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The Role of Human Factors in the Certification of eVTOLs in the Artificial Intelligence (AI) Era

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ABSTRACT

The emergence of electric Vertical Take-Off and Landing (eVTOL) aircraft represents a paradigm shift in urban air mobility, promising safer, more efficient, and environmentally sustainable transportation. As the eVTOL industry progresses toward commercial deployment, certification processes have become a critical bottleneck, especially as they integrate advanced technologies such as Artificial Intelligence (AI). While the focus often lies on the technical and operational aspects of eVTOL certification, human factors play an equally vital role in ensuring safety, reliability, and public acceptance in this transformative era of aviation. This paper explores the intersection of human factors and AI-driven technologies in the certification of eVTOLs, emphasizing their impact on pilot training, operational frameworks, human-machine interfaces, and regulatory compliance. eVTOL certification introduces unprecedented challenges due to integrating novel propulsion systems, automation technologies, and AI-powered decision-making tools. Unlike traditional aircraft, eVTOLs rely heavily on AI for autonomous flight, collision avoidance, and air traffic integration functions. These systems require rigorous evaluation for their technical soundness and compatibility with human operators and the broader airspace ecosystem. Human factors encompass the cognitive, psychological, and physiological aspects of human interaction with aviation systems and are integral to the certification process. Regulators such as the Federal Aviation Administration (FAA) and the European Aviation Safety Agency (EASA) have recognized the importance of addressing these human factors, as evidenced by their increasing focus on human-machine interaction and pilot workload management in certification criteria. The certification process must evaluate the usability of AI systems through rigorous human-in-the-loop testing, ensuring that pilots can interact with AI systems in a way that enhances situational awareness and decision-making. Human factors considerations include the layout of control panels, clarity of AI-generated alerts, and the transparency of AI decision-making processes. Beyond regulatory compliance, addressing human factors is critical for gaining public acceptance of eVTOLs. Passengers must feel confident in the safety and reliability of these novel aircraft, particularly when AI is involved in their operation. Clear communication, robust safety protocols, and transparent certification processes can help build this trust. Human factors research plays a vital role in understanding and addressing passenger concerns, from designing comfortable and reassuring cabin environments to developing emergency response procedures. The certification of eVTOLs in the AI era requires a comprehensive approach that integrates human factors into every stage of the process. From human-machine interaction and pilot training to operational frameworks and regulatory compliance, addressing these factors is essential for ensuring this transformative technology's safety, reliability, and acceptance. As AI continues to shape aviation's future, human factors' role in certification will remain central to the successful deployment of eVTOLs, paving the way for a new era of urban air mobility.

Keywords: Certification, Artificial intelligence (AI), Electric vertical take-off and landing (eVTOL), European aviation safety agency (EASA), Federal aviation administration (FAA), Human factors, Human error, Performance, Reliability, Resilience

INTRODUCTION

The global aviation industry is transforming with the rapid advancement of electric Vertical Take-Off and Landing (eVTOL) aircraft. Designed for short-haul urban mobility, eVTOLs promise to alleviate urban congestion, reduce carbon emissions, and offer a sustainable alternative to ground-based transportation (Thipphavong et al., 2018). The growing demand for urban air mobility (UAM) has spurred significant technological innovations, particularly in the integration of artificial intelligence (AI) for flight automation, collision avoidance, and airspace management (EASA, 2024). These advancements have, however, introduced complexities in the certification process, necessitating a comprehensive evaluation of human factors in eVTOL operations.

Unlike traditional fixed-wing and rotorcraft aviation, eVTOLs rely heavily on novel propulsion systems and AI-driven automation (FAA, 2023a). The existing regulatory frameworks developed for conventional aircraft face challenges adapting to the technological innovations inherent in eVTOLs. Certification authorities such as the Federal Aviation Administration (FAA) and the European Union Aviation Safety Agency (EASA) emphasize the need for robust safety measures, with particular attention to human factors engineering (EASA, 2024). Integrating AI into pilot decision-making and aircraft control systems creates a new paradigm in human-machine interaction, which must be rigorously assessed before commercial deployment (Ziakkas et al., 2024a).

Human factors encompass cognitive, psychological, and physiological elements that influence human performance in aviation (Harris, 2011). These factors ensure that pilots, ground operators, and passengers can safely interact with eVTOL systems. The increasing reliance on AI raises concerns about cognitive workload, situational awareness, and decision-making accuracy, particularly in high-density urban airspaces (Dekker, 2014). Poorly designed human-machine interfaces (HMIs) can contribute to operational errors, leading to safety risks and reduced efficiency.

To address these challenges, regulatory bodies have outlined guidelines focusing on pilot workload management, decision-support tools, and the usability of AI-driven control interfaces (EASA, 2023). Explainable AI (XAI) has emerged as a critical area of interest, ensuring that human operators can understand and validate AI-generated decisions in real time (Ziakkas et al., 2024a). The certification of eVTOLs, therefore, must integrate human factors considerations to enhance operational safety and regulatory compliance.

AI-powered automation in eVTOLs fundamentally alters the traditional cockpit environment. While AI-driven systems enhance operational efficiency, they also introduce new challenges related to trust, reliance, and adaptability (Harris, 2011). Pilots transitioning from conventional aircraft to eVTOLs must undergo specialized training to adapt to these new technologies. The design of intuitive and user-friendly interfaces is crucial in mitigating human errors and optimizing performance (Dekker, 2014).

Research has highlighted the importance of human-in-the-loop (HITL) testing in evaluating eVTOL control systems. HITL simulations allow regulators and manufacturers to assess pilot performance in diverse scenarios, ensuring that AI-generated recommendations align with human expectations (Joby Aviation, 2023). Effective human-machine interaction strategies enhance safety and pave the way for broader acceptance of AI-driven aviation technologies (Lilium, 2024).

Beyond regulatory compliance, public perception plays a crucial role in successfully deploying eVTOLs. The general public remains skeptical about AI-driven aviation, particularly regarding autonomous operations and emergency response protocols (Cummings, 2017). Addressing these concerns requires transparent communication about safety protocols, AI decision-making processes, and the reliability of automated flight systems (Joby, 2023).

Passenger experience research underscores the need for user-centered design in eVTOL cabins, emphasizing comfort, accessibility, and emergency preparedness. Public education campaigns and pilot demonstration programs can help bridge the gap between technological advancements and societal trust, fostering a positive reception for eVTOL integration in urban mobility networks.

As AI continues to shape the aviation landscape, future research must focus on enhancing the integration of human factors in eVTOL certification. Areas of interest include adaptive pilot training methodologies, AI transparency frameworks, and the development of advanced HMIs that optimize situational awareness (Ziakkas et al., 2025). Collaborative efforts between academia, industry stakeholders, and regulatory agencies will be essential in establishing best practices for human-AI collaboration in urban air mobility.

The rapid evolution of eVTOL technology necessitates a proactive approach to addressing challenges related to human factors. By prioritizing safety, usability, and public trust, the aviation industry can pave the way for the successful certification and adoption of eVTOLs in the AI era.

METHODOLOGY

This study employs a qualitative research design utilizing thematic analysis based on the Saunders' Research Onion framework (Saunders, 2019). This methodological approach allows for an in-depth exploration of human factors, AI integration, and certification challenges in eVTOLs, using a structured layer-based method that enhances the validity and reliability of findings.

The research follows an interpretivist philosophy, aiming to understand human interactions with AI-driven aviation technologies. A deductive research approach is applied, drawing from established theories in human factors, AI decision-making, and aviation certification. Data is collected through a systematic review of 55 peer-reviewed journal articles published between 2019 and 2024, regulatory documents from FAA and EASA, and industry reports from major eVTOL developers.

Data sources include:

- Peer-reviewed articles (2019-2024) related to human factors, AI, and eVTOL certification.

- Regulatory documents from EASA's AI Roadmap 2.0 and FAA's certification guidelines.
- Industry reports from Lilium, Joby Aviation, and other eVTOL manufacturers.
- Human factors literature addressing pilot workload and decision-making in AI-driven cockpits.

A comprehensive literature search was conducted using databases such as Scopus, Web of Science, IEEE Xplore, and ScienceDirect, ensuring a wide scope of credible sources.

A thematic analysis was conducted to categorize data into meaningful themes, ensuring a systematic examination of human factors, AI applications, and certification challenges. The following themes and codes emerged from the analysis:

Theme 1: Human Factors in eVTOL Operations

- *Cognitive Workload (HF-CW)*: Impact of AI automation on pilot situational awareness and cognitive strain.
- *Human-Machine Interaction (HF-HMI)*: Challenges in AI-driven cockpit designs and usability of automation interfaces.
- *Decision-Making Under Automation (HF-DM)*: AI influence on pilot control, autonomy levels, and risk perception.
- *Trust in AI Systems (HF-TRUST)*: Psychological and operational factors affecting pilot and passenger trust in automated eVTOLs.

Theme 2: AI Integration in eVTOL Certification

- *Explainable AI (AI-XAI)*: Transparency in AI decision-making processes and regulatory acceptance.
- *AI-Pilot Collaboration (AI-COL)*: Role of AI as a decision-support tool versus fully autonomous operations.
- *Autonomous Safety Systems (AI-ASS)*: AI-driven collision avoidance, emergency response, and automated landings.

Theme 3: Certification Challenges for eVTOLs

- *Regulatory Compliance (EVTOL-REG)*: FAA & EASA adaptation to AI-driven aircraft.
- *Pilot Training & Transition (EVTOL-TRAIN)*: Training requirements for transitioning from conventional aviation to AI-assisted eVTOL operations.
- *Public Perception and Safety (EVTOL-PUB)*: Societal concerns about AI autonomy in urban air mobility and public confidence in certification

The thematic analysis was performed in the following structured manner:

1. Familiarization with Data: Reviewing and coding textual data from selected studies.
2. Generating Initial Codes: Assigning preliminary labels to key concepts.

3. Identifying Themes: Grouping related codes into overarching themes.
4. Reviewing Themes: Refining themes based on patterns across sources.
5. Defining and Naming Themes: Establishing a final set of themes and sub-themes for structured reporting.

This method allowed for a rigorous analysis of how human factors, AI, and regulatory frameworks interact in eVTOL certification.

To ensure reliability, the following measures were implemented:

- Triangulation: Comparing findings across multiple sources (academic, regulatory, and industry reports).
- Intercoder Reliability: Independent validation of coding consistency.
- Theoretical Saturation: Ensuring themes reflect broad and relevant subject matter coverage.

As this study is based on secondary data sources, ethical considerations focused on accurate representation of findings, proper citation of sources, and avoiding misinterpretation of regulatory documents.

FINDINGS

The Findings section delves into the impact of Simulated Air Traffic Control Environments (SATCE) on aviation performance, focusing on ASTi's Simulated Environment for Realistic ATC (SERA) system. This analysis encompasses civil and military applications, highlighting key areas such as communication competency, system reliability, and regulatory compliance.

The findings of this study are informed by real-world case studies and industry announcements, including regulatory frameworks set by EASA and the FAA, alongside key developments in Lilium and Joby Aviation. The intersection of human factors, AI, and certification in eVTOLs demonstrates the challenges and opportunities posed by automation in the aviation sector.

Cognitive Workload and AI-Driven eVTOL Interfaces

A core human factor in eVTOL certification is the cognitive workload associated with AI-driven flight operations. Research from Dekker (2014) and Harris (2011) emphasizes the need for a balanced workload distribution to ensure pilot situational awareness. Lilium's flight test reports highlight how AI reduces workload but introduces new challenges in human-machine interaction, particularly in urban environments with high-density air traffic (Lilium, 2024).

Similarly, FAA's stance on AI integration emphasizes explainability and pilot oversight (FAA, 2023a). XAI is seen as critical in reducing uncertainty, allowing pilots to trust automated flight decisions without unnecessary cognitive strain (Ziakkas et al., 2024b). Joby Aviation's approach to autonomous operations aligns with these principles, integrating redundancy systems to maintain human oversight even in high-autonomy flight modes (Joby Aviation, 2023).

Human-Machine Interface Design for eVTOL Cockpits

EASA's AI Roadmap 2.0 (EASA, 2023) underscores the importance of intuitive HMIs in AI-assisted aviation. The roadmap sets guidelines for AI transparency, ensuring pilots understand how automation makes critical decisions. Lilium has pioneered this approach by designing an AI-supported cockpit that blends manual and automated controls, facilitating smoother decision-making processes (Lilium, 2024).

Moreover, human-machine interaction literature, particularly from Harris (2011), highlights the risks of automation bias. Joby Aviation's pilot training programs, structured around AI-assisted flying, actively counteract over-reliance on automation, ensuring that pilots remain engaged in decision-making processes even when AI executes primary flight tasks (Joby Aviation, 2023).

Trust in AI and Public Perception Challenges

Public trust remains a pivotal element in eVTOL adoption. Research on automation in aviation by Cummings (2017) suggests that public skepticism toward AI-powered systems stems from concerns about autonomy and system failures. FAA regulations address these concerns by mandating transparency in AI decision-making processes, ensuring that AI-driven eVTOLs meet rigorous safety benchmarks before obtaining certification (FAA, 2023a).

Lilium and Joby have both launched public outreach programs emphasizing the safety and reliability of their AI-driven flight technologies. Lilium's AI-driven safety assessments have been publicly disclosed to build confidence among potential passengers, demonstrating a proactive approach to trust-building (Lilium, 2024). Similarly, Joby's partnerships with NASA in autonomous flight testing have contributed to increased public and regulatory acceptance of AI-enhanced eVTOL operations (Joby Aviation, 2023).

Regulatory Perspectives: EASA and FAA Certification Challenges

EASA's AI Roadmap 2.0 provides a structured framework for AI integration in eVTOL certification, setting parameters for AI explainability, risk assessment, and compliance (EASA, 2023). EASA's approach ensures that AI's role remains within human-centric safety frameworks, emphasizing human oversight even in autonomous flight operations.

On the other hand, the FAA has taken a step-by-step approach, requiring human pilot engagement in early-stage AI-driven eVTOL operations (FAA, 2023a). This phased certification process allows AI capabilities to be gradually validated before enabling full autonomy. Joby Aviation's FAA certification process aligns with this framework, demonstrating how AI can enhance flight safety while maintaining compliance with evolving regulatory requirements (Joby Aviation, 2023).

Explainable AI and Pilot Decision-Making

XAI is a critical component in AI-driven eVTOL certification. Litera highlights the necessity of XAI in ensuring that pilots can interpret

AI-generated recommendations effectively. Without clear AI reasoning, pilots may struggle to override system decisions in emergency scenarios.

Lilium has integrated XAI elements into its control systems, allowing pilots to review AI-generated navigation paths in real-time (Lilium, 2024). This transparency aligns with EASA's requirement for AI-human collaboration, ensuring that automation supplements pilot decision-making rather than replacing it outright.

Future Directions in Human Factors and AI Integration

Looking forward, the role of human factors in AI-driven eVTOLs will continue to evolve. As AI capabilities improve, regulators must develop adaptive certification processes that account for emerging safety challenges. Collaboration between regulatory agencies, industry leaders, and academic researchers is crucial in refining the balance between automation and human oversight.

Lilium and Joby have announced continued investments in AI-human collaboration research to enhance human-machine teaming capabilities. This research aligns with FAA's gradual AI certification roadmap, ensuring that eVTOL safety benchmarks evolve alongside technological advancements (FAA, 2023a; Joby Aviation, 2023).

CONCLUSION

The certification of eVTOLs in the AI era represents a fundamental shift in aviation safety, operational frameworks, and human-machine interaction. This study highlights the significant role of human factors in ensuring the successful integration of AI-driven eVTOLs, emphasizing cognitive workload management, trust in automation, HMI design, and public perception.

The study underscores the need for a balanced cognitive workload for AI-assisted eVTOLs pilots. AI can effectively reduce pilot burden but introduces new complexities, such as the risk of automation complacency. Lilium's AI-supported cockpit and Joby Aviation's focus on maintaining pilot engagement highlight the industry's efforts to optimize workload management while ensuring that pilots retain essential control functions.

Trust in AI-driven systems is critical to regulatory approval and public acceptance. FAA and EASA emphasize XAI as a crucial component of AI validation, ensuring that pilots can interpret and override AI-generated decisions when necessary. Lilium and Joby have incorporated XAI elements into their designs, offering transparency in automation logic and improving pilot situational awareness.

The HMI design is vital in AI-integrated aviation. EASA's AI Roadmap 2.0 emphasizes user-friendly HMI, ensuring intuitive control systems for pilots transitioning to eVTOLs. Lilium's and Joby's interface developments demonstrate industry alignment with regulatory standards, enhancing operational efficiency and safety.

Public perception remains a substantial hurdle in the commercial deployment of eVTOLs. Research suggests that societal skepticism toward AI-driven aviation stems from safety, reliability, and transparency concerns.

To address this, Lilium and Joby have launched extensive outreach initiatives, focusing on transparency in AI operations and compliance with safety protocols to build passenger confidence.

Regulatory bodies such as the FAA and EASA are progressively adapting certification frameworks to accommodate AI-driven aviation. EASA's AI Roadmap 2.0 provides structured guidelines for AI explainability, risk assessment, and compliance, ensuring that AI augments rather than replaces human oversight. The FAA's phased certification approach allows for gradual AI integration, reinforcing the necessity for human-in-the-loop validation.

XAI remains central to certification processes. The ability for pilots to understand AI-driven decision-making in real time ensures safety and accountability. Lilium's adoption of real-time pilot feedback mechanisms aligns with this requirement, fostering greater human-AI collaboration. Similarly, Joby's FAA certification process exemplifies a regulatory-compliant approach to AI integration in aviation.

Looking ahead, the aviation industry must continue investing in human factors research to refine AI-human collaboration. Adaptive pilot training methodologies, dynamic regulatory policies, and enhanced AI transparency frameworks will be critical in shaping the next generation of urban air mobility. Industry leaders, regulatory agencies, and academic researchers must collaborate to address emerging safety challenges while maintaining innovation in AI-assisted aviation.

Successfully deploying AI-driven eVTOLs depends on seamlessly integrating human expertise and automation. Human factors considerations—including cognitive workload management, intuitive HMI design, and trust in AI—remain at the forefront of certification efforts. Industry leaders such as Lilium and Joby are pioneering AI-human collaboration strategies that align with evolving regulatory expectations, ensuring operational safety and efficiency.

While AI presents opportunities to enhance aviation safety and performance, regulatory adaptation and public trust will determine the pace of eVTOL adoption. The future of urban air mobility hinges on a balanced approach that leverages AI's capabilities while preserving human oversight, ensuring a safe, efficient, and publicly accepted transformation in air transportation.

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REFERENCES

Cummings, M. (2017). Artificial intelligence and the future of warfare. https://www.semanticscholar.org/paper/Artificial-Intelligence-and-the-Future-of-Warfare-Cummings/7ad9f98c158d50e4f35f25f0f641b219f6a8a891

Dekker, S. (2014). *The field guide to understanding human error* (3rd ed.). Routledge.

European Union Aviation Safety Agency (EASA). (2023, May 10). *Artificial Intelligence Roadmap 2.0 published - A human-centric approach to AI in aviation*. EASA. https://www.easa.europa.eu/en/newsroom-and-events/news/easa-artificial-intelligence-roadmap-20-published

European Union Aviation Safety Agency (EASA). (2024, June 10). *Special condition for VTOL and means of compliance*. EASA. https://www.easa.europa.eu/en/document-library/product-certification-consultations/special-condition-vtol

Federal Aviation Administration (FAA). (2023a). Advanced Air Mobility. FAA. https://www.faa.gov/air-taxis

Federal Aviation Administration (FAA). (2023b). Air Traffic Controller Training and Certification: Title 14 CFR Part 65. FAA. https://www.faa.gov

Harris, D. (2011). *Human performance on the flight deck*. Routledge.

Joby Aviation. (2023, August 2). *Joby Aviation reports second quarter 2023 results*. https://www.jobyaviation.com/news/joby-aviation-reports-second-quarter-2023-results/

Lilium. (2024, October 23). *GE Aerospace partner to deliver eVTOL flight safety*. https://lilium.com/newsroom-detail/lilium-ge-aerospace-partner-to-deliver-evtol-flight-safety

Saunders, M., Lewis, P., & Thornhill, A. (2019). Research Methods for Business Students Eighth Edition. In *Research Methods for Business Students*. Pearson Education Limited.

Thipphavong, D. P., Apaza, R., Barmore, B., Battiste, V., Burian, B., Dao, Q., Feary, M., Go, S., Goodrich, K. H., Homola, J., Idris, H. R., Kopardekar, P. H., Lachter, J. B., Neogi, N. A., Ng, H. K., Oseguera-Lohr, R. M., Patterson, M. D., & Verma, S. A. (2018). Urban Air Mobility Airspace Integration Concepts and Considerations. 2018 Aviation Technology, Integration, and Operations Conference. https://doi.org/10.2514/6.2018-3676

Ziakkas, D., & Plioutsias, A. (2024a). *Artificial intelligence and human performance in transportation*. CRC Press. https://doi.org/10.1201/9781003480891

Ziakkas, D., Henneberry, D., & Pechlivanis, K. (2024b). *Application of emerging technologies in Electric Vertical Take-Off and Landing CBTA training*. In: Tareq Ahram and Waldemar Karwowski (eds) Human Factors in Design, Engineering, and Computing. AHFE (2024) International Conference. AHFE Open Access, vol. 159. AHFE International, USA. https://doi.org/10.54941/ahfe1005776

Ziakkas, D., & Henneberry, D. (2025). *The role of immersive technologies in the design of eVTOL simulators*. In: Tareq Ahram, Waldemar Karwowski, Carlo Martino, Giuseppe Di Bucchianico and Vincenzo Maselli (eds) Intelligent Human Systems Integration (IHSI 2025): Integrating People and Intelligent Systems. AHFE (2025) International Conference. AHFE Open Access, vol. 160. AHFE International, USA. https://doi.org/10.54941/ahfe1005869