which align with EASA's SC-VTOL standards. The use of VR and AI-driven performance assessment tools has enabled the company to reduce training times and costs while improving the quality of training. Volocopter has raised over €400 million and invested heavily in aircraft certification and pilot training. Volocopter anticipates breaking even within 7 to 8 years of launching its UAM services in European cities like Paris and Berlin (Volocopter, 2022).

Lilium's (Germany) training program incorporates AI-driven analytics to evaluate real-time pilot performance. The company has partnered with

FlightSafety International to create advanced simulators tailored to the unique flight dynamics of its eVTOL aircraft. Lilium has raised over $1 billion in funding and has invested significantly in training infrastructure. Lilium expects to begin commercial operations by 2026, with an expected ROI driven by its plans to operate eVTOL air taxis in multiple European and American cities (Lilium, 2023).

CONCLUSION

Developing specialized training programs for eVTOL pilots is essential for these aircraft's safe and efficient operation. Emerging technologies like VR, AI, and advanced simulators are critical in reducing training costs, improving pilot competency, and enhancing safety. Companies like FAST, CAE, and FlightSafety International are at the forefront of developing these training solutions, working closely with both FAA and EASA to ensure compliance with regulatory standards and implementing the CBTA concept. However, despite the promise of emerging technologies, challenges remain. The high upfront costs of developing eVTOL-specific simulators and training modules are significant, and the ROI for operators will depend heavily on the regulatory environment, demand for urban air mobility, and the scalability of training programs.

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