International Experience in Urban Low-Altitude Airspace Planning for Drones

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Abstract. The low-altitude economy and urban air mobility have emerged as major areas of interest, while drone-based express delivery and logistics are gradually entering urban operations. These activities will substantially reshape the structure of urban low-altitude airspace, affect its safety, efficiency, and capacity, and exert far-reaching impacts on the form, use, and governance of urban space. The three-dimensional development of future cities will no longer be confined to ground, above-ground, and underground layers; low-altitude airspace will become a fourth layer within a more complete spatial system. This trend introduces new questions and challenges for urban planning. It is therefore necessary to examine the implications of drone deployment through the relationship between airspace and urban space, review relevant international cases, and synthesize planning approaches for drone-oriented urban low-altitude airspace. The findings provide a reference for innovation in urban planning in China.

Keywords: smart city; low-altitude economy; drone; urban space; airspace; vertical city; urban planning.

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1 Development of Urban Low-Altitude Airspace for Drones and Its Spatial Implications

For more than a century, visions of the future city have often featured skies filled with aircraft, with the flying car portrayed as a defining feature of the technological metropolis [1]. Examples include the Boston Globe's 1900 vision of airships above the city [2]; representations of urban aircraft in Le Corbusier's future city and Frank Lloyd Wright's Broadacre City in the 1930s and 1940s [3]; and the air-mobility-oriented development (AOD) model proposed in 2023 by NIKKEN Future Lab, which integrates drones and flying cars into future urban design [4]. In practice, unmanned aerial vehicles (UAVs, or drones) and electric vertical take-off and landing aircraft (eVTOLs) are becoming increasingly mature and are beginning to exert tangible effects on urban airspace and urban form.

In China, advances in low-altitude aircraft technologies are transforming urban low-altitude airspace and accelerating the growth of the low-altitude economy①. In 2021, the Outline of the National Comprehensive Three-Dimensional Transport Network, issued by the CPC Central Committee and the State Council, incorporated the concept of the low-altitude economy into a national plan for the first time. In 2023, it received further attention as an emerging pillar industry with trillion-yuan potential.

From the perspective of urban planning and development, aircraft operating in cities differ from conventional general-aviation aircraft that fly at higher altitudes. Most urban operations occur in low-altitude airspace, are more closely related to the daily activities of urban residents, and are physically closer to the built environment. Activities such as drone delivery and logistics are gradually expanding, changing the safety, efficiency, and capacity of urban low-altitude airspace and producing major effects on the morphology, use, and management of urban space.

During the modern planning era, the automobile was treated as a core issue linking land use and transport [5]. Just as the invention of the car transformed modern planning, and autonomous vehicles are reshaping current urban transport systems [6], the development of the low-altitude economy and the maturation of drone technology may significantly restructure urban form during the smart-city era.

The vertical development of future cities will no longer be limited to ground, above-ground, and underground levels. Low-altitude airspace will constitute a fourth layer within a more complete spatial system. Unlike most eVTOL operations, which generally occur above 120 m, drones are more likely to operate below 120 m [7]. Their closer proximity to the ground means that they may exert a more direct influence on the relationship between urban surface space and low-altitude airspace in the planning and construction of future smart cities.

It is therefore necessary to analyze the implications of drone development from the perspective of airspace–space relations, review domestic and international practices, and synthesize planning methods for drone-oriented urban low-altitude airspace②. Such work can support innovation in both low-altitude airspace governance and urban spatial planning in China.

2 Urban Low-Altitude Airspace

2.1 Defining Urban Low-Altitude Airspace

With the growth of the low-altitude economy, urban air mobility (UAM) is becoming an important trend. Drones now perform a wide range of urban functions, including transport, fire prevention, disaster response, and surveying, and have become a strategic area of development in many countries. Their expansion will inevitably change the way airspace is used. Airspace, a concept closely associated with aircraft, generally refers to the volume of atmosphere above the Earth's surface in which aircraft may operate. Under the air-traffic-service and flight requirements of the International Civil Aviation Organization (ICAO), airspace is divided into controlled and uncontrolled categories, comprising seven classes: A, B, C, D, E, F, and G. Classes A–E are controlled; Classes F and G are uncontrolled [8].

Low-altitude airspace generally refers to airspace at or below 1,000 m above ground level [9]. Very-low-altitude airspace generally refers to airspace at or below 120 m and falls within uncontrolled Class G airspace③. According to first-quarter 2019 statistics from the Civil Aviation Administration of China, 96.5% of drones operated within very-low-altitude airspace and 99.9% below the low-altitude threshold. Low-altitude airspace is therefore closely associated with drone operations. China's Interim Regulations on the Flight Administration of Unmanned Aircraft, published in 2024, define airspace below 120 m as generally suitable for drone flight, whereas airspace above 120 m is controlled [10]④. Accordingly, this article focuses on urban airspace below 120 m, which is used primarily by consumer drones and small logistics drones.

The increase in drone use entails more intensive use of urban low-altitude airspace and raises the question of how that airspace should be governed [11]. This is a spatial layer that has received limited attention in conventional airspace management and urban planning, yet it is becoming an important component of future smart-city development and a potential source of spatial-management conflicts. Paul Cureton argues that urban air mobility is one dimension of the smart city and that low-altitude drones effectively fill a previously underused "void space" between conventional aircraft and the ground [2].

2.2 The Relationship Between Airspace and Urban Space

Because urban low-altitude airspace lies within the urban area, it is directly connected to the concept of urban space. A meaningful definition therefore requires clarification of both airspace and space. In cities, spatial rights are well established and relatively clear in both conceptual and legal terms. By contrast, existing Chinese law does not fully specify the meaning of airspace [12], and the scope of airspace rights remains underdeveloped [9, 13]. Airspace cannot be defined in excessively general terms; it refers specifically to the volume in which aircraft can theoretically operate safely [9]. The distinction between low-altitude airspace and above-ground urban space from a planning perspective remains unclear.

Drone operations in urban low-altitude airspace directly affect the built environment and alter the interface between aircraft and the city. Applications include passenger transport, medical delivery, express freight, emergency response, and infrastructure maintenance [11]. As drone numbers increase, low-altitude airspace becomes more visible as a spatial resource. Because current regulations do not define a minimum altitude for drone activity, airspace rights and spatial rights overlap near the ground. Drone deployment has therefore "removed the buffer of rights that existed between airspace rights and established terrestrial rights during the era of crewed aviation" [13]. Increasing drone activity will make both airspace and urban-space governance more complex [10].

2.3 Scope of Urban Low-Altitude Airspace Planning

Airspace planning is closely related to air-traffic management and airspace control. It refers to the strategic organization of air-traffic-management systems and the allocation and design of airspace resources to ensure safety and efficiency [14]. General-aviation airspace planning currently includes procedural design, structural planning of the airspace architecture, allocation of responsibility for air-traffic services, and classification of service airspace [15]. By contrast, the development and utilization of urban low-altitude airspace remain at an early exploratory stage and have not reached the technical maturity of general-aviation planning.

Zhang Honghai et al. [16] and Li Chenglong et al. [17] suggest that urban low-altitude airspace planning should cover three main areas: airspace zoning, structural design, and capacity. At the current stage, unmanned aviation is primarily being tested in representative operating environments and scenarios, and planning focuses on the designation of specific routes. At a mature stage, when drone traffic increases sharply, zoning and structural design will become the principal concerns, while routes that balance safety, equity, and efficiency will be generated by automated flight-planning systems [18].

3 Review of International Experience in Urban Low-Altitude Airspace Planning

The design of urban airspace is closely related to the flight patterns of drones. Airbus distinguishes four modes: basic flight, free route, corridor, and mixed route. Basic flight refers to the elementary state of aircraft operation. Under free routing, aircraft may follow any path while coordinating with other aircraft to avoid conflict. A corridor is a defined volume used to manage high-demand airspace or traffic. A mixed route combines fixed routes and supporting facilities where traffic density is high or structured operations are required for safety [19] (Figure 1).

Taking account of drone flight characteristics, urban airspace may be organized according to four basic structural models: fully mixed, layered, zoned, and corridor-based. These differ in the degrees of freedom permitted in direction, altitude, and speed [20-21] (Figure 2). The international experience can therefore be reviewed through three planning dimensions: zoning, structural design, and capacity.

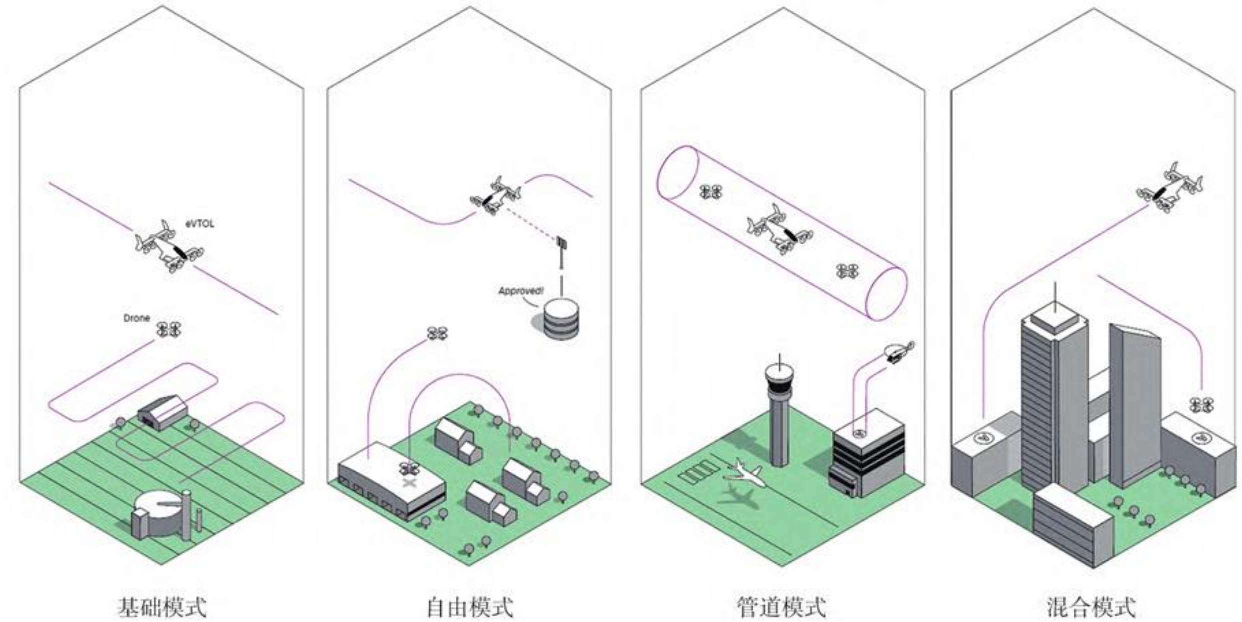

Figure 1. Four modes of drone flight [19]

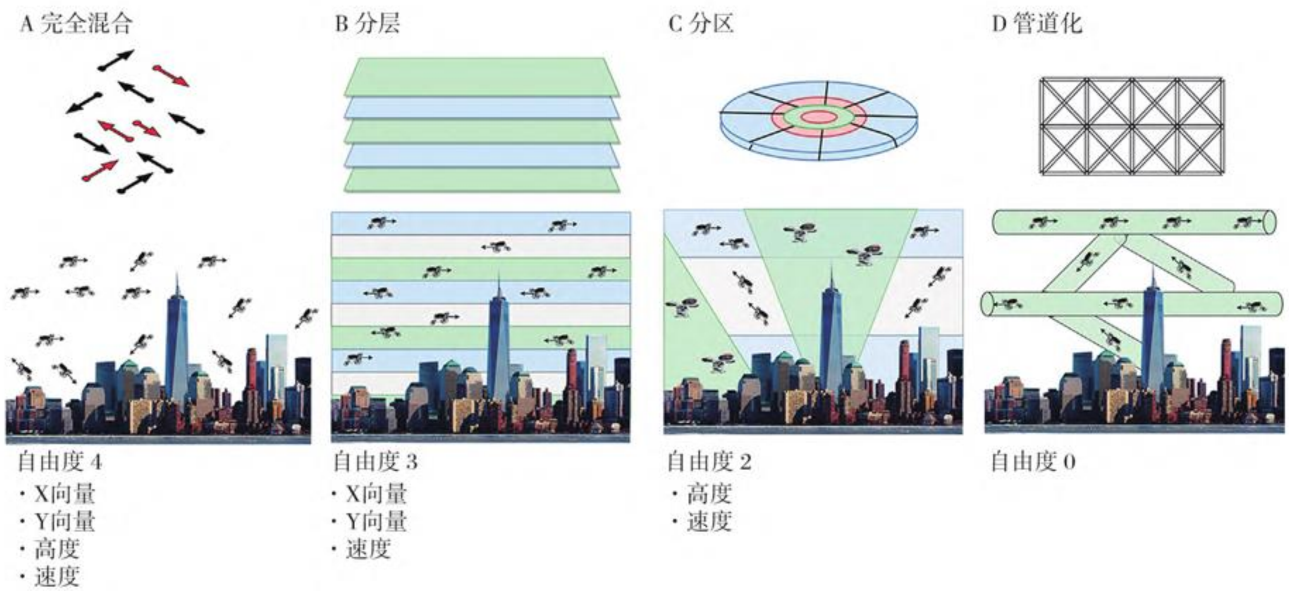

Figure 2. Four concepts of airspace structure [21]

3.1 Low-Altitude Airspace Zoning

Several countries, cities, and institutions have begun to explore layered and zoned management of low-altitude airspace. The US Federal Aviation Administration (FAA), drawing on the ICAO classification, treats uncontrolled very-low-altitude airspace from the surface to 120 m as suitable for small drones. The FAA and NASA Unmanned Aircraft System Traffic Management program have explored the integration of drone operations with other airspace classes. By creating transitional areas, they reserve airspace for drones and separate them from controlled traffic [8] (Figure 3).

Horizontal zoning is closely related to the functional requirements of drone operations and the land-use functions of the ground below. Take-off and landing areas and no-fly zones require dedicated designation and management. City centers, ordinary urban districts, rural areas, and airport surroundings impose different operational requirements and safety risks, and therefore require different planning controls. Vertical layering also responds to current drone technologies. Amazon, for example, divides low-altitude urban airspace into multiple layers: below 60 m, a local low-speed zone for terminal non-transport functions such as surveying, photography, and inspection and for less advanced aircraft; between 60 and 120 m, a high-speed transit zone for technologically advanced aircraft; between 120 and 150 m, a no-fly buffer; and beyond the urban area, a predefined low-risk zone [22] (Figure 4).

Zoning must also reflect flight risks and the people and objects that drones must avoid. For recreational consumer drones, the FAA prohibits flight over crowds and traffic and restricts night operations [23]. Comparative studies of geofencing rules for people, property, congested areas, buildings, and infrastructure report separation distances ranging from 30 m to 5 km [24]. Cureton [3] summarizes four avoidance principles: drones should remain clear of aviation facilities such as airports; stay at least 150 m from urban no-fly areas; remain 50 m from specified facilities; and remain 50 m from concentrations of people (Figure 5). Other studies propose protective radii of 10–60 m for take-off, landing, and flight [25-26].

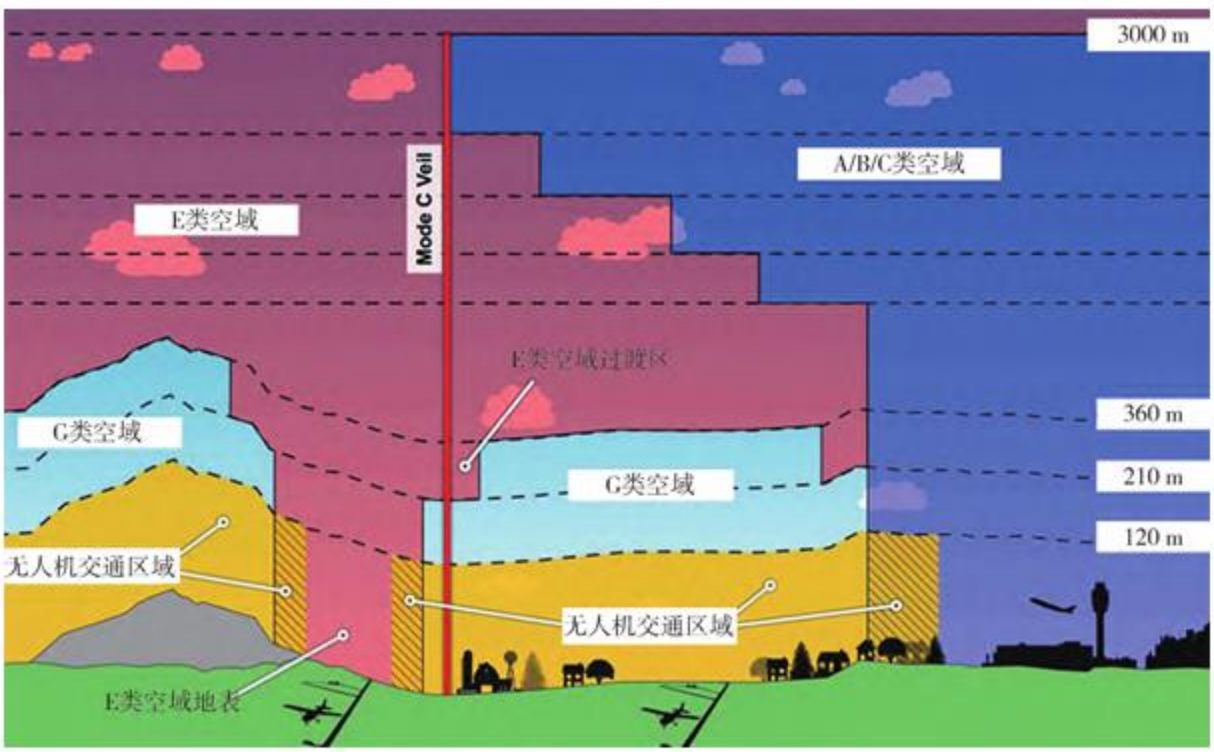

Figure 3. Drone operating areas in US airspace zoning [8]

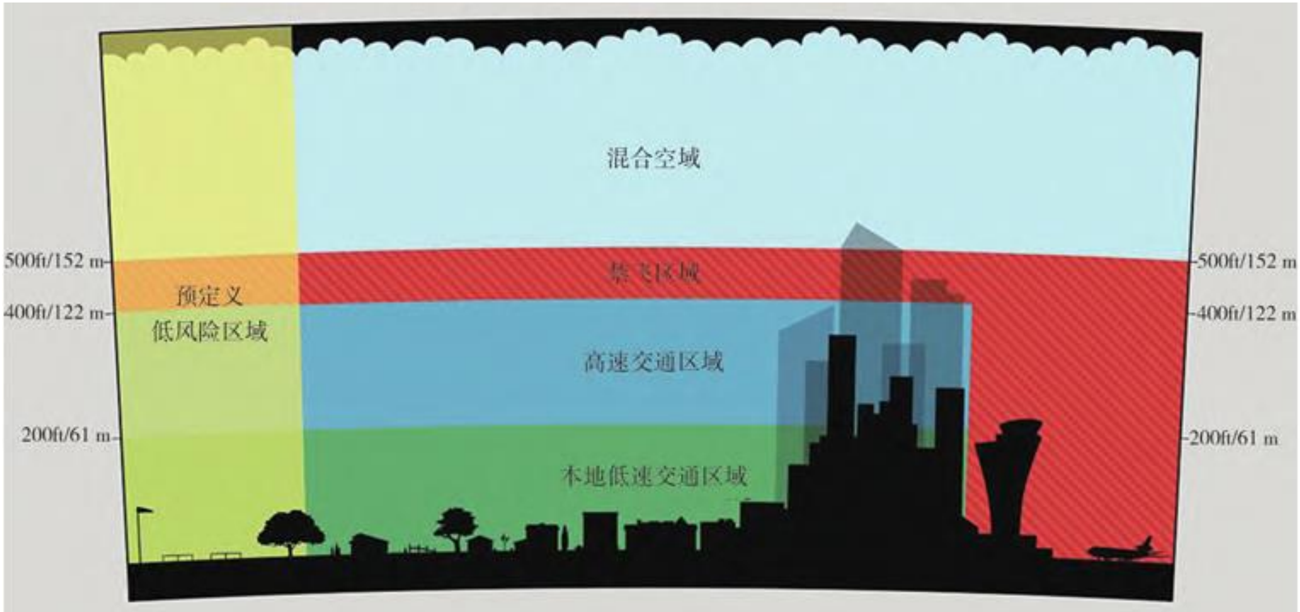

Figure 4. Amazon’s proposed layering and zoning of drone airspace [22]

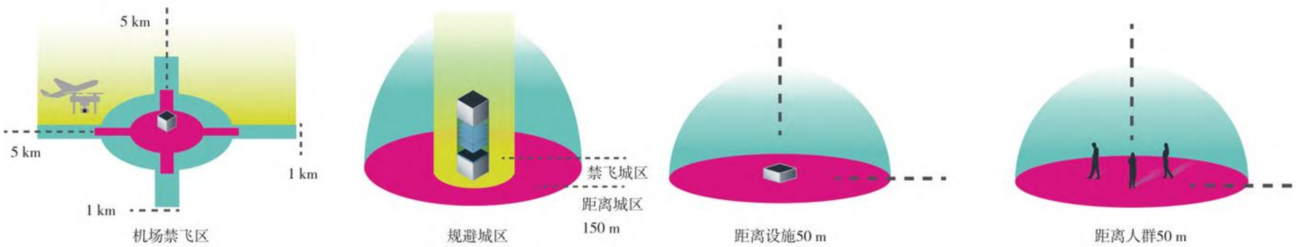

Figure 5. People and objects that drones must avoid [3]

3.2 Structural Design of Low-Altitude Airspace

As drone traffic grows, low-altitude airspace requires increasingly refined traffic structures to improve efficiency and ensure safety. NASA has proposed a multilayer urban-airspace structure in which each layer contains a network above the city and between dense high-rise buildings. The structure may include sky lanes, sky tubes, and sky corridors, each offering a different degree of freedom. Sky lanes impose the greatest restrictions on altitude, heading, speed, and position, whereas sky corridors permit the greatest flexibility [8]. The design of urban Class G low-altitude airspace may follow the model shown in Figure 6, combining vertical layering with horizontal, vertical, and diagonal corridors [27].

From the perspective of 6G high-speed communications, Rakesh Shrestha et al. summarize a multilayer drone-airspace model in which corridors are connected horizontally, vertically, and diagonally through nodes at intersections within and between layers. Airways are configured to guide aircraft along designated paths. Their cross-sectional dimensions depend on aircraft performance, while their length depends on static obstacles, intersections, and nodes along the route [28] (Figure 7).

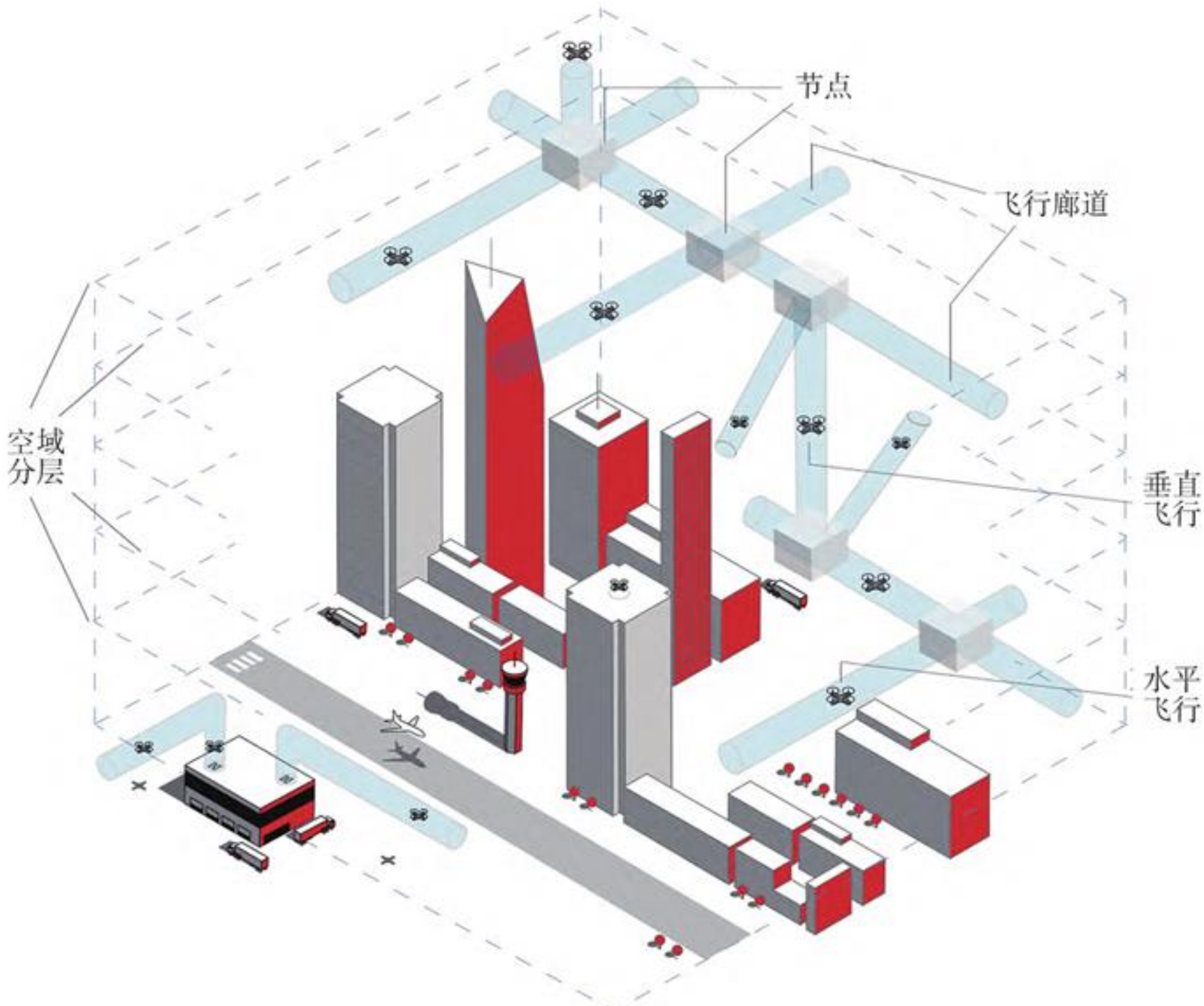

Figure 6. Design of Class G airspace structure [27]

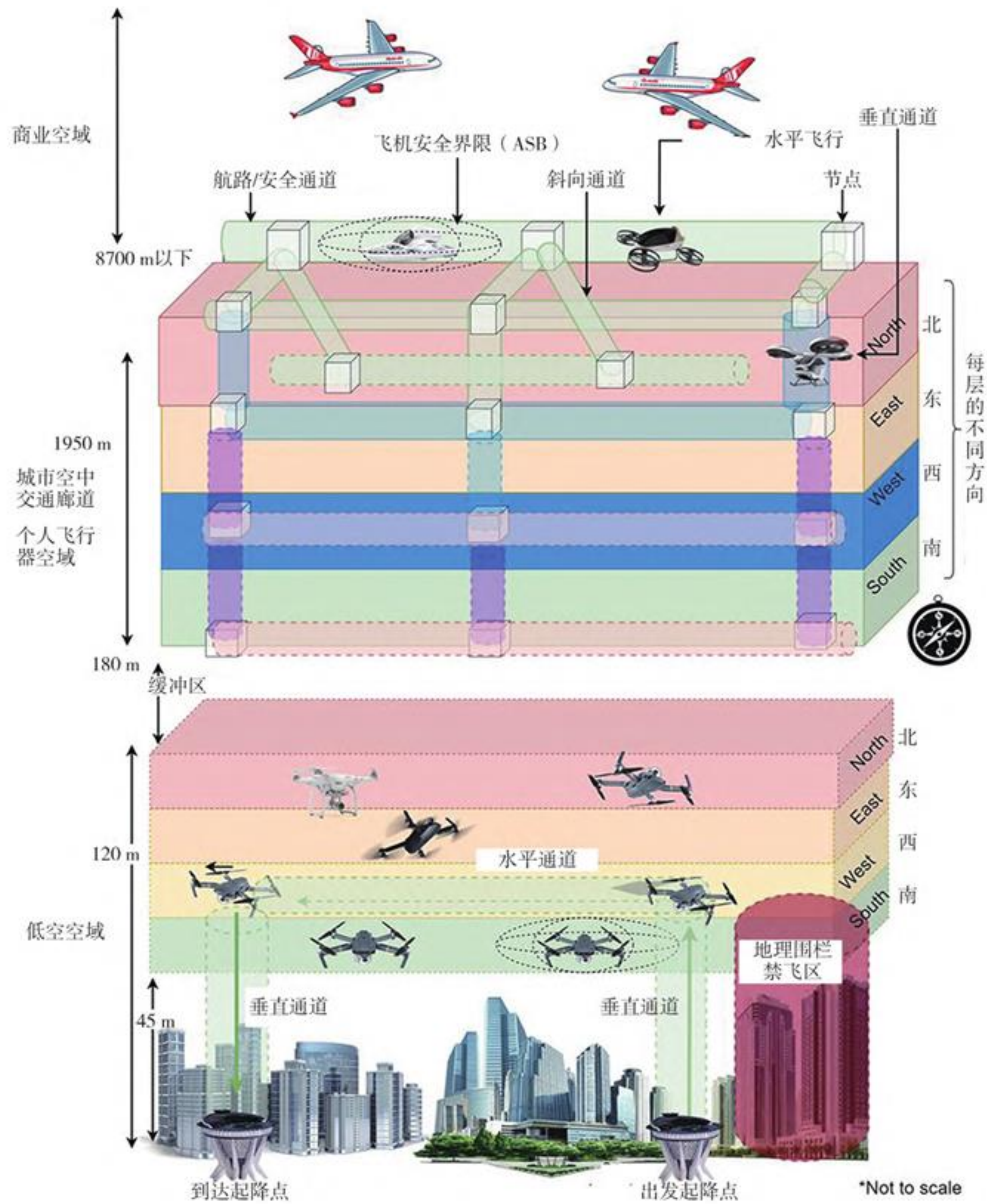

Figure 7. Airspace structure model proposed by Shrestha et al. [28]

3.3 Capacity Assessment and Planning

Airspace capacity generally refers to the maximum number of aircraft that can be accommodated within a specified airspace environment over a unit of time. Different structural designs produce different capacities. Urban low-altitude airspace is more complex than traditional controlled high-altitude airspace, which contains few static obstacles [29]. Urban form, development intensity, and environmental conditions are highly varied, and buildings exceeding 100 m or even several hundred meters are common. Where drones operate below 120 m, they must inevitably adjust to buildings, structures, and other elements of the ground environment. Relevant planning and management practices therefore take the urban built form as a primary reference.

Capacity assessment should account for the complexity of the low-altitude environment and combine aircraft performance with operating scenarios [30]. Delft University of Technology has proposed “geovectoring,” which increases capacity by reducing traffic complexity [20]. Nanyang Technological University in Singapore evaluates urban low-altitude route networks using capacity and throughput. NASA distinguishes periods of low, medium, and high traffic density and identifies technical pathways for expanding urban airspace capacity [17].

Capacity control is also closely related to flight safety. To reduce collision risk, planning should define the maximum hourly drone density at different altitudes [31]. Exclusive measures may include temporarily expanding controlled or segregated airspace.

4 Prospective Considerations for Urban Low-Altitude Airspace Planning

Low-altitude airspace is an immovable spatial resource with pronounced locational value, much like other spatial resources. Demand is higher in densely populated areas and lower in remote locations, producing substantial value differences [32]. As drone technologies mature and large numbers of low-altitude aircraft enter practical service, urban low-altitude airspace will become increasingly scarce. This will require finer subdivision and reallocation and will further promote the restructuring of urban space to incorporate the use of low-altitude airspace.

The full utilization of low-altitude airspace will help create a more complete spatial structure that integrates physical urban elements with the airspace above them. Research from the aviation perspective has generated substantial knowledge on vertical and horizontal airspace zoning, but urban planning has paid insufficient attention to the issue. The integration of low-altitude airspace and urban space makes it necessary to explore, in a forward-looking manner, the principal components of drone-oriented urban low-altitude airspace planning.

4.1 Integrated Planning to Coordinate Low-Altitude Airspace and Urban Space

FAA drone-corridor concepts and the European Single European Sky ATM Research project SESAR AMU-LED consider corridor layouts across city centers, suburbs, rural areas, and airport environments [33-34] (Figures 8 and 9). Their diagrams generally distinguish planning arrangements by urban location [26, 33]. This highlights the relationship between airspace zoning and the planning and management of urban form, demonstrating the importance of urban spatial elements in airspace planning. However, detailed management of drone airspace below 120 m remains limited.

Urban form can be represented through the urban–rural transect used in form-based codes [35]. Urban low-altitude airspace planning may be understood as adding an airspace-management layer to that transect, thereby creating a common spatial framework for airspace zoning and urban planning control.

A new planning approach may integrate low-altitude zoning with urban spatial management in three respects. First, planning requirements should differentiate city centers, ordinary urban districts, suburbs, rural areas, and airports; corresponding requirements for altitude layers, speeds, and facilities can then be added to integrate zoning with spatial control. Second, planning should account for drone performance, operating scenarios, and supporting take-off, landing, communication, charging, and control facilities, and relate their layout to the urban–rural transect to create coordinated zoning by area and type. Third, integrated planning should address ground risk, airborne risk, and emergency response through targeted facility layouts and capacity controls that prevent aerial collisions and reduce threats to pedestrians and vehicles.

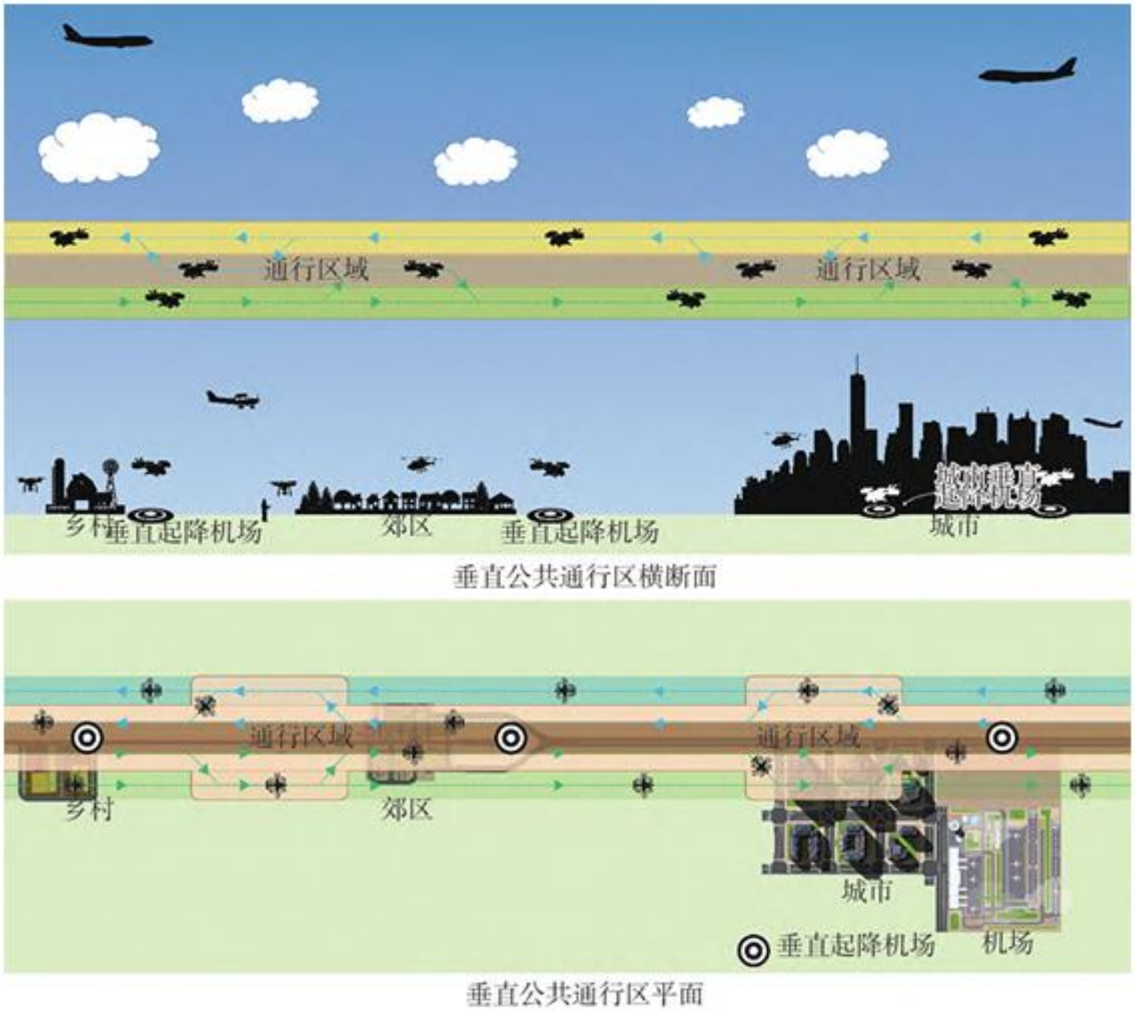

Figure 8. FAA drone-corridor design [33]

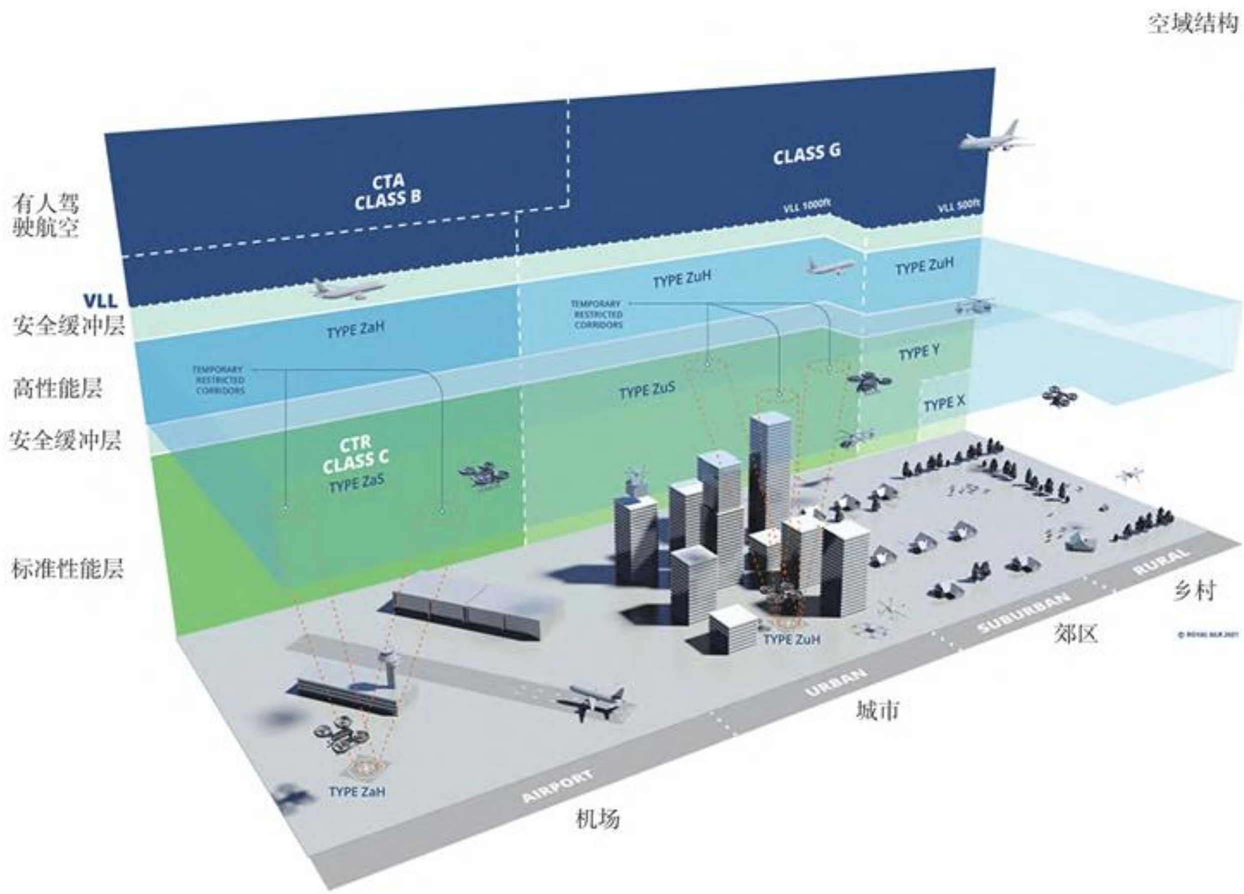

Figure 9. Airspace zoning in AMU-LED [34]

4.2 Structural Design Through Layering, Zoning, and Corridors

The core of airspace design is its structure, which directly affects capacity, safety, and efficiency. Less structured airspace, such as the free-route model in Figure 2, allows higher capacity and route efficiency but requires stronger technical capabilities to ensure safety. More restrictive structures, such as corridors, enable technologically simpler aircraft to operate reliably but may reduce efficiency and increase delays [8, 29]. In general, the simplest structure that remains reliable is preferable [8]. A successful design must safely accommodate aircraft with different technical capabilities while maintaining efficiency and avoiding unnecessary delay.

From an urban-planning perspective, the structure of drone-oriented low-altitude airspace involves three components. First, altitude layers should be established, as in Amazon's distinction between high-speed transit and local low-speed operations. Second, zones should be defined according to airspace type, ground-space functions, and facility characteristics, including permitted and prohibited areas. Third, corridors should be designed for low-altitude flight, including vertical, horizontal, and diagonal routes, with specified numbers, locations, and nodes. Meituan's drone-delivery operations in Shenzhen, for example, use route-by-route approval to define corridors.

4.3 Planning and Layout of Drone Facilities

Small drones suitable for urban low-altitude operations vary greatly in type, performance, and size [28], and therefore impose different requirements on space, airspace, and supporting infrastructure. Meituan drones, when fully charged, can serve deliveries within a 3 km radius in no more than 15 minutes [36].

Antwork, by contrast, organizes 10–15 km delivery zones around intelligent drone-logistics stations [37]. These differences in aircraft performance correspond to different service scales.

Supporting facilities also vary across products and applications and should be planned systematically. For logistics operations of different scales, cities should establish hierarchical systems of drone take-off and landing sites [38]. Low-altitude airspace planning should coordinate take-off and landing, communications, charging, and control facilities for different drone products and incorporate them into the airspace structure. In addition to transport and logistics facilities, emergency infrastructure such as ground-control stations and emergency landing sites should also be planned for the diverse functions of drones.

4.4 Developing Governance Mechanisms and Standards for Air–Ground Relations

As drones are deployed in cities, low-altitude airspace gains use value and is transformed from a natural resource into an economic resource [35]. Yet regulations do not clearly define the lower operational limit for drones—how low they may fly. From the perspective of traditional property law, this conflict appears as a restriction of spatial rights by airspace rights [13]. The issue resembles the role of road rights in cities, the changing scope of conventional vehicle rights under autonomous driving, the long-standing conflict between public and private rights in building setbacks, and planning tools such as assigning, rewarding, and transferring floor-area ratios. The changing relationship between spatial and airspace rights therefore merits forward-looking study.

To address conflicts over low-altitude rights, some scholars advocate a dualistic property-rights framework [20] and an airspace-rights system centered on the right to use a public good under state intervention [9], transforming the “right to use airspace” into a production factor analogous to land-use rights [39]. Urban planning should develop governance mechanisms and technical standards for the air–ground interface. First, technical methods should respond to the spatial characteristics and value differences of different land-use areas. Second, because the interface involves both publicly owned and privately controlled property, cities may draw on floor-area-ratio management and transferable development rights to assess the value of low-altitude airspace above different parcels, design suitable governance models, and establish corresponding standards.

5 Conclusion

The value of low-altitude airspace resources is fundamentally a form of “rent” derived from monopoly ownership of the resource [40]. Differences in urban location generate differences in spatial value and, in turn, differences in airspace value, which feed back into the valuation of urban space. In response, urban low-altitude airspace planning will evolve as an innovative field and contribute to broader reform of urban spatial planning.

Because urban low-altitude airspace lies close to the built environment, coordination between airspace and urban space will become a central concern. Planning requirements will differ across urban areas and become increasingly connected to terrestrial spatial planning. Effective implementation depends on integrating airspace zoning with spatial control, defining an appropriate airspace structure, and resolving rights at the air–ground interface. Future urban planning may move toward a new synthesis of airspace planning and spatial planning, requiring cooperation among specialists in aviation, information and communications, urban planning, and law.

Notes

① This article focuses primarily on drones.

② The concept of low-altitude airspace planning used here derives from aviation scholarship. It is framed by urban air mobility and focuses on planning from the perspective of low-altitude traffic, while also encompassing consumer drones and other uses.

③ Class G airspace generally refers to airspace below 300 m above ground level outside Class B and C airspace, excluding Class W airspace, and to airspace below 6 km above mean sea level that does not affect public civil-aviation transport. Class B airspace is designated above civil transport airports. Class C airspace is designated above tower-controlled general-aviation airports, typically in a single-ring structure with a radius of 5 km extending from the runway surface to 600 m above airport elevation.

④ The value of 120 m is converted from 400 ft and is not absolute. Some European and Japanese standards use 150 m as the upper limit of low-altitude airspace, while South Korea sets the maximum drone altitude at 300 m; see Reference [21].

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