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Editorial

Prospects of eVTOL and modular flying cars in China urban settings

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1 Transformative shift from rural roots to city centric living

Throughout much of human history, the vast majority of people lived in small communities. However, in the last few centuries, and particularly in recent decades, there has been a dramatic shift. A massive migration has moved populations from rural to urban areas. United Nations reports state that over 4.3 billion individuals now inhabit urban regions, which accounts for more than half (55% as of 2017) of the global population. In most high-income nations, including Western Europe, the Americas, Australia, Japan, and the Middle East, over 80% of people live in urban areas. This figure ranges from 50% to 80% in upper-middle-income countries like Eastern Europe, East Asia, North Africa, South Africa, and South America (United Nations, Department of Economic and Social Affairs, Population Division, 2019). The urban population is anticipated to rise across all countries in the coming decades, albeit at different rates. By 2050, the global population is expected to reach approximately 9.8 billion, with about 6.7 billion residing in cities and 3.1 billion in rural areas. Despite this rapid urbanization, only around 1% of the Earth's land is allocated for urban and infrastructure development. While urbanization has spurred socio-economic growth, it has also led to significant challenges such as traffic congestion and air pollution. In China, the swift growth of cities has notably expanded urban areas and extended the commuting times of residents. The "2022 Commuting Monitoring Report of Major Chinese Cities" reveals that in 2022, over 14 million people in 44 major Chinese cities experienced extreme commuting, with upwards of 13% spending over an hour in transit (Baidu Maps, 2023). Beijing recorded the highest rate, where 26% of commuters faced this issue.

2 Evolution and future of three-dimensional urban transportation systems

This phenomenon stems from the fact that our existing transportation system remains largely two-dimensional, and the capacity of surface transportation infrastructure cannot expand indefinitely. This limitation hampers the ability to effectively address urban traffic congestion at its root. The ongoing advancement and refinement of intelligent and electrification technologies have broadened the scope of transportation to include aerial vehicles. This innovation paves the way for low-altitude intelligent transportation systems, which integrate aerial and ground elements to create a three-dimensional transportation network. Such systems can significantly reduce ground traffic demand and address congestion issues more fundamentally. These low-altitude systems primarily comprise urban air mobility and drone logistics. Unlike traditional airplanes, these vehicles typically operate at altitudes below 1 km, with adjustments possible based on urban landscapes and building heights. Developmentally, these systems are envisioned to progress through three phases: drone logistics, piloted flying cars, and unmanned flying cars. To date, drone logistics have undergone testing in various countries and were employed during the COVID-19 pandemic. As part of the evolution of low-altitude transportation, flying cars necessitate innovation in design, flight control, and propulsion technologies. As tools for low-altitude intelligent transportation and three-dimensional traffic, current flying cars are mainly conceptualized in two designs: electric vertical take-off and landing aircraft (eVTOL) and amphibious cars.

The goal of developing flying cars is to enable a seamless transition between "airplane mode" and "car mode". However, given the current state of energy technology, structural materials, and intelligent control systems, achieving a fully functional "car with wings" in one step is not technically feasible (Liu et al., 2023; Qu et al., 2022). Additionally, the aviation/aircraft and road/car sectors have significantly different regulations, standards, and technical specifications, making it impractical to simply merge or adapt these frameworks. As such, a pragmatic "three-step" development strategy is proposed, focusing on the gradual advancement and integration of technology and regulations to ultimately enable seamless mode-switching applications. The first step involves the use of electric flying vehicles capable of vertical takeoff, utilizing current technologies like multi-rotors, compound wings, or tilt power/tilt wings, depending on the specific application. These vehicles would be combined with new energy ground transportation systems to initiate early implementation of three-dimensional transport. Concurrently, this phase would involve developing urban and inter-city integrated airspace management, multi-modal intelligent air traffic control systems, and environmentally friendly vertical takeoff facilities, laying the groundwork for more extensive applications in the future. The second step centers on modular flying cars. Building upon the

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vertical take-off and landing (VTOL) technology from the first stage, this phase would combine air vehicles with ground electric intelligent driving chassis and passenger capsules to create modular flying cars. This approach allows for the early validation of crucial technologies, such as the integration of intelligent control systems for aircraft and cars, and paves the way for the potential harmonization of aviation and road transport regulations. The final step envisages the development of fully integrated flying cars. This advancement would follow significant breakthroughs in energy technology, including high-energy and high-power density systems (exceeding current levels by 5–10 times), as well as the use of lightweight, high-performance materials, and efficient structural designs. These innovations would facilitate the seamless transition between air and ground travel using the same vehicle. As intelligent traffic technology and infrastructure continue to evolve, the vertical takeoff and flight capabilities of eVTOL vehicles will be enhanced in smart cars, leading to the development of amphibious flying cars. This progress represents a step towards realizing the long-held human aspiration of making cars "fly".

3 Comparing eVTOL and modular flying cars in market viability

As an innovative land-air amphibious transport option, flying cars, especially in urban environments, rely on factors such as takeoff performance, speed, ease of driving, safety, cost-efficiency, and accessibility in intricate low-altitude areas to gain mass market acceptance. Over the past decade, extensive research has examined the feasibility and impact of eVTOL on current transportation systems (Kai et al., 2022). A key finding is that eVTOL services, even with essential first-mile and last-mile ground transport, might not substantially reduce travel times as expected. This inefficiency largely results from the placement of vertiports and potential increases in nearby ground traffic, which could offset the time savings of short-distance air travel, diminishing their competitiveness against direct, door-to-door ground transport. Enhancing the transportation benefits of eVTOL requires strategically accessible vertiport locations and a well-planned vertiport network. An alternative focus on developing flying cars that can both fly and drive on roads, like modular flying cars, might fundamentally address the first-and-last-mile issue. Nevertheless, it is crucial to assess and understand the market potential of both eVTOLs and modular flying cars before deciding on a development path. As eVTOL technology becomes increasingly advanced and mature, and with the successful global launch of various air taxi applications, there is substantial research interest in developing vertiport infrastructure for eVTOL. This encompasses aspects from selecting suitable locations to planning for capacity (Kai et al., 2022). Strategic vertiport deployment is essential for the successful global application of eVTOL. However, it is still unclear whether the potential benefits justify the necessary infrastructure investment. Moreover, given that modular flying cars, such as the Audi Pop. Up Next, do not require vertiport infrastructure and are already in development, the need for vertiport investment is in question. Therefore, there is an urgent need to further explore the potential market demand for the two flying car designs: eVTOL and modular flying cars. Understanding how these two operational modes will develop in various regions and accurately predicting their future evolution will provide a more logical way forward. Additionally, the impact of vehicle performance factors like flying speed and passenger capacity on the market demand for different types of flying cars, considering various urban geographical contexts, needs comprehensive analysis for effective vehicle design.

Through the analysis and modeling of comprehensive travel data from Shanghai, Guangzhou, Qingdao, and Shenzhen, we have forecasted the market adoption rates and estimated sales volumes for two types of flying cars. Notably, modular flying cars have a considerably higher market adoption rate compared to eVTOL, primarily because of the additional ground travel time required for eVTOL. Among these cities, Shenzhen leads in eVTOL market adoption, followed by Qingdao, a trend that correlates with the unique terrain of these cities and the flexibility of their low-altitude traffic networks. Conversely, Guangzhou exhibits the highest market adoption rate for modular flying cars, with the largest projected sales volume in Shanghai. The trip demand for modular flying cars surpasses that of eVTOL by more than fourfold in Shanghai. In sum, the overall trip demand for eVTOL in these four cities is just a third of that for modular flying cars.

4 Conclusions

In conclusion, modular flying cars demonstrate greater market potential in the studied cities, particularly in Shanghai. While eVTOL's market potential is smaller, it remains significant in specific urban areas. Geographic and topographic factors greatly influence flying car adoption rates, with eVTOL models showing higher rates in cities like Shenzhen and Qingdao, which have adaptable low-altitude traffic networks and unique landscapes. Given the infrastructure costs associated with eVTOL, such as vertiport construction, modular flying cars offer a more cost-effective solution with considerable potential for development. A more detailed and sophisticated analysis across various regions is needed, but it may be time for businesses to focus on developing and deploying detachable flying cars, given their higher market adoption rates, lower initial costs, and promising future prospects.

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Declaration of competing interest

The authors have no competing interests to declare that are relevant to the content of this article.

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