Available Online: 29 September 2025 DOI: 10.54254/2977-3903/2025.27486

eVTOL development under the low-altitude economy paradigm: technologies, applications, and challenges

Xiyuan Wang

Nanchang NO.5 High School, Nanchang, China

3760099384@qq.com

Abstract. As an emerging industrial paradigm, the low-altitude economy is rapidly developing, with Electric Vertical Take-off and Landing (eVTOL) aircraft as a key enabling platform. This paper reviews major advances in eVTOL technologies, including configuration design, distributed electric propulsion, and flight-control and autonomous-navigation systems. It also analyzes the progress of representative companies and products, application scenarios, demonstration projects, and supporting infrastructure and operational systems. Current challenges include flight safety and noise control, delayed airworthiness certification and airspace management, and unclear business models. In the future, the integration of artificial intelligence, cooperative low-altitude traffic management, and standardized regulatory frameworks is expected to enable autonomous and large-scale eVTOL operations, driving the low-altitude economy toward maturity.

Keywords: eVTOL, low-altitude economy, flight safety

1. Introduction

Low-Altitude Economy (LAE) is an emerging, integrated economic paradigm centered on low-altitude flight operations. It combines crewed and uncrewed aerial systems with low-altitude aeronautical Internet-of-Things (IoT) and is closely linked with airspace resources and industrial market [1]. LAE covers four main sectors: low-altitude manufacturing, operations, assurance, and integrated services, spanning primary, secondary, and tertiary industries. Representative platforms include Unmanned Aircraft Systems (UAS), Electric Vertical Take-off and Landing (eVTOL) vehicles, rotorcraft, and conventional fixed-wing aircraft, serving applications such as passenger mobility, cargo logistics, precision agriculture, and emergency response. LAE is characterized by multi-dimensional spatial use, industrial integration, and technology-driven development.

In China, LAE has advanced rapidly. In March 2024, the term “low-altitude economy” appeared in the State Council’s Government Work Report for the first time. In July, the Third Plenary Session of the 20th CPC Central Committee called for the development of general aviation and LAE. In November, Airshow China launched a “Low-Altitude Economy Pavilion” to showcase related equipment and operational models. These initiatives provide national-level strategic signals and opportunities for the entire industrial chain.

Among various aerial platforms, eVTOL aircraft have emerged as key enablers for Urban Air Mobility (UAM) and short-range transport due to their low-carbon, safe, efficient, and flexible feature [2]. Advances in Distributed Electric Propulsion (DEP), high-energy-density storage systems, and lightweight composite materials have supported eVTOL commercialization. Morgan Stanley projects the global UAM market will reach USD 1 trillion by 2040 and USD 9 trillion by 2050. In China, policy, technology, and commercialization efforts are advancing in coordination: a national Low-Altitude Economy Development Department has been established, and over twenty provinces and municipalities have launched industry funds totaling more than RMB 100 billion. The EH216-S by EHang became the first eVTOL worldwide to obtain Type, Production, and Airworthiness Certificates, and AutoFlight’s cargo eVTOL has also received TC certification. Current applications include urban commuting, medical evacuation, and freight transport. By 2035, China’s LAE market is expected to exceed RMB 3.5 trillion, with eVTOL as a core growth driver.

This paper reviews key eVTOL technologies, including configuration design, propulsion and power systems, and flight-control and autonomous-navigation systems. It analyzes industrial ecosystems and representative use cases, identifies technical, regulatory, and business-model challenges, and outlines future development directions.

2. Current state of eVTOL technology development

2.1. Configuration design

The configuration of an eVTOL vehicle directly affects its aerodynamic efficiency, mission suitability, and system complexity. Three main configurations are commonly used based on lift and propulsion methods: multi-rotor, lift-plus-cruise (compound wing), and tilt-rotor. Each configuration has distinct advantages in Urban Air Mobility (UAM), regional transport, and specialized missions.

Multi-rotor configuration. Multiple fixed-pitch rotors generate both lift and thrust. The absence of tilting mechanisms results in a simple structure with high redundancy. Failure of a single rotor can be compensated by the remaining units [3]. This configuration offers strong vertical take-off and landing capability and agile control, suitable for short-range city operations (< 50 km) with small payloads (1-4 passengers). The EHang EH216 is a typical example. Limitations include lower energy efficiency, shorter range, and higher noise levels.

Lift-plus-cruise configuration. This design combines vertical-lift rotors with a fixed wing. Lift rotors provide vertical lift during take-off and landing, while the fixed wing and separate cruise propulsors provide thrust during cruise. This separation improves lift-to-drag ratio and extends range. Representative vehicles include Joby S4 and VoloConnect. Challenges include complex flight-control requirements and coupled dynamics during mode transitions, but the configuration is advantageous for medium-range regional transport.

Tilt-rotor configuration. Rotors tilt mechanically between vertical and horizontal positions, allowing helicopter-like take-off and fixed-wing cruise. This configuration supports high cruise speeds (250-320 km/h) and long ranges (> 200 km). The Autoflight AE200 is an example. Benefits include high cruise efficiency, flexible mission profiles, and safety redundancy. Drawbacks include mechanical complexity, high maintenance demands, and strict requirements for noise and vibration control.

2.2. Propulsion and energy systems

Contemporary eVTOL propulsion mainly adopts two approaches: distributed electric propulsion and hybrid-electric architectures. Distributed Electric Propulsion deploys multiple small electric motors with propellers or ducted fans across the airframe. Independent thrust control enables vectored thrust, redundancy, and load sharing, while allowing aerodynamic optimization to improve lift-to-drag ratio [4]. This layout reduces single-point failure risks and enhances control flexibility. Hybrid-electric propulsion combines internal combustion engines with electric motors in series, parallel, or series-parallel configurations to achieve extended range and rapid refueling, suitable for long-distance and high-payload missions. Challenges include complex power management and mechanical transmission efficiency losses.

Energy storage technologies include high-specific-energy lithium-ion batteries, hydrogen fuel cells, and emerging superconducting propulsion. Lithium-ion batteries are mature and easy to maintain, but their energy density limits range [5]. Hydrogen fuel cells provide higher gravimetric energy and fast refueling, yet hydrogen storage and safety remain critical constraints. Superconducting propulsion is still in experimental stages, offering potential for substantial gains in power density and efficiency in the long term.

2.3. Flight control and autonomy

Flight-control and autonomous-navigation systems form the safety-critical core of eVTOL operations. The control paradigm is evolving from classical stability-augmentation loops to AI-enabled adaptive control and autonomous decision-making, supported by high-precision sensor fusion, real-time computing platforms, and advanced algorithms [6].

Localization and mapping Simultaneous Localization and Mapping (SLAM) integrates vision, LiDAR, and IMU data to achieve centimeter-level positioning and mapping in unknown or GPS-denied environments. Vision-based SLAM is cost-effective and information-rich but sensitive to lighting; LiDAR-based SLAM offers stability in low-visibility conditions. Multi-sensor fusion combines these advantages to enable high-accuracy navigation in complex urban airspace.

GNSS and INS integration A tightly coupled GNSS/INS system provides absolute positioning and continuous dead-reckoning. Kalman-filter-based algorithms maintain accuracy and reliability even when satellite signals are blocked.

Environmental perception Cameras, LiDAR, and millimeter-wave radar form a complementary sensor suite. Cameras detect dynamic obstacles and runway features, LiDAR produces dense 3D point clouds for geometric avoidance, and radar ensures detection in adverse weather. Multi-modal perception allows real-time obstacle avoidance and 4-D trajectory planning in congested airspace.

The future flight control and autonomous navigation systems will further enhance the level of task autonomy, enabling the entire process of vertical takeoff and landing, cruising, obstacle avoidance and landing to be carried out autonomously. At the same time, higher requirements will be placed on algorithm verification, system redundancy and regulatory compliance.

3. eVTOL industrial ecosystem and application scenarios

3.1. Leading enterprises and product progress

In the global market, Joby, Lilium, Archer, and Volocopter represent different technological approaches and business models. Joby's S4 uses a six-rotor tilt-prop design with a range of about 240 km. The company has obtained FAA Part 135 operating authority and is in the final stage of type certification. Lilium Jet features distributed electric jet propulsion, focusing on regional air mobility. It has received EASA Design Organization Approval and secured multiple international orders. Archer's Midnight targets short-range urban transport. The aircraft is advancing through FAA certification and supported by partnerships with United Airlines for route development and Stellantis for large-scale production. Volocopter follows a simplified multi-rotor design. It has already started trial operations in Europe and aims to provide urban air taxi services with its VoloCity platform.

In China, EHang's EH216-S became the first eVTOL worldwide to obtain all three certificates: Type Certificate, Production Certificate, and Standard Airworthiness Certificate. This milestone enabled the aircraft to enter commercial service. Fengfei's AE200 has made progress in tilt-rotor design and cargo applications. Other companies, such as Shidai Technology, are speeding up prototype development and testing.

Overall, international companies tend to focus on long-range performance and premium markets, while Chinese companies benefit from supportive policies and rapid deployment in practical scenarios. These differences are reflected in technology choices, investment levels, and certification progress, forming a diversified global development pattern.

3.2. Use cases and demonstration programmes

The principal application domains of eVTOL include Urban Air Mobility (UAM), Regional Air Mobility (RAM), low-altitude cargo logistics, emergency medical transport, and aerial tourism. UAM focuses on improving commuting efficiency in high-density metropolitan areas, typically through on-demand air taxis and fixed-route "aerial bus" service [7]. RAM serves as a supplement to intercity and regional transport, covering mid-range distances of 50-200 km. Cargo logistics are oriented toward express delivery and last-mile distribution, particularly for time-sensitive and high-value goods. In the medical field, applications highlight emergency rescue and organ transfer. Tourism, meanwhile, leverages the advantages of low noise and vertical take-off and landing to create new business models within the low-altitude economy.

Demonstration programmes underscore differing regional approaches. Dubai has taken the lead in developing urban aerial corridors, planning four vertiports to establish a low-altitude transport network. Singapore has carried out air-taxi flight trials in the Marina Bay area, exploring integration with smart-city infrastructure. In China, Guangzhou and Shenzhen have established low-altitude economy pilot zones, with EHang's EH216 already approved for commercial operations and engaged in passenger demonstration flights. These practices suggest that international demonstration programmes concentrate on validating air-mobility operations, whereas domestic initiatives are more policy-driven and emphasize ecosystem collaboration, reflecting divergent development pathways.

3.3. Enabling infrastructure and operating ecosystem

The large-scale deployment of eVTOL relies on a complete infrastructure and operating system. On the vertiport side, a distributed network must be built, including both land-based and water-based take-off and landing sites, equipped with fast-charging or battery-swapping stations to support high-frequency operations. For airspace management, digitized systems will integrate satellite navigation, 5G/6G communications, and high-resolution meteorological services to provide real-time monitoring and dynamic scheduling, ensuring safe and efficient use of low-altitude routes [8]. Internationally, the FAA is conducting UAM Corridor trials in the United States, while Skyports in the UK has constructed multiple demonstration vertiports, showing that future low-altitude hubs will be closely linked with airports and urban transport nodes. In terms of operations, intelligent dispatch platforms will connect flight routes, fleets, and energy supply, enabling unmanned scheduling and cluster management. Furthermore, eVTOL must be integrated into a broader mobility ecosystem, achieving seamless connections with metro, bus, and taxi services to form an "Space-air-ground integrated" multimodal transport system. Overall, infrastructure development and digital operational capability are the key enablers for the commercialization of eVTOL.

4. Current challenges and bottlenecks

4.1. Critical technology challenges

The development of eVTOL systems continues to face multiple technological bottlenecks. Energy and endurance. Current lithium-ion batteries typically provide less than 300 $Wh \cdot kg^{-1}$ at the pack level, limiting operations to short-range flights and falling short of the range and high-frequency rotations required for Urban Air Mobility [9]. Key breakthroughs will depend on improving specific energy, cycle life, and fast-charging capability, or adopting alternative energy sources such as solid-state batteries and hydrogen fuel cells. Flight safety and redundancy. With most eVTOL platforms adopting distributed electric propulsion architectures, any single motor or control-unit failure must be accommodated by redundant design and real-time fault-tolerant control to meet airworthiness standards and build public trust. Yet, the relevant technologies and certification frameworks remain under development. Noise control and urban compatibility. Although eVTOLs produce lower overall noise than helicopters, high-frequency rotor harmonics and the cumulative effect of fleet operations may still disturb residents in dense urban areas. Reducing rotor noise at the design stage, while optimizing flight paths and operational altitudes, will directly affect their acceptance in city airspace and the pace of large-scale adoption.

4.2. Regulatory and standardization barriers

The large-scale commercialization of eVTOL requires a comprehensive regulatory and standardization framework, yet significant barriers remain. First, airworthiness certification systems lag behind technological advances. Existing certification frameworks, designed primarily for conventional manned aircraft, do not fully address the characteristics of distributed electric propulsion, all-electric powertrains, and automated flight functions. As a result, certification processes are lengthy and ambiguous, hindering rapid product iteration and timely market entry. Second, airspace management and traffic regulations lack systematic solutions. In China, low-altitude airspace remains largely under military control with limited civil access, and there is no unified standard for classification or entry conditions. Complex approval procedures further limit the feasibility of high-frequency, large-scale UAM operations. Third, interoperability of technical standards remains insufficient. Communication links, charging and battery-swapping infrastructure, and digital air traffic management systems are not yet standardized, leading to compatibility issues across manufacturers and regions. This constrains the seamless integration of operational platforms, scheduling systems, and ground transportation networks.

4.3. Business models and user acceptance

The commercialization of eVTOL faces challenges in both cost structure and operational support systems. Current vehicle manufacturing and Research and Development costs are substantial, while limited passenger capacity results in high unit operating expenses. At the same time, maintenance networks and energy supply infrastructure remain underdeveloped, constraining large-scale and routine operations. In addition, public acceptance requires further improvement. Concerns regarding flight safety, noise impacts, and privacy protection reduce user trust in low-altitude air mobility. Compared with ground-based transport, eVTOL services currently lack price competitiveness and a proven record of reliability, which significantly restricts consumer demand. Finally, viable business models are still in the exploratory stage. Present operations focus mainly on niche markets such as premium business travel, medical emergency response, and aerial tourism, leaving a gap before sustainable large-scale markets can emerge. Governments may foster adoption through demonstration projects and policy incentives, while encouraging operators to experiment with diversified revenue models to facilitate the transition from subsidy dependence to market-driven growth.

5. Development trends and future outlook

5.1. Technological integration and intelligent evolution

The future development of eVTOL will increasingly rely on the deep application of artificial intelligence, large-scale models, and edge computing to enable a transition from manual piloting to fully autonomous operations, enhancing environmental perception and decision-making capabilities. Digital twin technology, by integrating physical models, sensor data, and historical operational information, can create a virtual representation of the entire lifecycle of an aircraft, supporting design optimization, operational monitoring, and maintenance decision-making. Meanwhile, Prognostics and Health Management (PHM) systems are emerging as a core focus, using sensors and intelligent algorithms to provide real-time diagnostics and life-cycle predictions, thereby improving safety and reliability. As these technologies mature, eVTOL platforms are expected to evolve into intelligent aerial transportation systems with autonomous learning and self-maintenance capabilities.

5.2. Coordination with low-altitude air traffic management

The large-scale operation of eVTOLs requires deep integration with low-altitude air traffic management systems. Future development should establish a “space-air-ground integrated” digital ATC platform, enabling real-time connectivity among aircraft, ground stations, and air traffic control center. Airspace management can adopt a layered structure, dynamically allocating corridors based on altitude, mission type, and risk level, while AI scheduling and edge computing provide real-time route optimization and conflict prevention. Digital twin mapping of airspace will play a critical role, simulating flight states and environmental constraints to support risk prediction and operational simulation. Simultaneously, interface standards with existing civil ATC systems should be gradually developed to ensure interoperability and operational redundancy.

5.3. Evolution of standards and policy frameworks

The industrialization of eVTOL depends on comprehensive policy and standards frameworks. First, airworthiness certification and operational regulations tailored to the low-altitude economy should be accelerated, covering safety certification, flight rules, and service assurance, while exploring zoned and classified regulatory approaches. Second, pilot demonstration cities should be promoted to test infrastructure, operational platforms, and ATC integration, generating replicable experience. At the same time, industry clustering along the supply chain should be encouraged to build a collaborative ecosystem encompassing complete aircraft manufacturing, critical components, and operational services. Policy support, such as financial subsidies, tax incentives, and government procurement, can reduce enterprise costs and stimulate market participation.

6. Conclusions

Electric Vertical Take-Off and Landing (eVTOL) aircraft, as a core enabler of the low-altitude economy, are gradually demonstrating application potential across urban air mobility, regional connections, cargo logistics, and emergency response due to their low noise, zero emissions, and high maneuverability. However, the industry currently faces multiple challenges, including limited energy density, stringent requirements for flight safety and system redundancy, noise mitigation, and urban environmental compatibility, alongside lagging regulatory frameworks, standards development, and nascent commercial models. Future development requires coordinated efforts on three levels: first, the technological level, by accelerating the adoption of intelligent, autonomous operations and digital-twin-based health management systems; second, the policy level, by improving airworthiness certification, airspace management, and unified standards while supporting pilot cities and industrial clusters; and third, the industrial level, by exploring sustainable business models and enhancing user trust and acceptance. Through technological innovation, policy support, and multi-stakeholder collaboration, eVTOL is poised to become a key driver for the large-scale growth of the low-altitude economy.

References

[1] Ren, X., & Wang, J. (2025). Symbiotic evolution mechanism of urban air mobility industrial innovation ecosystem: Evidence from low altitude air mobility in Shenzhen. *Journal of Air Transport Management, 124*, 102750.

[2] Sadrani, M., Adamidis, F., Garrow, L. A., Bäumer, M., & Fichert, F. (2025). Challenges in urban air mobility implementation: A comparative analysis of barriers in Germany and the United States. *Journal of Air Transport Management, 126*, 102780.

[3] Shahjahan, S., Gong, A., & Moore, A. (2024). Optimisation of proprotors for tilt-wing eVTOL aircraft. *Aerospace Science and Technology, 144*, 108835. https: //doi.org/10.1016/j.ast.2023.108835

[4] He, J., He, Q., & Xu, Z. (2024). Key technologies and upgrade strategies for eVTOL aircraft energy storage systems. *Journal of Energy Storage, 103*(Part B), 114402. https: //doi.org/10.1016/j.est.2024.114402

[5] Osman, A. A., Mistarihi, M. Z., & Ramadan, M. (2025). A review and bibliometric analysis of intelligent techniques for advanced battery state estimation in aviation propulsion systems. *Results in Engineering, 27*, 106741. https: //doi.org/10.1016/j.rineng.2025.106741

[6] Xiang, S., Xie, A., & Ye, M. (2024). Autonomous eVTOL: A summary of researches and challenges. *Green Energy and Intelligent Transportation, 3*(1), 100140. https: //doi.org/10.1016/j.geits.2023.100140

[7] Zewde, L., & Raptis, I. A. (2025). Conceptualizing UAM: Technologies and methods for safe and efficient urban air transportation. *Green Energy and Intelligent Transportation*, 100265. https: //doi.org/10.1016/j.geits.2025.100265

[8] Pongsakornsathien, N., El-Din Safwat, N., Xie, Y., & Delahaye, D. (2025). Advances in low-altitude airspace management for uncrewed aircraft and advanced air mobility. *Progress in Aerospace Sciences, 154*, 101085. https: //doi.org/10.1016/j.paerosci.2025.101085

[9] Yang, J., Chen, S., & Pang, T. (2025). A concurrent estimation framework for multiple aging parameters of lithium-ion batteries for eVTOL applications. *Applied Energy, 399*, 126500. https: //doi.org/10.1016/j.apenergy.2025.126500