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Қазақстан мен Германиядағы билік тармақтарының бөлінуі және сот билігінің тәуелсіздігі: салыстырмалы құқықтық талдау

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Abstract: The low-altitude economy has rapidly developed into a strategic emerging industry in China, driven by reforms, policy initiatives, and technological innovation. While the Civil Aviation Law provides a foundational legal framework, existing legislation has revealed contradictions in normative logic, fragmented regulation, and insufficient responsiveness to technological advances. This article examines the legislative predicaments of China's low-altitude economy and proposes "legislative synergy" as a guiding theoretical perspective to address them. Using literature review, empirical analysis, and comparative study, the paper identifies three core challenges: hierarchical imbalance within the normative system, regional coordination obstacles, and lagging adaptation between technical standards and legal norms. By analyzing international experiences – particularly the hierarchical framework of the United States and the regional coordination mechanism of the European Union – the study offers a path for reconstructing China's normative system. It argues that achieving coherence across legal hierarchies, enhancing cross-regional governance, and embedding technological adaptation into legislation are crucial for transforming policy into effective legal norms. The findings contribute to theoretical and practical discussions on airspace governance and provide legislative support for the high-quality development of the low-altitude economy.

Keywords: low-altitude economy, legislative predicament, normative system synergy, airspace governance, UAV regulation

Introduction

The low-altitude economy is a comprehensive economic form that relies on low-altitude airspace below 3,000 meters, driven by low-altitude flight activities of manned or unmanned aircraft, and radiates to promote the integrated development of related fields.(Qin Rui,2023) As

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a typical representative of new productive forces,(Liu Songlin, etc., 2025) The innovativeness and complexity of its industrial characteristics impose special requirements on institutional supply: the lightweight application of technologies has broken the barriers of traditional aviation industry; (Fan Yijiang, etc., 2024) the synergy of management models requires inter-entity collaboration; the diversification of application scenarios covers multiple fields such as logistics, cultural tourism, and emergency response; and the cross-border integration of industrial ecology has broken traditional industry boundaries.

Globally, the low-altitude economy faces universal legislative challenges: the rapid iteration of UAV and eVTOL (Electric Vertical Take-Off and Landing) technologies outpaces legal updates; cross-border airspace coordination lacks uniform standards; and the balance between safety supervision and industrial development remains unresolved. The unique strategic value and industrial characteristics of the low-altitude economy have led to the continuous upgrading of the country's positioning. In 2021, the *Outline of the National Comprehensive Transport Network Planning* included "low-altitude economy" in the national plan for the first time. In 2023, the Central Economic Work Conference clearly defined the low-altitude economy as a strategic emerging industry in terms of its development orientation(Xue Liang, etc., 2025), In 2024, the *Government Work Report* and the Third Plenary Session of the 20th Central Committee of the Communist Party of China further arranged the development tasks of general aviation and the low-altitude economy(2023), Driven by policy dividends, the development of China's low-altitude economy has entered a stage of rapid cultivation. However, challenges in the development process have gradually emerged, with issues such as weak core technologies,(DLR, 2024) a backward market system, and a management system that needs improvement intertwined, the essence of these challenges lies in the fact that the pace of technological iteration has outstripped the rhythm of institutional updates, the breadth of scenario innovation has exceeded the coverage of existing supervision, and the adaptability gap between the current legislative system and the development needs of the industry has become increasingly prominent.

The current regulatory system, centered on the *Civil Aviation Law,* while providing a basic legal framework for low-altitude flight activities, has increasingly prominent limitations in addressing the cross-regional and multi-departmental nature of the low-altitude economy, its technical dependence on new technologies such as unmanned aircraft, and the continuous emergence of innovative "unmanned aircraft +" new business forms. Systemic flaws such as regulatory dissonance and fragmented supervision have become bottlenecks restricting the high-quality development of the industry. Therefore, how to achieve precise adaptation to the low-altitude economy by optimizing the legislative system and finding a dynamic balance between safety supervision and industrial promotion has become a core proposition urgently needing to be solved. Existing international studies mainly focus on the U.S. and EU systems, lacking analysis of "policy-legal" transformation mechanisms in transitional economies. This paper fills this gap by exploring China's path, with a focus on legislative synergy mechanisms, to provide a comparative reference for global low-altitude economy governance.

Material and Method

This paper employs three research methods – literature analysis, empirical analysis, and comparative study – to explore the coordination of China's low-altitude economy normative system.

Literature analysis method – By sorting out various documents in the field of low-altitude economy at home and abroad, including laws, administrative regulations, departmental rules, normative documents, and technical standards – such as China's Civil Aviation Law and Interim Regulations on the Administration of Unmanned Aircraft Flights, the United States' 49 U.S.C. § 40103 and Drone Flight Rules (Part 107), and the EU's Drone Regulation (2019/947) – while also referring to academic research results on the coordination of low-altitude economy normative systems (including scholars' perspectives, controversies, and comparative law studies).

Empirical analysis method – Combining the actual development of China's low-altitude economy, this method analyzes specific problems arising in practice. For example, it takes practical cases such as cross-border unmanned aircraft management in the Guangdong-Hong Kong-Macau Greater Bay Area (selected for its status as a national-level pilot zone with cross-jurisdictional characteristics), cross-border unmanned aircraft logistics, and security vulnerabilities in the data exchange interface specifications for unmanned aircraft real-name registration as research objects**. Comparative Study –** This method compares the hierarchical coordination logic and practice of the U.S. low-altitude traffic normative system with the coordination mechanisms of the EU's inter-regional unmanned aircraft regulatory system, focusing on three dimensions: legislative hierarchy, regulatory subject responsibility division, and technical standard embedding methods.

Literature Review

Research focus in foreign countries on low-altitude economy and related fields revolves around technical frameworks, scenario applications, and management mechanisms, forming a multi-dimensional exploration pattern, as detailed below:

In terms of the coordination between airspace management and transportation systems, the HorizonUAM project by Germany's DLR proposes to realize digital management of low-altitude airspace through U-space, establish a dynamic airspace division mechanism, and ensure safe separation between unmanned aerial vehicles and manned aircraft(Zhang Xiaolan, etc., 2024); The altitude-based airspace design schemes proposed by American companies such as Amazon and Google are widely cited by scholars, which divide Class G airspace into a low-speed local traffic layer with an altitude of less than 200 feet, a high-speed layer with an altitude of 200-400 feet, and a no-fly zone with an altitude of 400-500 feet(Ali B. S., etc., 2022); Japanese scholars emphasize in the AAM planning that it is necessary to dynamically adjust airspace usage rights according to urban density and realize real-time traffic control through the UATM system. (2024)

In terms of cross-stakeholder collaborative governance, Saudi Arabia's AAM roadmap emphasizes multi-stakeholder collaborative governance, where the government is responsible for formulating regulations and allocating airspace, enterprises take the lead in technology implementation, and third-party institutions provide data support(2024); Japanese scholars further propose a "public-private collaborative committee" model to coordinate the interest conflicts among stakeholders in route approval and other aspects. (2024)

In terms of social acceptance and sustainability coordination, German scholars found through social surveys that noise, privacy, and carbon emissions are key obstacles to social acceptance. Therefore, the regulatory system needs to include environmental protection requirements such as noise map planning, flight routes avoiding residential areas, and battery recycling. (DLR,

2024) Research by NASA in the United States shows that the UTM system needs to have a built-in "fail-safe" mechanism to establish an inter-departmental emergency response system, so as to quickly coordinate air traffic control, fire protection, medical care and other institutions in the event of an accident. In addition, scholars also generally emphasize the establishment of a "safety redundancy" design through multi-sensor navigation to solve the positioning errors caused by the urban canyon effect. (Ali B. S., etc., 2022)

Compared with foreign practices, domestic research focuses on the construction and coordination challenges of China's local low-altitude economy normative system. Wang Xueying et al. sorted out a multi-level framework centered on the Civil Aviation Law, covering administrative regulations, departmental rules, and administrative normative documents. Among them, the Interim Regulations on the Management of Unmanned Aircraft Flights mark the beginning of China's full-chain regulation of UAVs. (Wang Xueying, et al., 2024)

At the theoretical framework level, Chinese academic circles have generally reached a consensus on "balancing safety supervision and industrial development", advocating the construction of a hybrid model of hard and soft law and a multi-stakeholder collaborative governance approach (Gao Zhihong, 2024) and forming a legal incentive system through management-oriented, coordination-oriented, promotion-oriented, and restrained legislation. (Jiang Bohan, 2025)

At the level of comparative law research, studies by Huang Xiaorong and Zuo Rongchang found that the localization transformation of comparative law in the field of low-altitude economy is not in-depth, and the effect of law implementation lacks quantitative evaluation. (Huang Xiaorong, et al., 2022) They proposed learning from the market competition and risk classification models of the United States, Japan, and Europe, emphasizing localization adaptation. (Zuo Rongchang, 2018)

At the practical level, studies by Lan Shourong, Zhang Yanshu, and Zeng Fanlei found that problems such as "multi-agency governance fragmentation" and "regulatory gaps" in China's low-altitude economy practice are prominent; (Lan Shourong, 2025) the interdepartmental comprehensive supervision mechanism is insufficiently detailed; the airworthiness certification of eVTOL in new business scenarios relies on "case-by-case discussion"; airspace demand does not match current regulations; (Zhang Yanshu, 2025) supporting rules for "low-altitude economy +" integration scenarios are lacking; and the connection between local "pilot-and-promote approach" authority and central legislation is unclear. There is a lack of empirical analysis on legislative conflicts. (Zeng Fanlei, 2025)

However, there are still different research viewpoints in the academic community on two main aspects of the low-altitude economy:

Firstly, at the level of improvement paths, there are two representative viewpoints. One is the "traditional extension theory" represented by scholar Jiang Dudu, which holds that the low-altitude economy is a technological derivative of the traditional aviation industry, and advocates realizing the adaptation of the normative system through flexible transformation of traditional aviation regulatory rules. (Jiang Dudu, 2025) The other is the "independent regulation theory" represented by scholars such as Gao Zhihong, which proposes the concept of "scenario-based legislation," emphasizing that the industrial particularity requires breaking through the traditional aviation law framework (Gao Zhihong, 2024) and formulating a Low-Altitude Economy Promotion Law.

Secondly, at the level of the legal attribute of low-altitude airspace, there is a divergence on whether to include the right to use low-altitude airspace into the traditional property rights framework. For example, Chen Chengxi advocates clarifying the possession, use, and income rights of the airspace use right, regulating it as a new type of usufructuary right under the property rights chapter of the Civil Code to achieve connection with the traditional property rights system. (Chen Chengxi, 2023) In contrast, Wang Xizhu emphasizes that "low-altitude airspace has particularities different from traditional objects such as land and buildings, and its legal attribute should not be simply classified into the existing property rights system, advocating the construction of an independent airspace rights system. (Wang Xizhu, 2017)

Overall, foreign countries focus on forming adaptive coordination mechanisms through practice, while domestic research faces the dual tasks of system improvement and theoretical breakthrough in the process of learning and exploration, needing to strike a balance between localization and innovation.

Results

As an emerging field where the digital economy and the aviation industry are deeply integrated, the legalization process and industrial practice of China's low-altitude economy have shown a synchronous evolution trend. Chinese legislative bodies and regulatory authorities, adhering to the core governance logic of "balancing safety supervision and industrial development", have gradually built a multi-level normative system to meet the development needs of new business forms such as unmanned aircraft and eVTOL. From the perspective of development stages, legislative work has shifted from early decentralized responses to systematic layout, laying a solid basic framework for the orderly development of the low-altitude economy. The characteristics of its normative system are mainly manifested in the following three aspects:

1 The institutional supply for China's low-altitude economy has taken initial shape

According to incomplete statistics, China has currently issued a total of 55 laws, administrative regulations, departmental rules, normative documents, and technical standards in the field of low-altitude economy. The Civil Aviation Law (2021 Revision), as the superior law in the normative system, establishes a basic legal framework. Five administrative regulations, including the Interim Regulations on the Administration of Unmanned Aircraft Flights (2023), form the main framework for technical safety supervision. Ten departmental rules and ten normative documents provide detailed provisions on specific matters such as market access and flight control. Additionally, 18 technical standards, such as the Classification and Grading of Civil Unmanned Aircraft Systems (2022), regulate technical requirements, including performance parameters and communication, navigation, and offering solutions to address protocol adaptation issues between unmanned aircraft and the industrial internet of things.

2 Key areas of China's low-altitude economy have achieved special breakthroughs

In response to the regulatory needs of new forms of low-altitude economy, China has gradually filled institutional gaps in key areas, reflecting the dynamic response of legislation to practice. In April 2018, the Measures for the Administration of Commercial Flight Activities of Civil

Unmanned Aircraft (Interim, 2018) was issued, which standardized the market access process for commercial flights for the first time and provided compliance operation guidelines for commercial scenarios such as unmanned aircraft logistics and mapping. The Interim Regulations on the Administration of Unmanned Aircraft Flights (2023) are of landmark significance. It innovatively established a full-chain management approach of "registration-qualification-flight-supervision", built basic management mechanisms such as real-name registration of unmanned aircraft and flight approval, and formed a systematic legislative practice. At the same time, various technical standards have formulated specific indicators for key links such as classification and grading of unmanned aircraft and data interfaces, specifically filling the gaps in the field of technical supervision and providing a detailed operational basis for standardized implementation.

3 China's Smart Supervision System for the Low-Altitude Economy Has Taken Its First Steps

With the deepening of the concept of digital governance, the national-level "Civil Unmanned Aircraft Integrated Management Platform (UOM)" was officially launched in January 2024. Relying on digital technologies, it has built a full-chain management system covering unmanned aircraft registration, qualification verification, flight operations, and supervision, promoting the transformation of the regulatory model from traditional "manual approval" to automated "intelligent control". It also provides a technical carrier for cross-departmental data sharing and collaborative governance, marking a key breakthrough in China's low-altitude economy rule of law towards intelligence and precision. Through full-life-cycle digital management, it not only enhances the precision of regulatory efficiency but also connects scattered regulatory requirements through technical means, offering a practical solution to issues such as poor inter-departmental collaboration and inconsistent standards, thus injecting institutional momentum into the standardized development of the industry.

4 The necessity of promoting the synergy of the regulatory system for the low-altitude economy in China

The necessity of legislative coordination for China is reflected in three aspects in terms of policies and practices: national policies require the unification of normative systems for the low-altitude economy, but in practice, the lag of higher-level laws such as the Civil Aviation Law coexists with fragmented local legislation, urgently requiring legislative coordination to break institutional fragmentation; cross-departmental collaborative governance is a clear policy orientation, but practical dilemmas such as approval obstacles between military and civil aviation and overlapping powers and responsibilities among multiple departments indicate that defining power boundaries through legislative coordination is more conducive to optimizing governance effectiveness; technological innovation requires legal norms to have dynamic response capabilities, but the current standard revision cycle far exceeds the speed of technological iteration, and gaps in defining new legal relationships frequently occur in practice, requiring legislative coordination to build flexible normative mechanisms. The necessity of legislative coordination for China is essentially the result of the combined effect of the industrial laws of the low-altitude economy and China's institutional environment.

Discussion

The practical challenges in coordinating China's regulatory system for the low-altitude economy are not a one-dimensional issue, but rather the result of the interplay and superposition of multiple structural contradictions. The core root of these contradictions lies in the defects in the hierarchical design of the regulatory system itself – such problems as the vague definition of core rights like airspace usage rights in higher-level laws, and the disconnection between mid-level administrative regulations and departmental rules. These fundamentally lead to a lack of a unified logical framework within the regulatory system, and this endogenous flaw further manifests itself as a mechanism obstacle in cross-domain governance. At the same time, the speed of technological iteration has outpaced the update rhythm of the regulatory system. The rapid development of new forms of business, such as unmanned aerial vehicles and eVTOL, continues to break through the adjustment boundaries of traditional regulations, directly exposing the lag of hierarchical design. Eventually, a vicious circle is formed: the more technology develops, the more prominent the hierarchical defects become; the more hindered cross-domain governance is, the more delayed the institutional update is. This has led to a growing adaptability gap between China's regulatory system for the low-altitude economy and the industrial practice of the low-altitude economy.

1 The hierarchical imbalance in China's low-altitude economy normative system

Currently, China's legislation on the low-altitude economy exhibits a significant "fragmentation" feature. According to incomplete statistics, there are 55 existing normative documents in China's low-altitude economy field, including laws, administrative regulations, departmental rules, normative documents, and technical standards.

From the perspective of the hierarchical structure of the normative system, the *Civil Aviation Law of the People's Republic of China (2021 Revision),* as a higher-level law, has ambiguities in defining the scope of rights in low-altitude areas, especially failing to clarify the core legal issue of airspace use rights, resulting in the lack of unified rights-based norms for lower-level laws. The five administrative regulations, such as the *Interim Regulations on the Administration of Unmanned Aircraft Flights(2023),* mainly build a regulatory system around the dimension of technical safety, with obvious shortcomings in connecting industrial development goals. The 10 departmental rules, such as *the Measures for the Administration of Commercial Flight Activities of Civil Unmanned Aircraft (Interim, 2018),* focus on procedural norms, mostly involving procedural provisions such as market access and operation approval, with relatively vague definitions of substantive rights and obligations. The 10 normative documents issued by the National Air Traffic Control Commission and other departments mainly target flight control needs in specific periods or regions, featuring strong temporality and regional characteristics. In addition, although 18 technical standards such as the *Classification and Grading of Civil Unmanned Aircraft Systems(2022)* have established technical normative systems for unmanned aircraft performance parameters, communication and navigation, etc., they have problems of overlapping content and poor connection with regulations at different levels, failing to form a complete institutional closed loop covering rights definition, safety supervision, and industrial promotion.

This hierarchical discontinuity has plunged local legislation into a governance dilemma where "regulatory vacuum" and "excessive regulation" coexist. Take cross-border unmanned

aircraft management in the Guangdong-Hong Kong-Macau Greater Bay Area as an example: Hong Kong's *Civil Aviation Ordinance (Cap. 448)* requires unmanned aircraft operators to hold CAD pilot qualifications; the Chinese mainland mandates real-name registration and obtaining CAAC pilot qualifications and licenses; Macau prohibits unmanned aircraft from flying over casino areas. The differences in penalty standards for violations among the three regions exceed 10 times. Meanwhile, industrial subsidy policies are unequal – Shenzhen provides 50% subsidies for R&D expenses to eVTOL enterprises, while Hong Kong Science Park only offers office rent reductions, which may easily trigger a resource siphoning effect. At the same time, regarding the cross-border flow of relevant personnel and materials between Hong Kong, Macau and the mainland, it is necessary to strengthen rule connection and policy innovation in related fields, such as issues of aircraft control and route setting. (2025)

From the perspective of normative content, emerging business forms such as unmanned aircraft logistics and eVTOL have broken through the traditional legal regulatory framework. Taking unmanned aircraft logistics as an example, although micro, light, and small unmanned aircraft commonly used in logistics transportation are restricted to a flight altitude of no more than 120 meters in the *Interim Regulations on the Administration of Unmanned Aircraft Flights (2023),* they often need to fly through building clusters or crowded areas in actual transportation. However, supporting standards such as the *Specification for Unmanned Aircraft Express Delivery Services (2024)* have not specified the quantitative horizontal safety distance between flight paths and buildings in densely populated areas. This lack of standards has led to significant differences in local regulatory practices: Hunan Province designates a 200-meter radius around core areas as control zones, while Zhanjiang City sets a 500-meter horizontal no-fly radius for sensitive areas, with a 150% difference between the two local standards, directly increasing the compliance costs for enterprises operating across regions.

The fragmentation of the normative system caused by the hierarchical imbalance in China's low-altitude economy normative system has further exacerbated the cross-regional and cross-departmental coordination dilemmas in China's low-altitude economy industrial practice. Under the traditional "multi-agency governance fragmentation" model, the institutional conflicts between the cross-domain nature of the low-altitude economy and the closedness of China's current low-altitude economy regulatory system pose severe challenges to regional and departmental coordination in the development and management of China's low-altitude economy.

2 The difficulties in regional coordination within China's low-altitude economy normative system have become prominent

Under the traditional legislative model, the supervision of China's low-altitude economy industry tends to fall into the predicament of "formalistic coordination". The root cause of this dilemma lies in the failure of the legislative and law enforcement systems to effectively break through the governance bottleneck of "segmented management by vertical departments". Although the State Council's *Guiding Opinions on Further Promoting Cross-Departmental Comprehensive Supervision (2023)* has initially established a cross-departmental comprehensive supervision system framework, clearly requiring the realization of collaborative governance through formulating key matter lists, clarifying powers and responsibilities, and implementing joint inspections and credit supervision,(2023) in the practical level of China's low-altitude economy field, departments such as civil aviation and transportation still follow the traditional

vertical management logic in multiple aspects, resulting in a significant gap between system design and implementation effects.

Taking the typical scenario of cross-border drone logistics as an example, its business chain spans multiple fields, including airspace management, ground transportation, customs supervision, and data security, involving multiple regulatory entities such as the Civil Aviation Administration, the Ministry of Transport, the General Administration of Customs, and the Cyberspace Affairs Commission. Under the current regulatory system, although various departments have clear divisions of authority, there is a lack of joint law enforcement procedures and unified standards, which seriously weakens regulatory efficiency. In the airspace approval link, in accordance with the requirements of the *Interim Regulations on the Administration of Unmanned Aircraft Flights(2023)*, the Civil Aviation Administration stipulates that units or individuals organizing flight activities shall submit applications through the Civil Unmanned Aircraft Integrated Management Platform (UOM) by 12:00 on the day before the intended flight; in terms of ground transportation connection, the Hong Kong Transport Department takes up to 14 working days to approve the ground connection points of cross-border logistics stations, and if the connection point is located in a residential area or sensitive area, an additional 7-day public opinion collection period is required (this period is not included in the statutory approval time limit).

This means that cross-border drone logistics enterprises need to meet both the urgent approval requirements of the Civil Aviation Administration and the long-term procedural requirements of the Transport Department, with the longest compliance cycle reaching 3 weeks. Although the Hong Kong Transport Department has piloted a "pilot-and-promote approach" since 2024, compressing the approval time limit for small stations to 7 working days, the approval time differences and procedural barriers between different departments still fundamentally restrict the timeliness of logistics.

Another example is that in terms of international connections, the problems of legislative gaps and lack of coordination are particularly prominent. Article 2 of the Rules on the Administration of Flights of Foreign Civil Aircraft stipulates that "foreign civil aircraft may only enter, exit or fly within the territory of the People's Republic of China in accordance with the air transport agreements or other relevant documents signed between the government of the People's Republic of China and the government of that country, or upon application to the government of the People's Republic of China through diplomatic channels and receipt of a reply accepting the application". However, it does not clarify the collaboration details with customs, border control and other departments. In practice, there are no unified provisions in departmental rules on whether drones need to simultaneously submit airworthiness certificates, radio use permits and customs declaration documents when entering the country, leading enterprises to face difficulties such as repeated submission of materials and chaotic approval procedures. This "each managing a segment" supervision model not only increases the compliance costs of enterprises but also may lead to regulatory vacuums or duplicate law enforcement due to information barriers.

3 The technical standards and legal adaptation of China's low-altitude economy normative system are lagging behind

If the hierarchical imbalance and cross-domain obstacles in China's low-altitude economy normative system are defined as institutional-level coordination challenges, then the lagging

adaptation between technical standards and legal norms constitutes a unique coordination dilemma of the normative system in the digital era. As China's low-altitude economy gradually transforms toward intelligence and digitalization, the time gap between technological innovation and institutional supply has become increasingly prominent, emerging as another core bottleneck restricting the coordination of China's low-altitude economy normative system.

On January 1, 2024, the Civil Aviation Administration of China (CAAC) launched the Civil Unmanned Aircraft Integrated Management Platform (UOM), which, relying on the *Interim Regulations on the Administration of Unmanned Aircraft Flights (2023),* established a full-life-cycle closed-loop management system. The implementation of this national-level information system marks a crucial step toward digitalization and standardization in China's unmanned aircraft management. However, in terms of the technical implementation of the smart platform and data governance, the current standard system still has significant lag and structural flaws. Taking the *Specification for Data Exchange Interface of Civil Unmanned Aircraft Real-Name Registration (2023)* as an example, it reveals two major security vulnerabilities in its cryptographic application design:

First, the lack of encryption mode and initialization vector (IV) management mechanisms. Although Section 4.2.3 of the specification requires the use of the SM4 symmetric block cipher algorithm for transmitting citizen information, it fails to specify the selection of encryption modes or IV management rules, directly violating the mandatory provisions of Article 5.2.3 in *Basic Requirements for Cryptographic Application in Information Security Technology Information Systems (GM/T 0054-2021).* From a cryptographical perspective, SM4, as a block cipher, must rely on IV-dependent modes such as CBC/CTR to resist statistical analysis attacks – CBC mode breaks the statistical regularity of plaintext through chain dependency between IV and ciphertext blocks, while CTR mode avoids key reuse risks by generating dynamic key streams via IV and counters. In practice, some manufacturers may adopt the ECB (Electronic Codebook) mode to cut costs; due to the absence of IV, this mode generates fixed ciphertext for identical plaintext blocks. For structured data such as ID numbers, after ECB encryption, hackers can construct a "plaintext-ciphertext mapping table" through the frequency of ciphertext repetitions, directly decrypting users' private information.

Second, the absence of a key full-life-cycle management mechanism. The national cryptographic industry standard *GM/T 0054-2021* explicitly requires transmission keys to be updated every 12 hours and storage keys every 72 hours – a cycle designed to balance key exposure risks and computational resource consumption. The security of the SM4 algorithm essentially depends on a three-in-one protection system: "algorithm standardization – correct selection of cryptographic modes – dynamic key management." However, the current specification fails to set technical requirements for the entire process of key generation, storage, distribution, and update, leaving unmanned aircraft real-name registration data in a predicament of "superficial encryption." Even with the SM4 algorithm, the lack of a dynamic key update mechanism makes it difficult to resist brute-force attacks and side-channel attacks, reducing data confidentiality protection to a formalistic measure.

Third, the lack of data integrity verification mechanisms. Section 4.4.4 of the specification only requires "encrypted transmission" of SN codes but does not mandate the use of the national cryptographic SM3 hash algorithm for integrity verification, failing to align with Article 8.1.4.3 of *Basic Requirements for Cybersecurity Classified Protection (GB/T 22239-2019).* The SM3

algorithm, with its 256-bit hash value and collision resistance design, can accurately detect data tampering—its iterative compression function ensures that any minor change in input data will cause an avalanche effect in the hash value. However, due to the specification's failure to require integrity verification, attackers may tamper with SN codes through man-in-the-middle attacks or even forge data to bypass interface verification, significantly weakening the security effectiveness of encryption technologies due to the lack of integrity protection. The digital and intelligent characteristics of the low-altitude economy are challenging traditional legislation. The above issues confirm the view of Tian Wenying et al. that "technical security should be embedded in legal norms"(Tian Wenying, et al., 2005), essentially reflecting systemic flaws in the specification's design of cryptographic application systems – it neither strictly adheres to the mandatory requirements of national cryptographic standards nor constructs a collaborative protection chain covering "encryption algorithms – encryption modes – key management – hash verification." This exposes unmanned aircraft real-name registration data to multiple risks, such as privacy leakage and data tampering during transmission and storage, highlighting the urgency of accelerating the improvement of the unmanned aircraft data security standard system. In the future, efforts should start from the full life-cycle management of cryptographic applications, building a multi-dimensional protection framework where technical standards and management norms work in synergy, thereby laying a solid data security foundation while promoting the development of the low-altitude economy.

4 Experience in the coordination of low-altitude traffic regulatory systems in developed economies

One of the important manifestations of the maturity of foreign low-altitude economy normative systems is the formation of multi-dimensional institutional explorations centered on the coordination of normative systems. The United States has clarified the distribution of federal sovereignty and citizens' usufruct through a hierarchical legislative framework, and on this basis, further constructed a "law-regulations-technical standards" closed-loop system, providing a reference model for resolving logical conflicts in normative systems. The European Union, focusing on regional coordination, has broken down barriers to cross-domain governance coordination through a unified regulatory framework and flexible adaptation mechanisms. Extracting the commonalities of their practical experiences and interpreting them in a localized context can provide important insights for China to build a coordination framework of low-altitude economy normative systems adapted to its local context.

First, the hierarchical coordination logic and practice of the U.S. low-altitude traffic normative system offer references. In 2024, the global low-altitude economy market size reached 223 million yuan, with the North American market accounting for more than 40%. The dynamic evolution of the economic system has driven the optimization of rule supply in the corresponding legal field through endogenous institutional demands. Against the backdrop of the rapid development of the North American low-altitude traffic market, the United States began early in legislating for the low-altitude economy. In 2013, the Federal Aviation Administration (FAA) integrated drones into the national airspace system; in 2016, it promoted the construction of the Unmanned Traffic Management (UTM) system. In the same year, the FAA issued the Drone Flight Rules (Part 107), which, by formulating federal-level drone regulations, established to a certain extent the federal government's leading role in the management of commercial

small unmanned aircraft operations, and in practice restricted state or local governments from repealing legislation in the same field. (Shields B., 2017) Responding to the practical needs of low-altitude traffic development, 49 U.S.C. § 40103(a)(1) clearly states that "the United States Government has exclusive sovereignty over the airspace of the United States," excluding state or local governments from fragmented management rights.(2024)§ 40103(a)(2) points out that "a citizen of the United States has a public right of transit through the navigable airspace, which is uniformly planned and implemented by the federal government." § 40103(b)(1) authorizes the FAA to formulate airspace use plans and allocate resources, and § 40103(b)(2) requires the FAA to formulate flight rules covering the entire chain of management, including aircraft navigation and ground personnel protection. (Connot M. J., et al., 2016)

The construction of this hierarchical legislative framework presents a clear institutional logic: On the one hand, with 49 U.S.C. § 40103 as the top-level design, it establishes the legal principle that "airspace sovereignty belongs to the state," fundamentally eliminating safety risks caused by fragmented airspace management between localities and the military. On the other hand, it grants citizens "public right of passage in navigable airspace," activating the vitality of market entities through the institutional design of usufruct. (Cahoon C., 1990) This right allocation breaks the state monopoly model in traditional aviation, allowing enterprises and individuals to carry out innovative businesses such as commercial drone operations and low-altitude logistics within the federal planning framework, and balances the goals of safety and development through statutory powers. At the middle-level normative level, Part 107 transforms the right system established by federal legislation into specific implementation rules through commercial drone classification standards and exemption mechanisms. At the grassroots implementation level, the UTM system embeds the right boundaries into management processes through technical means, converting legal right definitions into enforceable.

Second, the EU's inter-regional drone regulatory system provides references for coordination mechanisms. It is estimated that by 2029, the European drone market will reach $11.07 billion, a scale that poses severe challenges to the air traffic control systems among EU member states. In this context, in sharp contrast to the U.S. experience in coordinating low-altitude economy normative systems, which focuses on hierarchical coordination within a single country's normative system, the EU, based on its regional integration characteristics, centers its coordination of low-altitude economy normative systems on rule adaptation in cross-domain scenarios among EU members. Facing practical constraints on industrial collaborative development caused by regulatory differences in the drone industry among member states, the EU has formed a distinctive model of inter-regional normative system coordination through establishing a cross-domain flight approval system that combines a unified airworthiness certification framework with flexible mechanisms,(Tojal M., et al., 2021) providing important references for China's exploration of cross-domain governance in the low-altitude economy. The EU established a three-level operational classification system of "open category – specific category – certified category" through the *Drone Regulation (2019/947),* (2018), among which Article 13 specifically designs a coordination mechanism for cross-border flight operations to balance safety supervision and the efficiency of cross-border drone industries. (E.C., 2019) The core logic of this mechanism is as follows:

To begin with, establish cross-border operation rules combining basic authorization and local adaptation – operators who have obtained "specific category" authorization in their

registered country need to submit a copy of the operation authorization, location information, and supplementary response plans for local risks to the destination country, ensuring both the unity of basic safety standards and allowing adjustments to prevention and control measures according to special environments such as densely populated areas and complex terrain in the destination. Next, build a rapid assessment and mutual recognition approval process: the destination country must assess the effectiveness of supplementary measures "without undue delay" and synchronize the results with the registered country and the operator, avoiding efficiency losses caused by duplicate reviews. Lastly, design a simplified declaration and filing process for low-risk cross-border operations that meet the "specific category": operators can start cross-border flights after submitting a copy of the declaration from the registered country and obtaining confirmation from the destination country.

Finally, member states must recognize authorizations or declarations from other member states to avoid operators applying repeatedly in each country. This institutional design, through the logic of cross-regional collaborative governance that combines unified standards and flexible adaptation, focuses on adapting local risk response measures without re-examining the basic authorization already approved by the applicant country, effectively shortening the approval cycle. It requires member states to mutually recognize authorizations and declarations to reduce enterprises' cross-border compliance costs, while ensuring operational safety through local risk assessment mechanisms, providing a practical path to achieve the multiple governance goals of "standardized airspace management, liberalized industrial flow, and refined safety guarantees." (Bassi E., 2019)

Third, core insights from foreign experiences for China's coordination of low-altitude economy normative systems. Although the U.S. hierarchical framework and the EU's regional coordination mechanism adopt different regulatory paths, both respond to the cross-domain and technical industrial characteristics of the low-altitude economy around the core proposition of normative system coordination. Extracting their common laws in right definition, mechanism design, and technical adaptation can provide direct insights for China to build a localized coordination framework of low-altitude economy normative systems:

In the first place, the United States established a dual right basis of "federal sovereignty – citizen usufruct" through 49 U.S.C. § 40103, refined implementation rules through the *Drone Flight Rules (Part 107,2016)*, and achieved technical implementation through the UTM system, ultimately forming a "law – regulations – technology" hierarchical closed loop. By coordinating elements within the system, it eliminates normative conflicts caused by vague right definitions, ensuring the coordinated realization of "safety supervision and industrial promotion" goals. This logic directly addresses prominent contradictions in China's legislation: *the Civil Aviation Law of the People's Republic of China (2021 Revision)* ambiguously defines core rights such as airspace use rights, leading to a lack of unified guidelines for lower-level laws; departmental rules and local legislation have overlapping and disjointed provisions in drone management and airspace use. Foreign practices suggest that only by building a clearly hierarchical and logically consistent normative system through legislative coordination can the dilemma of "lagging higher-level laws and chaotic lower-level laws" be resolved, providing stable institutional expectations for the development of the low-altitude economy.

In the next place, the EU's *Drone Regulation (2019/947)* breaks down barriers among member states through the "basic authorization + local adaptation" cross-border mechanism,

while ensuring safety bottom lines through risk assessment. Its core is to balance "free industrial flow and precise and effective supervision" through institutional coordination. This practice strongly resonates with China's practical needs for cross-domain governance: China's low-altitude economy involves multiple departments and regions, such as civil aviation, transportation, and customs, but the "multi-agency governance fragmentation" system leads to disjointed approval processes and inconsistent regulatory standards, severely restricting industrial efficiency. Foreign practices suggest that legislative coordination is key to breaking administrative barriers—by clarifying the boundaries of powers and responsibilities among cross-domain subjects through legislative coordination, it is more conducive to optimizing governance efficiency.

Conclusion

In response to the predicaments existing in China's low-altitude economy legislation, such as hierarchical imbalance, regional obstacles, and lagging technical adaptation, and drawing on the experience and enlightenment from the hierarchical legislative framework of the United States and the regional coordination mechanism of the European Union, it is necessary to construct a legislative coordination system from three dimensions: normative system, coordination mechanism, and technical adaptation, so as to achieve a dynamic balance among "safety supervision, industrial promotion, and technological innovation".

1 Establish a Coordination Mechanism for the Low-Altitude Economy Normative System with Clear Hierarchies

The core contradiction in China's low-altitude economy legislation lies in the "ambiguity of the right basis in higher-level laws and the chaos of implementation standards in lower-level laws".(Jiang Hao, 2020) This determines that reconstructing a hierarchical coordination system requires efforts from three aspects: First, strengthen the supply of right basis in higher-level laws. Taking the *Civil Aviation Law of the People's Republic of China (2021 Revision)* as an opportunity, clarify the boundary between public and private attributes of airspace use rights. On the premise of adhering to national airspace sovereignty, define the subject, scope, and exercise conditions of the "public right of passage in navigable airspace", to provide a legal basis for the rights of new business forms such as unmanned aerial vehicles and eVTOL. (Li Shouping, et al., 2015) Second, promote the connection and integration of mid-level norms. To address the issue of overlapping between the *Interim Regulations* on the *Administration of Unmanned Aircraft Flights (2023)* and departmental rules, a content connection mechanism between "administrative regulations and departmental rules" should be established. Led by the legislative affairs department of the State Council, a systematic review of the existing 5 administrative regulations and 10 departmental rules should be conducted to delete conflicting clauses and supplement missing norms (such as standards for horizontal safety distances in unmanned aircraft logistics), ensuring that mid-level norms are logically consistent throughout the entire chain of "market access, flight control, and liability determination". (Chen Jiayi, et al. 2025) A joint assessment team should be established by the Legislative Affairs Commission of the Standing Committee of the National People's Congress, the Civil Aviation Administration, the Ministry of Industry and Information Technology, and other relevant departments. This

team will focus on the challenges posed by new business forms to the law and conduct periodic comprehensive evaluations of the norms in the low-altitude economy field. Additionally, the revision cycle of technical standards should be linked to the pace of industrial iteration, to prevent standards such as Classification and Grading of *Civil Unmanned Aircraft Systems (2022)* from becoming institutional obstacles due to lag.

2 Improving the Coordination Path of the Normative System for Cross-Regional Linkage in China's Low-Altitude Economy

A clearly hierarchical normative system for the low-altitude economy provides a basic framework for collaborative governance. However, the cross-regional nature of the low-altitude economy requires further breaking down the governance barriers between regions and departments. Drawing on the EU's collaborative logic that combines basic authorization with local adaptation, institutional innovations are needed to remove obstacles to cross-regional linkage, extending from "intra-system collaboration" to "cross-regional collaboration".

First, in terms of regional collaboration, a "dual-track system" should be piloted in the Guangdong-Hong Kong-Macau Greater Bay Area. On one hand, establish a "one-place approval, mutual recognition across the region" licensing mechanism – after enterprises obtain unified approval from the Civil Aviation Administration, the three regions of Guangdong, Hong Kong, and Macau shall not add additional approval conditions. With reference to *EU Drone Regulation (2019/947)* Article 13, only enterprises are required to submit risk response plans for local sensitive areas; On the other hand, a "Low-Altitude Economy Legislative Coordination Group" should be jointly established by the three regions to review and eliminate conflicting regulations within the region on a quarterly basis, forming a replicable model for regional coordination.

Secondly, at the inter-departmental coordination level, formulate the *Regulations on Inter-Departmental Coordination for the Low-Altitude Economy* to clarify the list of powers and responsibilities as well as procedural rules. For scenarios involving multi-department supervision, such as unmanned aircraft cross-border logistics, establish a joint approval mechanism featuring a "leading department-collaborating departments" structure, and implement a "unified supervision standards list". Specify national unified benchmarks for matters such as no-fly zone radii and airworthiness certification, while allowing localities to make scientific and reasonable refinements within these benchmarks. This will address the issue of excessive differences in no-fly zone radius standards across regions.

Finally, at the international alignment level, formulate the *Operational Procedures for the Administration of Foreign Unmanned Aircraft Entry* with reference to the EU's cross-border operation coordination mechanism. Unify the declaration requirements of customs, border control, and civil aviation authorities, and clarify the specific procedures and time limits for "approval through diplomatic channels". Establish a rule mutual recognition platform with countries along the "Belt and Road" initiative, and give priority to signing memorandums of understanding on regulatory cooperation in fields such as cross-border e-commerce logistics and international emergency rescue. Simplify the mutual recognition procedures for technical standards as appropriate according to specific application scenarios.

3 Promote the collaborative adaptation of the normative system between law and technology in the low-altitude economy

After addressing the adaptation issues in the spatial dimension of the low-altitude economy industry through the cross-regional coordination mechanism of the low-altitude economy normative system, it is necessary to further meet the requirements for in-depth integration of technology and law in the low-altitude economy industry in the digital era. To tackle the problem of lagging adaptation between technical standards, technical regulations, and legal norms, a dynamically responsive normative coordination system for the low-altitude economy should be established to foster positive interaction between technological innovation and institutional supply. (Yang Kuan, et al., 2019)

First, the mechanism for transforming technical standards into laws. Revise standards with security vulnerabilities such as the *Specification for Data Exchange Interface of Civil Unmanned Aircraft Real-Name Registration(2023),* clearly stipulating that SM4 encryption must adopt the CBC/CTR mode, compulsorily standardizing the generation and management rules of the initialization vector (IV), and prohibiting the use of the ECB mode; incorporate key full-life-cycle management and SM3 hash verification into mandatory clauses, and connect them with national cryptographic standards such as the *Basic Requirements for Cryptographic Application in Information Security Technology Information Systems (GM/T 0054-2021), t*o eliminate the risk of privacy leakage from the technical bottom layer.

Second, the system involves interdisciplinary experts in legislation. Establish a "Low-Altitude Economy Legislative Technology Pre-Research Group" that includes experts in fields such as cryptography, aviation engineering, and artificial intelligence to participate in the assessment of technical feasibility during the legislative demonstration stage; set up a fast track for "technological innovation-legal response". For new technologies such as unmanned aircraft, automatic obstacle avoidance and low-altitude communication frequency spectrum, the pre-research group shall put forward suggestions on legal adaptation to provide technical support for legislative revisions.[40]

Third, the embedding of norms in smart supervision platforms. Based on the UOM platform, the requirements for legislative coordination should be embedded into digital management processes: Algorithm modules will be used to realize automatic retrieval and conflict early warning of "higher-level laws - lower-level laws - technical standards"; A closed-loop management and control module covering "encryption - verification - auditing" will be established to ensure that the entire process of data transmission and storage complies with legal requirements, thus promoting technical supervision to become a visualized carrier of legislative coordination.

The law-based development of the low-altitude economy requires breaking through current institutional bottlenecks through legislative coordination, with its core lying in addressing the value imbalance among "safety supervision, industrial promotion, and technological innovation". This is specifically manifested in the ambiguity of the right basis in higher-level laws, the formalization of cross-regional governance coordination, and the lagging adaptation between technical standards and legal norms. Foreign practices suggest that drawing on the experience of the hierarchical legislative framework of the United States and the regional coordination mechanism of the European Union, China should clarify the boundaries of airspace use rights by revising the *Civil Aviation Law of the People's Republic of China (2021 Revision)*, implement the "one-place approval, mutual recognition across the region" mechanism on a pilot basis in the

Guangdong-Hong Kong-Macau Greater Bay Area, and embed the full-life-cycle management of cryptographic applications into technical standards. By doing so, a legislative system featuring "hierarchical coordination, cross-regional coordination, and technical coordination" can be built to achieve precise alignment between institutional supply and industrial demand. This will promote the transformation of the low-altitude economy from "policy-driven" to "rule-of-law guaranteed", providing a solid legal foundation for its high-quality development.

Contribution of the authors

Both authors contributed equally to this article. **Jian yu Hu** prepared the initial draft and worked on the literature review and case study analysis. **Rui xue Hou** revised the structure of the article in accordance with academic requirements, provided detailed comments on the first draft, and finalized the submission. The theoretical framework and comparative analysis were jointly developed. All revisions and comments were discussed and accepted by both authors. The authors made equal contributions to the preparation and publication of this article.

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Законодательные вызовы и реконструкция нормативной системы низковысотной экономики Китая: перспективы синергии

Аннотация: Высотная экономика в Китае стремительно развивается как стратегическая новая отрасль, чему способствуют реформы, государственные инициативы и технологические инновации. Несмотря на то, что Закон о гражданской авиации формирует основное правовое основание, существующее законодательство выявляет противоречия в нормативной логике, фрагментарность регулирования и недостаточную адаптивность к технологическим

изменениям. В статье анализируются законодательные проблемы правового обеспечения низковысотной экономики Китая и предлагается использовать концепцию «законодательной синергии» как теоретический подход к их решению. На основе анализа литературы, эмпирических данных и сравнительного исследования выделяются три ключевые вызова: иерархический дисбаланс в системе норм, препятствия для межрегиональной координации и отставание между техническими стандартами и правовыми нормами. Рассматривается международный опыт, в частности иерархическая модель США и механизм региональной координации Европейского Союза, что позволяет предложить пути реконструкции нормативной системы Китая. Результаты исследования вносят вклад в разработку эффективной системы регулирования и создают законодательную основу для качественного развития низковысотной экономики.

Ключевые слова: низковысотная экономика, законодательные проблемы, синергия нормативной системы, управление воздушным пространством, регулирование БПЛА

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Қытайдың төмен биіктіктегі экономикасын құқықтық реттеудің қиындықтары мен жүйелік реконструкциясы: нормативтік жүйе синергиясы тұрғысынан

Аңдатпа: Төмен биіктіктегі экономика Қытайда реформалар, саясаттық бастамалар және технологиялық инновациялар нәтижесінде стратегиялық жаңа сала ретінде қарқынды дамып келеді. Азаматтық авиация туралы заң негізгі құқықтық негізді қамтамасыз еткенімен, қолданыстағы заңнамада нормативтік логикадағы қайшылықтар, реттеудің бытыраңқылығы және технологиялық өзгерістерге бейімделудің жеткіліксіздігі байқалады. Бұл мақала Қытайдағы төмен биіктіктегі экономиканы құқықтық қорғаудың қиындықтарын талдап, оларды шешудің теориялық бағыты ретінде «заңнамалық синергия» тұжырымдамасын ұсынады. Әдебиеттерге шолу, эмпирикалық талдау және салыстырмалы зерттеу негізінде үш негізгі мәселе анықталды: құқықтық жүйенің иерархиялық теңгерімсіздігі, аймақаралық үйлестірудегі кедергілер және техникалық стандарттар мен құқықтық нормалардың сәйкессіздігі. АҚШ пен Еуропалық Одақ тәжірибесін талдау арқылы Қытайдың нормативтік жүйесін қайта құрудың жолдары ұсынылады. Зерттеу нәтижелері заңнамалық иерархияның бірізділігін қамтамасыз етуге, аймақаралық басқаруды жетілдіруге және технологиялық бейімделуді заңнамаға енгізуге бағытталған, бұл төмен биіктіктегі экономиканың сапалы дамуына құқықтық негіз қалайды.

Түйін сөздер: төмен биіктік экономикасы, заңнамалық қиын жағдай, нормативтік жүйенің синергиясы, әуе кеңістігін басқару, UAV реттеу

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