Designs for Low-Altitude Drones in the Aspect of Transportation Efficiency and Safety

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Abstract. With the rise of the low-altitude economy, drone logistics has become a crucial component in smart city development. This paper systematically investigates the core characteristics and current state of development for low-altitude transport drones. It first analyses research progress concerning transport efficiency, focusing on recent achievements in route planning, airspace utilization, and energy consumption optimization. Subsequently, it comprehensively reviews innovative breakthroughs in safety technologies, including developments in key techniques such as perception-avoidance systems based on multi-sensor fusion and power redundancy design. By establishing a multi-dimensional comparative framework with consumer-grade drones, the study deeply reveals the fundamental differences between the two drone systems across three dimensions: design philosophy, technical standards, and operational models. Finally, addressing core challenges such as current technical bottlenecks, regulation frameworks, and insufficient societal acceptance, the paper proposes systematic development recommendations encompassing three dimensions: technical pathways, policy frameworks, and public engagement. This research provides theoretical foundations and practical guidance for the technological evolution, policy formulation, and commercial application of low-altitude transport drones.

Keywords: Low-Altitude Drones, Efficiency, Safety, Design, Comparison.

1. Introduction

Recorded from 2021, data for the size of the low-altitude economy market in China maintained a stable increasing rate of 20% yearly, and it was valued at 506 billion RMB (65 billion EUR) at the end of 2023 [1]. With the evolution in technical aeronautics and communications and industrial transformation, the low-altitude economy has risen over the past few years. There is no doubt that drones play an essential role in it. Except for precise navigation and automatic industrial manufacture, there are other prerequisites for the popularity of drones. For example, the latest energy system provide a longer battery life, while the development in artificial intelligence make it wiser in decision-making process, which can respond rapidly and avoid obstacles properly. In the long run, the cost on drone transportation is much lower than that on traditional delivery. According to the statistics, the packages delivered in China in 2024 is 2.7 million [2]. In the same year, there are 29 provinces in China introduced friendly policies in order to facilitate related industries to develop the applications of drones around the low-altitude economy, including the aspects of manufacture of drones, related tourism [3].

Another reason why drones rose rapidly these years is the social demand. This can be divided into two main categories, commercial demand and public emergency demand. Drones are able to save time spent during the delivery, which results in a significant increase of transportation efficiency. For Takeout companies, a high working efficiency means that more orders can be delivered within a fixed time, which represents higher profits. Likewise, for public emergency demand, drones can be responsible for the urgent delivery of medical supplies, like medicine and part of medical devices. Even blood samples can be transported efficiently through drones.

As for the low-altitude economy, it is defined as a rising economic system that consists commercial as well as service activities, within the vertical height scope of 0 to 3000 meters [4]. Besides, for the low-altitude drone, it is described as a small unmanned aircraft, which can be controlled by humans on the ground [5].

Since drones are widely used in low-altitude economy, their potential is discovered not only in the field of material delivery, but also in agriculture system, which can help spray pesticides precisely. However, there are several types of drones available on the market with different designs and efficiency. Furthermore, with a large amount of drones flying in a low altitude, it is unavoidable to experience impacts, especially in crowded cities. The purpose is to analyze the dialectical relationship between efficiency and safety on drones. This essay is going to talk about the following contents: background theories, progress of drone-transportation efficiency (key factors and the fitment with city) up to now, current safety research, comparison between low-altitude drone and normal drones, and finally the challenges and developments as well as future trends of drone design. Further explanation on these topics will be given in the following text.

2. Progress of The Delivery Efficiency

2.1. Background Theories

Aerodynamics is the main principle behind the development of drones, which acts as an important part in Fluid Mechanics. The most fundamental theories are Bernoulli’s Equation

$$\mathrm{p}+\frac{1}{2}\rho\mathrm{v}^2+\rho\mathrm{gh}=\mathrm{constant} \tag{1}$$

And Drag Force Equation

$$F_D=\frac{1}{2}\rho v^2 C_D A \tag{2}$$

Concerning the transportation efficiency, Bernoulli’s Equation is mainly used to find the relationship between fluid velocity and the pressure at the same location. To simplify this principle, the pressure will decrease when velocity increases. For instance, it can help design the shape of wings of some specific drones, which has a similar outline as ordinary planes, with an attack angle on the upper surface of and a smooth lower surface. This design leads to higher air velocity at the upper surface and lower air velocity at the bottom surface. As a result the pressure above is lower than that at bottom surface, which creates an upward force (lift force). For the Drag Force Equation, the drag force can be calculated if the data for the air density, the flying velocity, the drag coefficient of drones (C_D), and its windward area are given. The drag coefficient of drone can directly influence the of drag force, and thus different shapes of wings and fuselages are designed to minimize their drag coefficient (C_D). Likewise, the lift force can be figured out through the same form of the equation since the drag coefficient (C_D) is replaced by the lift coefficient (C_L).

When considering the safety issues, Bernoulli’s Equation and the attack angle explain the stall phenomenon. Once the attack angle is excessive, the fluid will get separated and lead to the loss of lift force, which can cause crash accidents. The drag force not only affects power of the motor, but also the stability when flying.

2.2. Research Progress

Drones have made significant progress in the field of low-altitude transportation during the recent years, and they can be classified into two main categories, fixed-wing drones and rotor-wing drones [6]. The fixed-wing drones adopt a configuration that is similar to manned planes, including main structures of the fuselage, wings, stabilizers. Besides, they also comprise auxiliary parts, such as flaps, rudder and so on [6]. The fixed-wing drones are characterized by their long endurance and high working efficiency, which are capable of undertaking the large-scale tasks. As for rotating-wing drones, they can be categorized into Mono copter, Tri copter, Quadcopter, Hex copter, and Octa copter based on the number of motors and layout, with various central structures of square, circular [6]. This type of drone possesses the capacity to take off and land vertically as well as perform maneuvers nimbly.

2.3. Key Factors

In the field of low-altitude drone transportation, the delivery efficiency depends on several key factors, such as endurance, payload, flight environment, etc. According to the research, most of the rotor-wing drones have an endurance about 20 to 30minutes, while their actual flying distances are about 15 to 35 kilometers, which can be significantly limited by the battery techniques, weather conditions as well as the various payloads [7]. The flying distance can shorten directly when the load increases. With respect to energy efficiency, though the energy consumption per unit-distance increases as load grows, its ratio to unit distance-load ($\mathrm{wh/km \cdot kg}$) drops as the scale expands [7]. However, the enlargement of drones and high payloads will also lead to the rise of safety risks, noise pollution, and regulatory limitations. For example, the Federal Aviation Administration (FAA) stipulated in 2016 that the flight altitude of drones must be under 400 feet [8]. Besides, drones must maintain Visual Line of Sight (VLOS) all the time to ensure the safety when flying, which sharply reduces the service radius. Thus, optimizing drones' transportation efficiency is a comprehensive work that should balance load, distance, energy, safety and infrastructure as well. The **Tab 1** below shows the key factors and their relationship between working efficiency.

Table 1. Key Factors Relationship Table

Key factors	Relationship between efficiency
Endurance	Positively correlated: more working hours--higher efficiency
payloads	Negative correlated: lower speed, more working hours --lower efficiency
Weather conditions	High wind speed, rainy--lower efficiency
Regulatory limitations	Height, speed, scope limited--lower efficiency

2.4. Fitment

To adapt the complex environment in residential area, especially in some developed cities, drones must be equipped sensitive perception systems, advanced obstacle avoidance system, and should depend on UTM (Unmanned Traffic Management). Low-altitude resources in cities are scarce, thus the UTM can realize the real-time management of drones and avoid strikes between drones, buildings, and other aircraft. Meanwhile, noise, privacy, as well as the availability of takeoff and landing areas are also key constraints of deploying drones throughout cities. As long as drones can maintain an efficient and reliable operational status, they can integrate into the urban logistics network.

Commercial drones have already been put into practice by a variety of companies, known as JD Logistics in China and Amazon in the U.S. As for JINGDONG, the latest model JDX-20 was launched in January 2025 and took responsibility to deliver materials among city and to rural, mountainous area [9]. JDX-20 has a maximum payload of 10 kilograms, maximum speed of 98 kilometers / hour, and a maximum service radius of over 10 kilometers, which can cover the delivery scope of most business districts; the high-precision millimeter-wave radar enables it to perceive surroundings sensitively [9]. For Amazon Company, the design payloads of its drones are 2.26 kilograms, and the speed of the drones is expected to be 50 mph (80.5 km/h) under such package weight [10]. Drones designed by Amazon possess a combination of different types of sensors and laser radar technology to make sure safety.

3. Safety Research of Low-Altitude Drones

This part is going to expound three main aspects of safety design of drones: Communication Safety, Collision and Avoidance Safety, and Legal Limitations.

3.1. Communication Safety

Communication Safety is mainly about the precision of positioning, and drones’ ability against interference. At present, drones’ navigation relies heavily on the Global Positioning System (GPS), yet its signals can be affected easily by interference or obstruction. This can lead to reduced positioning precision or even task interruption, causing significant safety risks. According to Akagi’s research [11], the project of combination of multiple sensors can be adopted, which includes GPS, magnetometer, and visual data. Kalman Filter is used to combine these data in order to maintain swarm state estimation during the failure of GPS signal. Besides, the Internet of Drones (IoD) architecture faces severe cybersecurity threats. AI-Garadi’s group pointed out in 2020 that Traditional encryption and authentication methods are no longer sufficient to counter complex cyberattacks [12]. Choudhary’s group systematically categorized potential vulnerabilities and threats within the Internet of Drones [13]. Future research opportunities lie in developing more intelligent defense system, such as security agreement based on machine learning, and achieving distributed autonomous navigation through edge computing. This approach reduces reliance on central networks and GPS, thereby comprehensively enhancing communication and navigation security for drones in complex environments.

3.2. Collision and Avoidance Safety

3.2.1 Collision Risks

Risk assessment of drone-human collisions represents a core challenge for the safe operation of low-altitude drones. Current international regulations, such as the EU's 80J standard [14], are primarily based on research involving military shrapnel or rigid object impacts. However, their applicability remains highly questioned. Research by Svaty’s team [14], adopting dynamic collision testing, demonstrates that both multi-rotor and fixed-wing drones undergo significant structural bending, deformation, or even fracture upon impact with the human body. This process absorbs and dissipates substantial impact energy, resulting in a lower kinetic energy transferred to the human body than the initial total kinetic energy [14]. This means relying on maximum kinetic energy as a safety benchmark significantly overestimates actual risks, leading to unnecessary operational restrictions. The research further indicates that injury assessment standards derived from the automotive industry, such as the Head Injury Criterion HIC and Neck Injury Criterion NCI [15-18], provide a more comprehensive evaluation by considering acceleration, duration of impact, and load distribution [14]. These standards demonstrate significantly greater accuracy and scientific than traditional kinetic energy models in predicting the probability of skull fractures or severe neck injuries. This offers crucial evidence for establishing more reasonable and evidence-based safety regulations for future collision safety of drones.

Mid-flight failures resulting in drone crashes represent a primary safety concern, with associated risks closely linked to high kinetic energy originating from the square of weight and speed [19]. The FAA report identifies kinetic energy, ignition sources from power systems, and rotating components as key factors that aggravate collision severity [20]. The intensive components such as batteries, motors, cargo, as well as propellers, further intensify injury risks.

3.2.2 Avoidance System

The obstacle avoidance system is central to ensuring the safe autonomous operation of drones, with its architecture typically following a three-layer structure of ‘perception-detection-avoidance’. Existing research mainly focuses on four key aspects: obstacle detection and avoidance puts emphasis on employing multi-sensor combination technologies such as vision and radar to identify static and dynamic obstacles in real time; collision avoidance algorithms concentrate on developing strategies based on geometry, potential fields, optimized control, and reinforcement learning to generate locally paths without collision; Drone swarm research addresses coordinated obstacle avoidance within formations while maintaining formation integrity; path optimization aims to plan globally optimal routes balancing safety, energy consumption, and efficiency [21]. Nevertheless, current systems face critical challenges including precise detection of moving and small obstacles, real-time computational limitations in complex environments, communication reliability under heavy weather conditions, and adaptability when transferring from simulation to real-world scenarios [21]. Future advancements depend on more sophisticated perception AI, lightweight algorithm design, and strong communication networks to achieve safe, efficient integration of drones within complex airspace.

In the design of drone avoidance systems, Deep Reinforcement Learning (DRL) has demonstrated significant potential. Cetin et al. proposed an architecture based on a Joint Neural Network (JNN), integrating front-end deep images with multiple state scalars, such as velocity and target distance [22]. Through training with the Double DQN algorithm, the system enables autonomous obstacle avoidance for drones in complex suburban environments [22]. The system successfully handles both static obstacles and dynamic obstacles, achieving a success rate of 98%-100% in testing [22]. This demonstrates DRL a high reliability and practicality for enabling safe low-altitude drone navigation.

3.3. Legal Limitations

Major aviation authorities worldwide generally regulate drone operations through registration and airspace classification systems. Regarding registration, most countries establish weight standard requiring hobbyists to register under their real names, though specific standards vary. For instance, in Japan drones over 100 grams must be registered, and England imposes stricter requirements that drones weigh over 250 grams or are equipped with a camera have to be registered, while China typically mandates registration for hobbyists [23]. In airspace management, the international community generally adopts a categorized zoning approach. Taking the United States as an example, its airspace is divided into controlled (Classes A, B, C, D, E) and uncontrolled (Class G) categories [23]. Operations within controlled airspace typically require prior authorization, compliance with equipment standards, and maintenance of communication with air traffic control (ATC); while flights in uncontrolled Class G airspace are permitted greater freedom with fewer restrictions. The core purpose of these regulations lies in clarifying responsibility, delineating operational boundaries, and thereby striking a balance between promoting drone technology applications and ensuring aviation safety as well as public privacy.

4. Comparison between Low-altitude Drone and Normal Drones

4.1. Concepts Introduction

The low-altitude drones in this part specifically represent the unmanned aerial vehicles that mainly used to deliver materials under the height of 1000 meters above the ground, which is 2000 meters lower than the effective range of Low-altitude Economy. The core working height range is below 120 meters above ground level.

The normal drones in this part means consumer-grade or light commercial-grade multi-rotor drones, which are designed unprofessionally with functions simplified. This kind of drones has a low threshold and is mainly used for entertainment and photography.

4.2. Difference in Efficiency

In terms of transport efficiency, low-altitude transport drones and conventional consumer drones exhibit fundamental differences due to their distinct core missions, primarily reflecting in three aspects: flight altitude, energy consumption, and environmental interference.

Initially, their strategies in flight altitudes and airspace utilization are widely different. Low-altitude transport drones focus on establishing standardized, networked fixed logistics routes at an extreme low altitudes, typically below 50 meter, which are similar to “aerial highways”. Though operating at lower altitudes and in more complex environments, this route design aims to achieve scaled, predictable, and efficient transport. Its value lies in route stability and repeatability. In contrast, normal drones typically operate flexibly below 120 meters within visual line of sight, prioritizing obstacle avoidance and filming perspectives. Their flight paths are variable and often random.

Secondly, their energy consumption evaluation systems are entirely different. The core efficiency metric for low-altitude transport drones is energy consumption per kilogram of cargo transported per kilometer. By cutting down some flight duration, they achieve greater payloads, which range from 5 to 100 kilograms, and greater transport distances. Their energy consumption directly translates into transport value. Conversely, for normal drones, the core energy evaluation is the consumption per unit flight time, pursuing extended hovering and filming duration with extremely low payloads, usually under 1 kilogram. Their energy consumption primarily sustains flight.

Finally, the nature and scale of environmental disturbances differ significantly between the two. Low-altitude transport drones must continuously deal with dense, dynamic disturbances in extreme-low-altitude environments. These include turbulent airflows between urban buildings, dense power lines, and sudden encounters with birds or other aircraft. This demands capabilities to proactively and predictively counter interference. Advanced flight control algorithms must dynamically adjust flight paths in real-time to ensure mission punctuality and reliability. Thus, their tolerance for environmental interference is significantly lower than that of consumer-grade models. However, normal drones primarily encounter sudden wind disturbances, a few static obstacles, and signal obstructions, employing strategies such as hovering, returning to base, or landing to prioritize self-preservation. It is evident that the pursuit of efficiency in low-altitude transport drones match more closely with the logic of traditional logistics systems than with that of consumer electronics.

4.3. Difference in Safety

In terms of safety, low-altitude transport drones face core different challenges and require distinct response strategy compared to standard consumer drones. This distinction originates from the varying complexity of operational environments and the severity of potential risks.

Low-altitude transport drones have to enter the most complex airspace: the urban extreme-low altitude environment. They tackle highly dynamic and unpredictable obstacles including turbulent air currents between buildings, dense power lines, sudden bird encounters, and potentially other drones in the future. Their safety risks extend far beyond self-damage, presenting significant public safety threats due to their high kinetic energy, which results from heavy weight and relatively high speeds. As highlighted in the FAA report [20], the severity of drone collisions correlates directly with kinetic energy, power systems, and rotating components. Thus, safety is the most essential principle for low-altitude drones. It adopts multiple redundant designs (such as multi-rotors and parachutes), advanced Detection and Avoidance (DAA) systems (integrating radar and visual algorithms for 3D environmental modelling and path planning), and real-time data interaction with city-level Unmanned Aircraft Traffic Management (UTM) systems to achieve proactive, predictive safety protection. The final purpose is to realize a dependable transport platform that maximizes safety for personnel, property, and other airspace participants even in the event of single-point failures.

Consumer drones primarily operate within visual line of sight over relatively open, low-altitude regions with low environmental dynamics. Their safety design prioritizes preventing crashes caused by user error or equipment failure. Drones’ safety largely relies on fundamental sensor-based obstacle avoidance, such as visual or infrared systems, and software-enforced, which belong to a passive and protective strategy.

4.4. Difference in Technical Emphasis

The technical emphasis varies between the two types of drones due to their difference in tasks and working environment.

Firstly, the core focus of low-altitude transport drones lies in payload capacity and redundant safety. They generally adopt multi-redundant configurations with six or more rotors, equipped with large-diameter propellers, aiming at offering substantial lift while ensuring safe landing capability even in the event of single-point power failure. Conversely, normal consumer-grade drones prioritize extreme lightweight construction, generally employing quadcopter configurations with small-pitch rotors to achieve an optimal balance of portability, agility and affordability. Their power systems are designed with the objective to support flight and basic stability.

Table 2. Comprehensive Comparison

Aspects	Specific Index	Low-altitude Drones	Consumer-grade Drones
Delivery Efficiency	Core Purpose	Efficient, Scaled Cargo Delivery	Shooting Perspective, Flight Experience
	Flight Altitude	Below 50 m	Below 120 m
	Route Characteristics	Networked, Predictable, Task-centered	Random, Operator-centered
	Energy Consumption Evaluation	Per Kilogram of Cargo Transported per Kilometer	Per Unit Flight Time
	Primary Disturbance	Wind, Wire, Dynamic obstacles	Wind, Static Obstacles, Signal Obstruction
Safety	Core Safety Purpose	Public Safety	Self Safety
	Primary Risk Sources	System Failure, Dynamic Crashes, Cargo Fell	Operational Error, Equipment Failure, static Crashes
	Environment	Complex Urban Environment	Open Environment
	Avoidance Strategies	Multi-sensors, Real-Time Modeling & Route Planning	Basic Sensors, Stop or Return
	Redundancy Design	Multi-rotors, Emergency Power	Almost None
Technical Emphasis	Power Design	Large Propellers, Power First	Less Rotors, Small Propellers, Cost First
	Perception Design	LiDAR, Precise Radar, Computational Visual	Optical, Ultrasonic, Infrared
	Algorithms Complexity	Extreme High	Low
	Interaction Ability	Bidirectional Interaction	Unidirectional Interaction
Regulations	Core Standard	BVLOS Certification, Special Permit	VLOS, Registration System
	Management	UTM	No-fly Zone

The **Tab 2** above shows the comprehensive comparison between low-altitude drones and consumer-grade drones in three aspects.

Secondly, the complexity levels of obstacle avoidance algorithms differ vastly. The avoidance system for low-altitude transport drones is considered as the core precondition for achieving Beyond Visual Line of Sight (BVLOS) fully autonomous operation, functioning as a ‘decision-making’ system. It must integrate LiDAR, millimetre-wave radar, and computer vision to perform real-time 3D environmental modelling and dynamic obstacle trajectory prediction. Based on this, it performs complex online path planning. As a result, the complexity level of obstacle avoidance algorithms for low-altitude drones is extremely high. As for consumer-grade drones, their avoidance systems are auxiliary, primarily preventing collisions with static obstacles within visual line-of-sight during user-operated flights. These rely on lightweight sensors such as optical and ultrasonic systems, adopting relatively straightforward algorithms.

Finally, the capacity for interaction with air traffic management systems is the fundamental distinction. Low-altitude transport drones must be deeply integrated into the Urban Air Traffic

Management (UTM) system. They require communication and broadcasting capabilities to report their identity, position, and purposes to management systems in real time, while receiving dynamic airspace constraint information to achieve coordinated avoidance with other aircraft. This constitutes a real-time and collaborative airspace interaction, with extremely high technical thresholds and regulatory requirements. Conversely, normal drones primarily rely on the GPS inside to detect no-fly zones, representing a passive form of isolation.

In conclusion, low-altitude transport drones centre their technology on ‘system integration and public safety’, thereby establishing a reliable node within the urban air logistics network; while Consumer-grade drones focus their technical design on ‘individual performance optimization’.

The above comparison clearly reveals the differences in design of these two drone categories. These theoretical characteristics are fully reflected in specific products. For instance, DJI's Phantom 3 series stands as a typical example for consumer drones [24], with its lightweight folding design and outstanding imaging system perfectly serving aerial photography needs. Within the low-altitude transport aspect, JD’s JDX-20 series stand as classic examples [9]. Their multi-rotor redundant architecture and substantial payload capacity collectively reflect the industrial-grade cargo drone's pursuit of safety, reliability, and transport efficiency. In summary, the fundamental distinction between low-altitude transport drones and conventional consumer drones in terms of efficiency, safety, and technical design derives from the essential differences in their core missions and operational environments. The former constitutes industrial-grade transport tools serving urban logistics networks, while the latter represents consumer electronics focused on aerial photography and entertainment.

5. Challenges and Future Developments

Low-altitude delivery drones are at a key turning point in their development, transitioning from technological verification towards large-scale commercial application. However, this leap faces systemic challenges across three aspects: technology, regulation, and societal acceptance.

Technical bottlenecks remain the most necessary constraint on drone development. The primary challenge lies in the tension between energy density and endurance. Current lithium-ion battery technology struggles to meet the demands of heavy payloads, extended flight times, and lightweight design at the same time, severely limiting the economic radius. Secondly, drones still exhibit insufficient perception and intelligent decision-making capabilities within complex urban environments. Extreme-low-altitude flight requires real-time, precise identification of static and dynamic obstacles. This places extreme demands on sensor fusion accuracy, computational power, and the reliability of artificial intelligence algorithms, where any errors could lead to severe consequences. Furthermore, BVLOS drone operations rely on cellular networks such as 4G/5G, which are susceptible to obstruction and interference within urban environment. This creates risks of latency or disruption, directly compromising flight safety.

Compared to technical challenges, regulations and airspace management present more complex barriers. Nowadays, the global regulatory framework for BVLOS drone operations remains incomplete, with complex approval processes and a lack of unified standards, which become the major obstacles to large-scale commercial applications. A deeper challenge lies in achieving comprehensive airspace integration. Integrating vast numbers of drones safely and efficiently into existing manned aviation airspace, while establishing a mature UTM system, which is capable of dynamic airspace distribution and automated conflict resolution, represents an ambitious systematic project. Meanwhile, the frameworks for responsibility confirmation, and insurance mechanisms after accidents require further clarification and establishment.

Except for technology and regulations, societal acceptance represents the critical ‘last mile’ determining implementation. Noise pollution is the primary driver of public resistance, with multi-rotor drone swarms potentially disrupting urban living. Privacy concerns caused by onboard sensors are also noticeable. As highlighted in the FAA report [20], a drone's kinetic energy, power systems, and rotating components can all worsen collision severity. Consequently, any incident involving heavy objects falling and causing injury could lead to a comprehensive crisis of confidence, potentially stagnating the entire industry's development.

In summary, the advancement of low-altitude is no longer a single aspect of technical challenges, but a systemic project requiring the coordinated advancement of technological research and development, regulatory innovation, and societal consensus. Only by integrating these three dimensions can we truly start a new era of urban air transportation.

6. Conclusion

In conclusion, this essay systematically concludes the research of low-altitude transport drones in efficiency and safety aspect and compares with consumer-grade drones, clearly outlining the core characteristics of low-altitude transport drones. Regarding transport efficiency, low-altitude drones do not pursue the agility and showmanship of consumer products. Instead, they focus on establishing standardized, networked air logistics system at low altitudes. Their performance evaluation system has fundamentally shifted towards ‘energy consumption per unit weight-kilometre’. Regarding safety, it has been revealed that the complexity of their operational environments, kinetic risks, and public safety responsibilities increase exponentially. Thus, their technological design idea has shifted entirely from the consumer-grade approach of ‘passive avoidance’ to ‘proactive warning and redundant fault tolerance’, which relies on multi-sensor fusion and advanced algorithms to ensure absolute reliability. The core of drones logistics advancement is that human must find the balance between working efficiency and safety. It is necessary to realize the dialectical relationship between the two aspects.

Nevertheless, the path to large-scale commercialization is beset with difficulties. Current development faces three primary challenges: technological, regulatory, and societal acceptance. Technologically, bottlenecks in endurance, perception, and communication require breakthroughs. Legally, lagging BVLOS operational rules and airspace integration (UTM) constitute the primary non-technical barriers. Socially, concerns over noise, privacy determine the final legality of their development. Addressing these challenges demands systemic breakthroughs. As for technology, significant investment is required in developing new-type power solutions such as hydrogen fuel cells and hybrid systems to overcome the limitations of battery energy density. Concurrently, more advanced AI algorithms and edge computing chips must enhance autonomous obstacle avoidance and decision-making capabilities. Furthermore, integrating 5G and satellite communication technologies is essential to establish a reliable integrated ground-air communication network. Regulatory frameworks depend on close collaboration between authorities and industry to formulate clear BVLOS operational rules. Socially, privacy protection principles should be embedded in product design, while rotors on drones should be optimized with less noise. Establishing demonstration zones and strengthening public engagement will highlight safety and utility, gradually building societal trust.

Consequently, the future development of low-altitude transport drones must evolve from isolated technological breakthroughs into a systemic project requiring the coordinated advancement of technological research and development, regulatory innovation, and societal engagement. Its success will depend not merely on engineers' ability to build excellent aircraft, but equally on regulators' capacity to build agile, intelligent governance frameworks as well as the industry's willingness to earn public trust. This study provides a systematic analytical framework and clear comparative perspective for this transformation, laying the theoretical foundation for subsequent technological breakthroughs and policy formulation.

References

[1] EAC International Consulting. EAC International Consulting. 2024.

[2] CHINA' S DRONE LOGISTICS REVOLUTION IN 2025 - MN Shipping Vietnam - Local strength, global reach. Mac-Nels Vietnam - Your Cargo? Never say never. 2025.

[3] Liu S, Liu M. Research on the Security Risk Governance Roadmap in Low-Altitude Economic Field Based on the Economic Externality Theory. 2nd International Conference on Green Aviation (ICGA 2024). 2025 Jan 6; 14.

[4] Grepow. Grepow. 2025.

[5] drone. In 2025.

[6] Shekh NM, Rani S, Datta R. Review on design, development, and implementation of an unmanned aerial vehicle for various applications. International Journal of Intelligent Robotics and Applications. 2024 Sep 4.

[7] The world's largest collection of open access research papers.

[8] Unmanned Aircraft Systems (UAS). Federal Aviation Administration.

[9] ChinaDaily. ChinaDaily. 2025.

[10] Amazon Prime Air. Wikipedia. 2025.

[11] Akagi J, Christensen RS, Harris MW. Centralized UAV Swarm Formation Estimation with Relative Bearing Measurements and Unreliable GPS. Centralized UAV Swarm Formation Estimation with Relative Bearing Measurements and Unreliable GPS. 2020 Apr 1; 383-91.

[12] A survey of machine and deep learning methods for internet of things (IoT) security. IEEE Journals & Magazine | IEEE Xplore. 2020.

[13] Choudhary G, Sharma V, Gupta T, Kim J, You I. Internet of Drones (IOD): Threats, vulnerability, and security perspectives. arXiv (Cornell University). 2018 Jan 1.

[14] Svatý Z, Nouzovský L, Mičunek T, Frydrýn M. Evaluation of the drone-human collision consequences. Heliyon. 2022 Nov 1; 8 (11): e11677.

[15] Wikipedia contributors. Federal Motor Vehicle Safety Standards. Wikipedia. 2025. Available from:

[16] Publications Office of the European Union. Publication detail - Publications Office of the EU. Publications Office of the EU.

[17] NHTSA. NHTSA. 2025.

[18] PubMed. PubMed.

[19] PDXScholar: The Institutional Repository of Portland State University.

[20] Assure - THE FAA's Center of Excellence for UAS Research. Assure - THE FAA's Center of Excellence for UAS Research. Assure. 2025.

[21] Comprehensive Review of Drones Collision Avoidance Schemes: Challenges and open issues. IEEE Journals & Magazine | IEEE Xplore. 2024.

[22] Drone navigation and avoidance of obstacles through deep reinforcement learning. IEEE Conference Publication | IEEE Xplore. 2019.

[23] Drone Laws. Drone Laws. 2025.

[24] DJI - the world leader in camera Drones/Quadcopters for aerial photography.