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Research on the Mechanism and Pathways of Low-Altitude Economy Empowering New Quality Productive Forces Driven by Digital-Real Integration

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Abstract: This paper systematically explores how the low-altitude economy, through deep integration with the real economy and the digital economy ("Digital-Real Integration"), collaboratively promotes the formation of new quality productive forces, and analyzes the critical role of Specialized, Sophisticated, Distinctive, and Innovative (SSDI) small and medium-sized enterprises (SMEs) within this context. Research indicates a bidirectional and mutually reinforcing relationship between the low-altitude economy and digital-real integration, where the development of the low-altitude economy relies on enabling digital technologies such as high-precision navigation, intelligent air traffic management, and digital twins; simultaneously, the massive data and diverse scenarios it generates provide a crucial testing ground for digital technology innovation and implementation. SSDI SMEs demonstrate significant vitality in niche UAV sectors, specialized solutions, and regional service network construction. To foster the ternary synergy among the low-altitude economy, digital-real integration, and new quality productive forces, efforts should focus on building data trading markets and secure channels, constructing intelligent integrated infrastructure, and creating comprehensive management platforms. Current challenges include technology maturity, safety regulation, airspace supply, and business model sustainability. Future work requires enhanced systematic planning, optimized regulatory environments, the construction of a collaborative ecosystem, and the promotion of new quality productive forces development.

Keywords: Low-altitude economy; Digital-real integration; New quality productive forces; Specialized; Sophisticated; Distinctive; Innovative (SSDI) SMEs

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1. Introduction

Entering the period of the "15th Five-Year Plan," China's economic development faces profound structural

adjustment and kinetic energy transformation. The "15th Five-Year Plan" outlines the need to accelerate the development of strategic emerging industrial clusters, including the low-altitude economy, while strengthening national security capacity-building in emerging fields such as low-altitude [1]. This marks the elevation of the low-altitude economy from localized industrial exploration to a major national-level strategy, with its development entrusted with multiple expectations to promote high-quality economic development and serve the national strategic landscape. The low-altitude economy is not a simple extension of the traditional general aviation industry. Instead, it is a comprehensive economic system centered on various low-altitude flight activities (both manned and unmanned) within low-altitude airspace (typically within 3,000 meters above ground), radiating to drive the integrated development of fields such as high-end manufacturing, artificial intelligence, next-generation communication technology, and advanced materials [2]. Characterized by high technology, high efficiency, and high quality, with innovation playing a leading role, the low-altitude economy is regarded as a typical representative of new quality productive forces.

Simultaneously, the deep integration of the real economy and the digital economy (referred to as "digital-real integration") serves as a strategic pivot for constructing a new development pattern and is becoming a critical path for advancing new industrialization and establishing a unified national market. The essence of digital-real integration lies in using real-world demand to pull digital innovation and using digital empowerment to feedback and upgrade the real economy, achieving a spiral development of "real foundation building-digital empowerment-value co-creation" [3]. Against this macro background, the low-altitude economy, with its inherent dual attributes of "three-dimensional physical space" and "digitalized operation management," provides digital-real integration with an exceptionally profound field of practice. The manufacturing, operation, and services of low-altitude aircraft are typical real economic activities, while their safe, efficient, and large-scale operation fundamentally relies on the comprehensive support of digital technologies such as high-precision navigation, real-time communication, intelligent sensing, and big data analytics. As a result, exploring how the low-altitude economy becomes a key link connecting digital-real integration and new quality productive forces holds significant theoretical value and practical meaning [4–6].

2. The ternary synergistic mechanism of low-altitude economy, digital economy, and new quality productive forces

The low-altitude economy, digital-real integration, and new quality productive forces constitute a mutually driven, tightly coupled synergistic development system [7]. New quality productive forces are the goal and outcome, with their core residing in revolutionary technological breakthroughs, innovative allocation of production factors, and deep industrial transformation and upgrading, moving away from traditional economic growth models to form an advanced productive force characterized by high technology, high efficiency, and high quality. Digital-real integration is the pathway and means, emphasizing the deep embedding of data, a new type of production factor, into the entire chain of the real economy's R&D, production, distribution, and services. It uses digital technology to amplify the efficacy of the real economy while providing the soil for digital technology iteration and upgrading through real-world scenarios. The low-altitude economy is both an important component of new quality productive forces and a "natural testing ground" for generating and validating the outcomes of digital-real integration.

From a theoretical perspective, the development of the low-altitude economy profoundly illustrates the innovative allocation of production factors. There exist diversified paths to stimulating urban low-altitude

economic vitality, which can be categorized into different models such as resource-technology co-driven, digital-real integration propelled, digital-intelligent economy oriented, and technology-market enabled [7]. Among these, technological factors constitute a necessary condition for stimulating the entrepreneurial vitality of the low-altitude economy. This indicates that beyond traditional factors like land, capital, and labor, the addition and recombination of new factors such as technology, data, and airspace form the basis for the emergence of the low-altitude economy as a new quality productive force. Digital-real integration plays the roles of "catalyst" and "reorganizer" in this process. For example, the operation of the low-altitude economy generates massive amounts of flight trajectory, environmental perception, equipment status, and mission payload data. The collection, transmission, processing, and modeling analysis of this data are themselves core activities of the digital economy. When this data is used to optimize flight routes, predict equipment failures, and improve operational efficiency, it directly empowers the quality and efficiency improvement of real economic activities like low-altitude logistics, inspection, and passenger transport, realizing value transformation.

Conversely, the complex application scenarios and stringent safety requirements faced by the low-altitude economy also impose higher and more specific demands on digital technology, thereby driving digital innovation in reverse [8]. For instance, ensuring the safety of integrated drone and manned aircraft flight in urban environments requires the development of high-precision real-time positioning, ultra-low latency communication, and intelligent conflict resolution algorithms that far exceed the needs of ground transportation. This kind of technology development driven by real-world scenario pain points vividly exemplifies the "real driving digital" aspect of digital-real integration. Ultimately, this bidirectional, mutually reinforcing fusion gives rise to entirely new products (e.g., eVTOLs), new services (e.g., urban air mobility), and new business formats (e.g., low-altitude data trading), which are direct manifestations of the "qualitative" leap of new quality productive forces. Therefore, the low-altitude economy can be seen as an efficient converter that transforms the process of digital-real integration into outputs of new quality productive forces. Together, the three constitute a positive feedback loop driven by technological innovation and factor restructuring [9].

3. Multi-dimensional characteristics of low-altitude economy driving new quality productive forces development

As a typical representative and important engine of new quality productive forces, the low-altitude economy will exhibit systematic innovation at the industrial, technological, economic, and social efficacy levels, fully aligning with the core features of new quality productive forces.

At the industrial level, the low-altitude economy exhibits significant characteristics of high technology, long chains, and strong integration. It aggregates high-end equipment manufacturing, new-generation information technology, new energy, new materials, and modern services, forming an industrial chain covering the entire process of R&D, manufacturing, and operation. It possesses powerful industrial radiation and synergistic upgrading capabilities, which constitute the industrial foundation required for cultivating new quality productive forces.

At the technological level, the development of the low-altitude economy relies on the integrated innovation of frontier technologies such as eVTOLs, highly reliable flight control systems, intelligent perception and obstacle avoidance, and high-energy-density batteries [10]. Relevant technologies have significant spillover effects, empowering related industries like new energy vehicles and robotics, continuously injecting technological

momentum into new quality productive forces.

At the economic level, the low-altitude economy creates new supply in areas like urban air mobility, instant logistics, and low-altitude tourism, opening up a trillion-level market space. It drives a virtuous cycle of "technology-market-capital-innovation," providing a sustainable market foundation for cultivating new quality productive forces.

At the social efficacy level, its applications in areas like emergency response and urban governance not only enhance the efficiency and precision of public services but also promote the systematic renewal of social operation and governance models, reflecting the deeper value of new quality productive forces as "high efficiency, high quality."

4. The digital development pathways of low-altitude economy driven by digital-real integration

In practice, the low-altitude economy and digital-real integration exhibit a symbiotic and co-evolutionary relationship, manifested as a systematic reliance on and deep integration with digital technologies, data elements, and digital infrastructure, promoting the comprehensive digital reconstruction of the low-altitude economy from its foundational architecture and operational system to its industrial ecosystem.

4.1. Constructing a digital foundation, consolidating integration bedrock

The construction of the digital foundational architecture for the low-altitude economy is the physical prerequisite for digital-real integration. Low-altitude flight activities occur in a three-dimensional airspace without physical attachments, where their safe and orderly management entirely depends on digital and intelligent means. This has given rise to the concept of the "Low-Altitude Digital Foundation." Taking Guangdong Province as an example, by integrating multi-source data such as real-scene 3D models, building/road networks, and meteorology to construct a "Low-Altitude Data Basemap," it has achieved an upgrade of airspace management from static 2D to dynamic 3D, providing a digital basis for route planning and flight navigation.

4.2. Achieving intelligent operation, deepening the integration core

The intelligent evolution of the low-altitude operation system is the core manifestation of digital-real integration. The operation of low-altitude aircraft, especially unmanned aerial vehicles (UAVs), is a typical data-driven, software-defined process. Data permeates the entire flight lifecycle: from front-end intelligent route planning and simulation verification based on the digital foundation, mid-end real-time data closed loops via "Beidou + 5G-A + Sensors," to back-end data analysis. Through "integrated air-space-ground monitoring" and AI decision-making, airspace management is propelled from "human-led" to "intelligent-led," achieving dynamic optimization and allocation of airspace resources.

4.3. Promoting data circulation, unleashing integration value

The valorized circulation of low-altitude data elements is an advanced form of digital-real integration. Data generated from low-altitude operations, such as flight status, environmental perception, and mission payload, not only concern flight safety but also hold high commercial value. Promoting their productization and assetization for circulation in data exchanges under safe and compliant conditions, and fostering new data service business formats, marks the transformation of low-altitude data from an internal element to a market production factor,

completing value co-creation at the factor level between digital and real.

5. The systemic framework for empowering low-altitude economy and new quality productive forces through digital-real integration

5.1. Taking data elementization as the pivot, driving value multiplication across the low-altitude industrial chain

Data is the "blood" driving digital-real integration and the "fuel" for the low-altitude economy's intelligence. Promoting the transformation of low-altitude data from a resource to an asset is a key pivot for cultivating new quality productive forces. For instance:

(1) Advance data standardization and assetization: Establish unified data standard systems for geographic information, flight status, equipment health, etc., and improve mechanisms for data property rights definition, value assessment, and registration, laying the foundation for compliant data circulation;

(2) Build a trusted low-altitude data space: Under the premise of ensuring security and privacy, establish institutional and technical environments that support trustworthy and controllable exchanges among data owners, users, and processors. Through this, enterprises can obtain desensitized operational data to optimize products, insurance companies can develop risk-based insurance products, and government departments can achieve cross-system data collaboration to enhance governance efficiency;

(3) Innovate data products and services: Developing "congestion prediction" products for flight routes based on meteorological and traffic flow data, or training AI models for identifying power line defects using drone inspection images for external service provision. The development and trading of such data products will catalyze new business formats like the "low-altitude data industry," becoming new growth points for the low-altitude economy and fully embodying the "digital-driven" characteristic of new quality productive forces.

5.2. Building scalable safe operation capabilities through low-altitude intelligent integrated infrastructure

The unleashing of new quality productive forces requires scalable application scenarios for support. The large-scale, high-density, and regularized operation of low-altitude aircraft is inseparable from a robust new infrastructure system, the low-altitude intelligent integrated infrastructure. This infrastructure system transcends traditional landing sites and ground control towers, as it is an intelligent system integrating communication, navigation, surveillance, computing, and services. In terms of communication, promoting the deep integration of 5G-A/6G networks with low-altitude scenarios is necessary to meet the high bandwidth, low latency, and high reliability communication demands for UAV beyond-visual-line-of-sight flight control and HD video streaming. In navigation, building a nationwide Beidou Ground-Based Augmentation Network is required to provide centimeter-level or even millimeter-level high-precision positioning services for low-altitude flights, which is fundamental for achieving precise takeoff/landing, dense formation flying, and obstacle avoidance in complex environments. In surveillance, integrating multiple sensing methods is needed to achieve "visibility, reachability, and controllability" over all legal aircraft. The completion of this infrastructure system will make low-altitude airspace a standardized, planable, measurable, and operable public service network, akin to ground road networks, significantly lowering entry barriers and operational costs for businesses, thereby stimulating numerous commercial innovations and propelling new quality productive forces across the critical leap from "demonstration pilots" to "scaled

application."

5.3. Optimizing factor allocation and industrial synergy with a "low-altitude industrial brain" as the central hub

Drawing on the concepts of "Industrial Internet Platforms" and "Industrial Brains," constructing a "Low-Altitude Industrial Brain" serving the low-altitude economy is a key pathway to achieve global resource optimization and industrial chain synergy. Based on cloud computing, big data, and AI technologies, this platform builds a digital governance system covering a "micro-meso-macro" three-layer architecture as follows:

(1) At the micro level, it interfaces with real-time "Air-Intelligence-Network" data to dynamically optimize airspace resource allocation, achieve intelligent flight traffic scheduling, and alleviate regional congestion;

(2) At the meso level, it aggregates production capacity, orders, inventory, and logistics information from upstream and downstream industry chains, promoting efficient collaboration between complete vehicle manufacturing, component supply, and operational services to enhance industrial chain resilience;

(3) At the macro level, it provides the government with a panoramic view of industrial operations, supporting policy simulation and scientific decision-making. For example, by analyzing eVTOL vertiport usage frequency and regional demand heat, it can assist in the precise layout of infrastructure investment planning.

Through data intelligence, the "Low-Altitude Industrial Brain" integrates dispersed airspace resources, manufacturing capabilities, service demands, and regulatory systems into an organically synergistic whole, promoting the innovative allocation of production factors across a broader scope, reflecting the systematic transcendence of new quality productive forces over traditional production organization models.

6. The innovation positioning and development strategies for specialized, sophisticated, distinctive, and innovative (SSDI) SMEs

Within the emerging field of the low-altitude economy, SSDI SMEs, characterized by their specialization, sophistication, distinctiveness, and innovativeness, have become a significant force driving technology implementation, enriching application ecosystems, and activating regional development. Although they do not occupy a dominant position, their flexible mechanisms, deep cultivation capabilities, and innovative vitality play an irreplaceable structural role in the industrial value chain, specifically manifested in three following aspects:

(1) SSDI SMEs are core explorers of niche scenario innovation and business validation. Facing highly differentiated vertical demands in areas such as agricultural plant protection, energy inspection, emergency surveying and mapping, and cultural-tourism performances, they leverage focused technical accumulation and agile responsiveness to continuously develop specialized UAV systems, intelligent operation algorithms, and customized solutions. They translate cutting-edge technologies into viable, operable business scenarios, injecting sustained application vitality into the low-altitude economy;

(2) SSDI SMEs are deep enablers of key industry chain segments and foundational capabilities. In critical areas such as high-end sensors, high-precision navigation, lightweight structures, specialized flight control software, and testing/certification services, these enterprises often possess profound technical expertise and process accumulation, becoming indispensable "supporting experts" and "hidden champions" within the industry chain. By providing highly reliable and high-performance components and services, they strongly support the overall technological advancement and supply chain security of the entire industry;

(3) SSDI SMEs are important promoters of regional characteristic development and ecosystem synergy. Relying on a deep understanding of local industrial foundations, resource endowments, and policy environments, they can swiftly respond to regional public service needs (e.g., river patrol, forest fire prevention) and the upgrade requirements of characteristic industries (e.g., scenic area low-altitude tours, logistics distribution within industrial parks). They promote the formation of service networks deeply integrated with the local economy, fostering the coordinated development and digital transformation of the low-altitude economy at the regional level.

However, SSDI SMEs still face multiple constraints in participating in the development of the low-altitude economy. For example, significant R&D investment, lengthy airworthiness certification cycles, shortage of interdisciplinary talent, complex airspace usage approval processes, and limited access to data channels. Therefore, a systematic support system needs to be constructed, including establishing special innovation funds, optimizing approval and access processes, promoting the orderly opening of public low-altitude data, and encouraging leading enterprises to engage in supply chain collaboration and technology sharing. This will help build an integrated innovation ecosystem characterized by "large enterprises leading small ones, small ones promoting large ones," fully unleashing the critical role of SSDI SMEs in the process of the low-altitude economy empowering new quality productive forces.

7. Conclusion

This study systematically explores the mechanism and pathways of the low-altitude economy empowering new quality productive forces driven by digital-real integration, revealing the synergistic relationships and implementation logic among the low-altitude economy, digital-real integration, and new quality productive forces. The main conclusions are as follows:

There exists an intrinsic relationship of bidirectional mutual promotion and symbiotic co-evolution between the low-altitude economy and digital-real integration. On one hand, the development of the low-altitude economy relies on the comprehensive empowerment of digital technologies such as high-precision navigation, intelligent air traffic management, and digital twins, driving its complete digital reconstruction from foundational architecture and operational systems to the industrial ecosystem. On the other hand, the massive data and diverse scenarios generated by the low-altitude economy also provide an important testing ground and demand-pull for the iterative innovation and commercial landing of digital technologies, forming a virtuous cycle of "real driving digital, digital strengthening real."

With its industrial attributes of high technology, long chains, and strong integration, the low-altitude economy, relying on the cluster breakthroughs and integrated innovation of frontier technologies, comprehensively aligns with and powerfully promotes the formation and development of new quality productive forces by creating new supply, opening new markets, and enhancing social operational efficiency. It is not merely a new industry but a key carrier connecting real-world demand with digital technology to achieve a qualitative leap in productive forces.

The realization of the low-altitude economy empowering new quality productive forces depends on a systematic pathway with data elementization as the pivot, intelligent integrated infrastructure as the support, and an industrial smart brain as the central hub. These three pathways are interlinked and work synergistically, collectively propelling the low-altitude economy from "demonstration pilots" to "scaled application," completing a profound transformation from resource-driven to innovation-driven, and from localized exploration to systematic

advancement.

SSDI SMEs play an irreplaceable role in the development of the low-altitude economy.They are core explorers of niche scenario innovation, deep enablers of key industry chain segments, and important promoters of regional ecosystem synergy. Stimulating their innovative vitality and building an integrated innovation ecosystem characterized by “large enterprises leading small ones, small ones promoting large ones” is of great significance for enhancing industrial chain resilience and overall competitiveness.

However, the low-altitude economy still faces multiple challenges on its path towards high-quality development, including technology maturity, regulatory standards, infrastructure, business models, and data security. In the future, it is necessary to strengthen systematic planning at the strategic level, break through key bottlenecks at the technological level, optimize the regulatory environment at the institutional level, and promote synergistic integration at the ecosystem level. Particular attention should be paid to providing precise support for SSDI SMEs, fortifying the bottom line of safe development, and promoting the sustained and healthy evolution of the low-altitude economy, thereby injecting a robust “low-altitude kinetic energy” into the construction of Chinese modernization.

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