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Review

Urban Aviation: The Future Aerospace Transportation System for Intercity and Intracity Mobility

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Abstract: This review discusses the challenges of integrating emerging transportation technologies into existing urban environments, considering their impact on equity, sustainability, and urban design. The aim is to provide readers with strategic insights and policy recommendations for incorporating aerospace innovations into transportation systems. This narrative review draws on a wide range of publications, including books, journal articles, and industry reports, to examine the multifaceted aspects of urban aviation. The review explores the scales of aerospace transport, detailing the technologies enabling urban aviation, the necessary urban adaptations to support such a system, and the social and regulatory challenges of integrating urban air mobility into existing transportation networks. The research suggests that for urban air mobility to be successfully integrated into existing transportation systems, further research is needed on the social and regulatory implications, particularly regarding equitable access, sustainable practices, and community engagement.

Keywords: AAM; advanced air mobility; delivery; drones; RPAS; transport; UAM; UAV; urban air mobility; UAS

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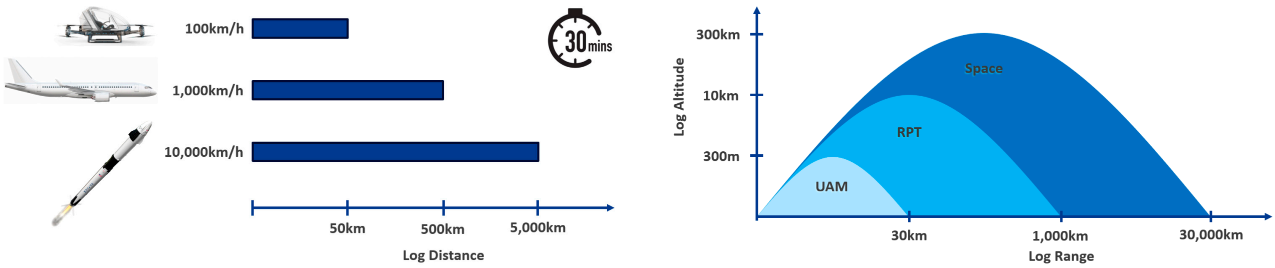
1. Introduction

From the moment the Wright Flyer completed the first crewed, powered, sustained, controlled, heavier-than-air flight in 1903 [1], humanity's fascination with flight has soared. How things fly is a persistent wonder [2], with the dream of "flying cars" enduring [3], and a staple of sci-fi. Examples range from the flying cars of the 1960s, such as the Fantasti-car from Kirby and Lee's *Fantastic Four* (1963), to the iconic DeLorean at the end of Robert Zemeckis' *Back to the Future* (1985). Pop culture has long envisioned a future where the skies are filled with personal aircraft, depicted in the retrofuturism (or at the time, futuristic populuxe) style in *The Jetsons* (1962) and in the dystopian style in both Ridley Scott's *Blade Runner* (1982) and Luc Besson's *The Fifth Element* (1997). These once-common portrayals in science fiction were direct allegories for future technology [4]; they inspired generations to look up and dream of a world where intra- and interurban travel would literally be elevated above the limitations of ground-based transportation. Figure 1 shows some visual examples of these sci-fi flying cars from iconic movies.

For decades the question has been, "Dude, where's my flying car?" [5]. However, today we are closer than ever to turning these sci-fi dreams into reality within the future aerospace transportation system. The future aerospace transportation system is broad in scope and scale, with elements of space transport [6], urban or intra/intercity mobility [7], and conventional aviation or regular passenger transport (RPT) [8]. The future aerospace transportation system will integrate revolutionary aerospace technologies such as urban air mobility (UAM) [9], drones [10], eVTOLs (electric vertical takeoff and landing aircraft) [11], as well as reusable spacecraft [12], both conventional rockets and spaceplanes. The scales (range and altitude) of these disparate aerospace modalities are illustrated in Figure 2. The innovations of the future aerospace transportation system promise to create a seamless and efficient transportation network that operates both within cities and across longer distances. By leveraging these advanced systems, the future aerospace transportation system aims to address current transportation challenges and pave the way for a more connected and sustainable future.

Figure 1. (**a**) The flying DeLorean shown on the poster for *Back to the Future Part II*. (**b**) The flying cars in *The Fifth Element*. (Creative Commons, Wikimedia).



(**a**) (**b**)

Figure 2. Future aerospace transportation scales infographics illustrating (**a**) speed and distance travelled in 30 min, and (**b**) altitude and average range, relatively speaking. Note the log axis, where each increment is an order of magnitude.

The future aerospace transportation system will be designed to create an integrated, seamless, efficient, and sustainable transportation network that addresses many of the current challenges, such as congestion [13], pollution [14], and accessibility [15]. Enabled by advancements in electric propulsion [16], autonomous systems [17], and air traffic management [18], the future aerospace transportation system offers the potential to revolutionize how people move within and between urban centers. By leveraging these innovative technologies, the intention is to enhance urban planning [19], stimulate economic development [20], and improve overall quality of life [21].

This paper is structured to provide a comprehensive overview of the future aerospace transportation system and its implications for urban and intercity (advanced) air mobility. It begins with an exploration of the nature of aviation, detailing the various scales of passenger transport and the diverse activities within general aviation (GA), as well as the role of drones and remotely piloted aircraft systems (RPAS) in GA. The discussion then expands to cover the different scales of aerospace transport, from intracity solutions like UAM and last-mile delivery drones to intercontinental and space travel innovations. The paper also examines the necessary adaptations in urban design and infrastructure to accommodate these advancements. Finally, it addresses the challenges and opportunities associated with integrating aerospace technologies, focusing on equity, sustainability, and regulatory considerations. Through this structured approach, the paper aims to provide strategic insights and policy recommendations to support the seamless integration of aerospace innovations into our transportation systems, as needed by urban designers and planners.

To establish the context of this work, a note should be taken of the previous review papers that exist in the literature on UAM. These were identified from a Scopus search for "urban air mobility" in "article title, abstract, keyword", limited to the document type "review", with no date range, with the search performed in October 2024. These reviews are given in Table 1. Even though there are 25 reviews on the topic of UAM, they present a limited perspective, primarily focusing on engineering. As such, this review is intended to address the gap in the literature from the urban science perspective.

Table 1. Prior reviews on the topic of UAM, giving the general perspective of each.

Ref	Year	Title	Perspective
[9]	2024	Urban Air Mobility for Last-Mile Transportation: A Review	O.R.
[22]	2024	Requirements and design of powertrains for eVTOLs	Propulsion
[23]	2024	Review of Wind Flow Modelling in Urban Environments to Support the Development of Urban Air Mobility	Weather
[24]	2024	Understanding the fixed pitch RPM-controlled rotor modeling for the conceptual design of UAM vehicles	Rotor
[25]	2023	A review of urban air mobility and its new infrastructure low-altitude public routes	Operations
[26]	2023	Noise from Unconventional Aircraft: A Review of Current Measurement Techniques, Psychoacoustics, Metrics and Regulation	Noise
[27]	2023	A holistic review of the current state of research on aircraft design concepts and consideration for advanced air mobility applications	Aircraft
[28]	2023	A review of Urban Air Mobility-enabled Intelligent Transportation Systems: Mechanisms, applications and challenges	System
[29]	2023	Towards Safe and Efficient Unmanned Aircraft System Operations: Literature Review of Digital Twins' Applications and European Union Regulatory Compliance	Digital/Reg
[30]	2023	Identifying challenges in maintenance planning for on-demand UAM fleets using agent-based simulations	Airworthiness
[31]	2023	Public perception of advanced aviation technologies: A review and roadmap to acceptance	Perception
[32]	2023	Addressing the emergence of drones—A policy development framework for regional drone transportation systems	Policy/Reg
[33]	2023	Air Traffic Management as a Vital Part of Urban Air Mobility—A Review of DLR's Research Work from 1995 to 2022	ATM
[34]	2023	Current Applications and Development of Composite Manufacturing Processes for Future Mobility	Materials
[35]	2022	Regulatory framework on the UAM operational concepts of the ASSURED-UAM project	Policy/Reg?
[36]	2022	Social Sustainable Urban Air Mobility in Europe	Public
[37]	2022	Advances in CFD Modeling of Urban Wind Applied to Aerial Mobility	Weather
[38]	2022	Airspace Deregulation for UAM: Self-organizing VTOLs in Metropoles	ATM
[39]	2021	Sound propagation modelling for manned and unmanned aircraft noise assessment and mitigation: A review	Noise
[40]	2021	Future urban air mobility management: Review	ATM
[41]	2021	Challenges and key requirements of batteries for electric vertical takeoff and landing aircraft	Batteries
[42]	2021	The state of the art and operational scenarios for urban air mobility with unmanned aircraft	Operations
[43]	2020	Overview of traffic management of urban air mobility (UAM) with eVTOL aircraft	ATM
[10]	2020	Unmanned aerial vehicle routing problems: A literature review	Routing
[44]	2020	An evaluative review of the VTOL technologies for unmanned and manned aerial vehicles	Aircraft
[45]	2019	Urban air mobility: Opportunities for the weather community	Weather

To address the multidisciplinary aspects of UAM, this study has three specific objectives and an underlying research goal. Objective 1 is to analyze the key challenges and opportunities associated with integrating UAM into existing urban transportation networks. Objective 2 focuses on evaluating the impact of UAM on urban design and infrastructure, particularly the requirements for vertiports, drone corridors, and their integration with public spaces. Objective 3 is to assess the social equity and sustainability implications of UAM, ensuring its accessibility, affordability, and minimal environmental impact. These can then be given as research questions, specifically the following primary questions:

1. What are the key challenges and opportunities associated with integrating UAM into existing urban transportation networks?
2. What are the requirements for UAM in terms of urban design and infrastructure?
3. What are the potential social equity and sustainability implications of UAM?

Also, associated are secondary questions:

1. How can the challenges be addressed while maximizing the potential benefits?
2. How can UAM be implemented to minimize negative impacts on existing public spaces and urban design?
3. What strategies can be implemented to ensure its accessibility, affordability, and minimal environmental impact?

The underlying research goal is to develop a comprehensive understanding of the sustainable, equitable, and efficient integration of UAM into future aerospace transportation systems, facilitating advanced urban transport. The intent is for this review to provide insights for policymakers, urban planners, and stakeholders to navigate the complexities of UAM implementation.

2. The Current Nature of Aviation

Current aerospace activities can be categorized into five groups. The first is what the industry calls RPT, or everyday air travel for business and leisure, *en masse*. Second is GA, with small aircraft performing an array of activities underneath RPT. Third, we have drones (RPAS/UAS/UAV), or what are referred to now as uncrewed systems or platforms in the industry. Fourth are leisure activities, collectively called recreational aviation (RA). Fifth is the vast array of space activities. These five categories of aerospace activities are depicted in Figure 3.

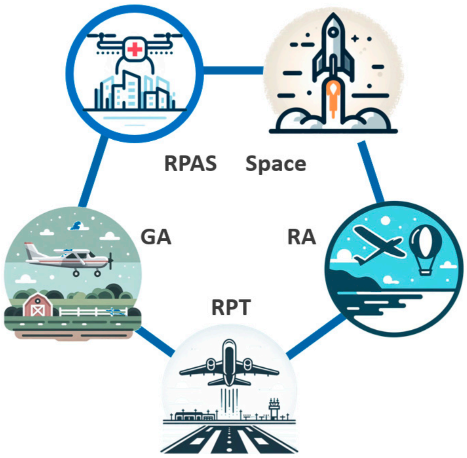


Figure 3. The current categories of aerospace (aviation and space) activities.

2.1. Regular Passenger Transport

Looking at an example, such as Australia, the breadth of RPT is quite broad [46]. The most conspicuous aspect to notice first is at the very large end of the RPT spectrum. International travel utilizes large, wide-body, twin-aisle aircraft. These could be Boeing 787, Airbus A350, or other similar large aircraft [47], travelling from one country to another country, usually spanning oceans, or even spanning the globe for ultra-long-range flights [48]. Then there is domestic aviation, the largest sector of RPT globally, using medium-size large-transport-category aircraft, what are called single-aisle, narrow bodies. These include different-sized Airbus A32x and Boeing 737 aircraft [49]. Domestic aviation transports the majority of people on the majority of flights around the world, in one of the many significant domestic markets globally; these include Australia, Japan, the United States, China, Europe, etc. The next step down in aircraft size is also common to many markets; this is called regional aviation [50]. This market can be served by large 90-seat turboprop aircraft and traditional small turbofan aircraft like the Embraer E190, the Airbus A220, and the Boeing 717. Next the market steps down again to smaller turboprop aircraft that have more than 19 seats (covered under Part 121–Scheduled Air Carrier Operations), serving smaller regional connections. Then, below that, there are niche island-hopping services, using sub-19-seat aircraft that are also common for linking disparate and remote areas in a large country with a dispersed population such as Australia. Technically, these sub-19-seat aircraft are commuter operations, which fall under Part 135 and are considered part of GA, but they are still critical transport for some communities. This variety of aircraft used for RPT in Australia is shown in Figure 4.

Figure 4. Examples of passenger services in Australia, with (bottom to top) a Qantas 747 for international travel, a Tigerair 737 for domestic travel, a Skippers Dash 8 and Sharp Metroliner for regional travel, and a King Island Airlines EMB110 for commuter travel. (Creative Commons, Wikimedia).

2.2. General Aviation

GA covers many flying activities [51]. Some of these revolve around farming, such as aerial application, top dressing, crop dusting, pest control, bush flying, tagging, mustering, etc., with these activities being performed with a mix of rotary-wing and fixed-wing aircraft on farms or ranches, as well as other agricultural properties (orchards, vineyards, etc.).

GA also includes important aviation services like air ambulance or aeromedical and angel flights (private pilots volunteering their time and aircraft to transport people for medical appointments, etc., free of charge), as well as search and rescue, police aviation, firefighting, etc. GA encompasses other forms of transportation: commuter aviation as previously mentioned, as well as chartered services, air cargo (including some small-scale airmail), air taxis, and corporate aviation utilizing business jets. There are many fun activities that can be either personal flying or commercial activities in GA: aerobatics, air races, air shows, warbirds, and parachuting, specifically the flying of parachutists. One of the main aspects of GA is flight training.

2.3. Remotely Piloted or Uncrewed Aviation

Drones are the fastest-growing facet of the aviation industry [52]. Most, if not all, of the applications of GA are going to be replaced by autonomous systems; many are currently being supplemented, some have already been displaced, and many more will transition from crewed to uncrewed aircraft in the coming years and decades. This excludes those that are unique to a person, with the pilot needing to be in the aircraft, and only a few GA cases will remain. Things like angel flights only exist because the pilot is volunteering their personal flying time; if there were no pilot, it would be charitable aeromedical transport. Flight training is a grey area; while a flight instructor will be supplemented with AI, the student pilot still needs to be in the aircraft. There are some things that border recreational aviation, such as aerobatics, air racing, etc., that will also likely remain in crewed GA. However, even these have uncrewed equivalents that are of growing interest. It is tempting to think that "there are still people on board for air ambulance, commuter, and corporate aviation"; in principle, those GA activities are concerned with flying people, in which case the aviator can still be replaced by an autonomous system.

Even for tourists and sightseeing, being able to have an autonomous helicopter with an autonomous tour guide is something that will be possible in the future. There is a wide array of current published work showing what uncrewed systems can do in terms of aerial imagery, agriculture, delivery, environmental conservation, construction, and emergency services [53].

2.4. Recreational Aviation

Finally, there is RA [54]; again, some of these activities fall within GA, typically when they involve commercial operations, such as being paid to race. Aerobatics, air racing, and ballooning are a few of the forms RA can take. There is also gliding, of which there are many different types, and parachuting itself. That is, the parachutist is participating in RA, whereas the person flying the aircraft is participating in GA. There is also a whole suite of other aircraft involved in RA; these include ultralight and microlight aircraft, gyrocopters, etc. RA is probably one of the areas where there will not be much change. These activities will be supplemented and augmented with uncrewed equivalents, but many of them will persist, because people like to recreate and have fun flying.

3. The Future Aerospace Transportation System

The aviation industry is critical to the world, with airlines playing a crucial role in global commerce, tourism, and trade. The aviation industry has experienced significant exponential growth, which is expected to continue [55]. This trend, which has been slightly decelerating over the decades, still shows continued expansion. This growth is shown in Figure 5, with data from 1929 to 2023 [56], and a forecast from the International Air Transport Association (IATA) to 2044 [57].

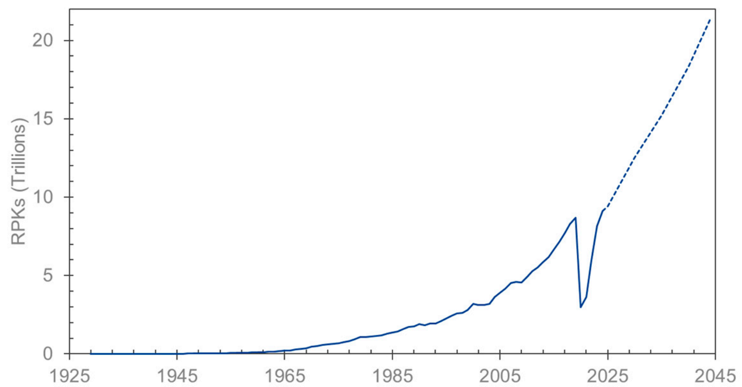


Figure 5. The growth of global aviation from 1929 to 2024, with IATA's forecast to 2044.

Historically, the scale and growth of global commercial air transportation have been substantial. For example, in 2019, the average passenger flew 1936 km, with a total of 4.486 billion passengers, resulting in 8.686 trillion revenue passenger kilometers (RPKs). Despite this exponential growth in traffic, the airline industry's economic reality often reflects narrow profit margins [49]. Air transport globally, in terms of domestic and international travel, is recovering post-COVID-19, with traffic in 2023 reaching 95.2% of the RPKs reported in 2019. The forecast for 2024 is for RPK to surpass that of 2019 by 4.8% [57], substantiating the claim made in 2020 that recovery would take half a decade for the airline industry [55]. Figure 5 shows the underlying growth of the airline industry, and IATA's forecast, suggesting 20 trillion RPKs in 2042, with the industry doubling in size after 16 years.

The future growth of the industry also needs to contend with net zero targets, for which IATA has set a timeframe of 2050. This puts significant pressure on the airline industry, which from 2000 to 2019 collectively averaged a profit margin of 1.03%, while the S&P 500 averaged 8.4% [49]. As the industry recovers from the COVID-19 pandemic, the trend of exponential growth is expected to return (shown in Figure 5), leading to more aircraft and passengers. This growth necessitates advancements in aerospace systems to accommodate increasing demand for intercity and intracity mobility. The future of urban aviation will likely transform transportation within and between cities, driven by the need for efficient, scalable, and sustainable solutions. In general, more demand means more aircraft in the air, impacting aerospace systems at all scales.

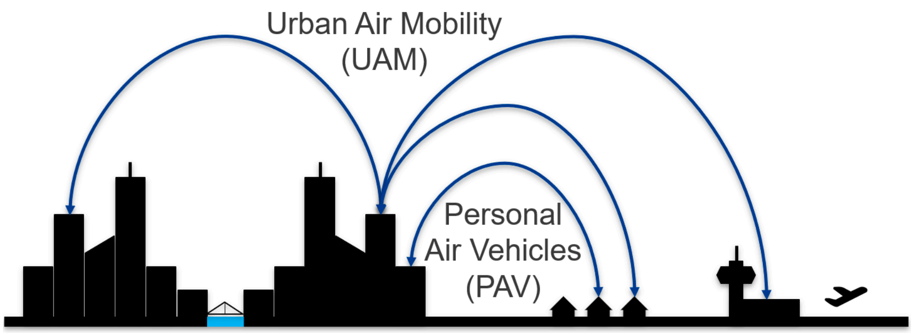
This then leads to the question, what are these scales of aerospace transport? There are five scales that will be discussed in terms of aerospace transport: intracity, intercity, intracontinental, intercontinental, and finally, space.

3.1. Intracity

With regards to intracity, the focus can be on the movement of people around a city or inside a city, illustrated in Figure 6a. This comes under two broad categories: UAM and personal air vehicles (PAV). These two aspects mirror the current surface modes, with commuter traffic in private cars as well as public transport traffic. Urban aviation will include both elements. First, some in their own PAVs will travel from their home to their place of work. Then there will be people utilizing UAM, what was once colloquially called Uber Air, to also get from home to work and back again. There will also be people wanting to move from important places, such as downtown large-population centers, to critical infrastructure like airports, etc. A UAM link would be an ideal way to be able to move people very easily from densely populated areas to critical places like airports. These major UAM links will involve the use of important key routes, what are called air corridors [58]. Importantly, the goal for UAM is to make this process accessible and affordable. At the upper end of this will be those people who can afford their own PAVs; rather than being parked in a hangar during the day, these vehicles are likely to be autonomous in nature such that they can participate in the daily UAM pool helping to move the general public around.

The other aspect for intracity aviation is the movement of goods, for which demand is growing [59]; this is illustrated in Figure 6b. Traditionally, couriers on bicycles move packages and envelopes from building to building. This is something that can readily be done with drones [60]. Considering the movement of goods on the larger scale, into and out of a city, the main hub for this is the airport [61]. Intracity aviation would facilitate the connection to a central distribution center, with imported goods received at the airport; once they are moved to the distribution center, they can be prepared for delivery. This could also mimic a manufacturing and distribution model. That is, either a wholesaler, a manufacturer, or other supplier would be the source of goods to be distributed, in which case the airport is replaced by a place of manufacture. In any of these situations, the goods from the distribution center can then be pushed out for local deliveries, either into a city or to residential areas. Amazon has patented a model here, associated with fulfillment onboard airships [62]. Drones would then also facilitate the flow of goods up to those platforms, to allow faster delivery in more disparate areas of high-demand items. Finally, goods can be moved between houses and homes, as people send things to each other directly.

(a)



(b)

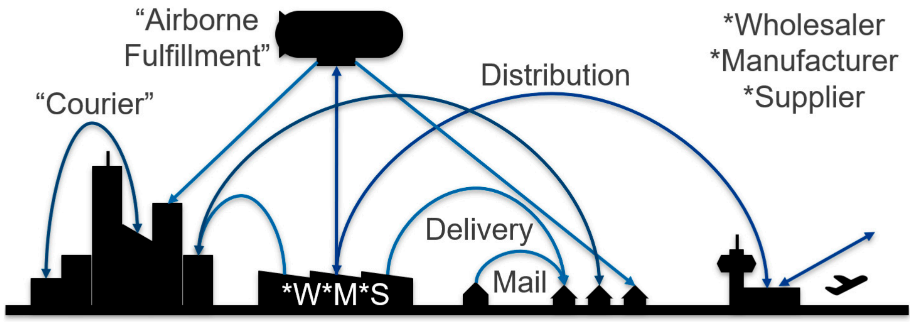


Figure 6. Intracity aviation moving (**a**) people and (**b**) goods.

3.2. Intercity

Intercity aviation refers to transportation from one city to another city, depicted in Figure 7. This modality is effectively traditional RPT, that is, with similar scales and scopes to what is associated with domestic travel. The classic example is Sydney to Melbourne, which is amongst the top five busiest air routes in the world, along with other routes like Sapporo to Tokyo. There will always be a demand for quick, high-speed domestic airlines utilizing Boeing- and Airbus-like aircraft for these routes even though there are other methods of transportation to move between these cities. For example, a 1 h Boeing or Airbus route would be more sustainably serviced with a 1.5 h turboprop flight; however, passengers prefer jet aircraft [63]. If the metropolitan areas are close enough together and the technologies being implemented for UAM vehicles can facilitate it, there will be a role for long-range UAM to transport people intercity. Technology facilitating this would also enable urban-to-rural or regional links of comparable distances. These elements collectively are termed advanced air mobility (AAM).

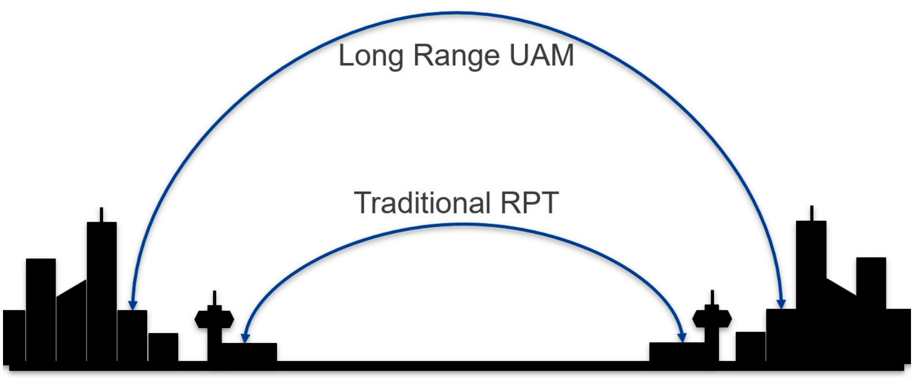


Figure 7. Intercity aviation, which includes long range UAM, called AAM, and current RPT methods.

In addition to city pairs, there are also tri-metro areas that are common in the United States. In these situations, three major cities are all in close proximity, typically where the corners of states meet (hence the alternative name of a tri-state area). Long-range UAM, AAM, will easily be able to service these markets, moving people from one city to another city, even across state lines. Beyond three cities are examples like Japan, specifically Tokyo, which incorporates far more than three cities; where large metropolitan areas are close together, commuters use trains to move between these cities. For those with time constraints, UAM will be invaluable. Figure 8 shows the New York Tri-State Area (a), and the Greater Tokyo Area (b), examples of where UAM would excel.

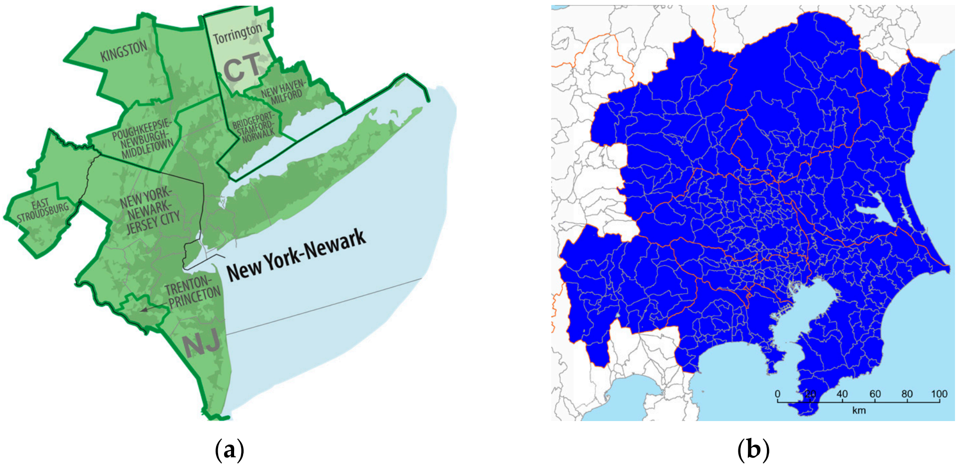


Figure 8. (**a**) The "Tri-State Area" of New York, New Jersey, and Connecticut; (**b**) the Greater Tokyo Area. (Creative Commons, Wikimedia).

3.3. Intracontinental

Intracontinental transport is across a single continent without spanning an ocean, as shown in Figure 9. This is also the realm of traditional RPT, serviced by domestic airlines. Consider going from one side of Australia to the other, Sydney to Perth, or in the United States from New York to Los Angeles. These examples highlight that intracontinental travel spans a large continent, moving from one side of a country to the other. Future aerospace transportation modalities need to be considered here as options for intracontinental transport. Quiet supersonic is one such modality [64]. If aerodynamicists can suppress the sonic boom associated with supersonic aircraft, one of the issues that prevented the Concorde from being more profitable [65], this will enable over-land flights of supersonic aircraft. This becomes a game changer in terms of technologies for rapidly moving people, specifically for corporate aviation, as a recent study of high-speed aircraft in development highlighted the focus on business jets [64].

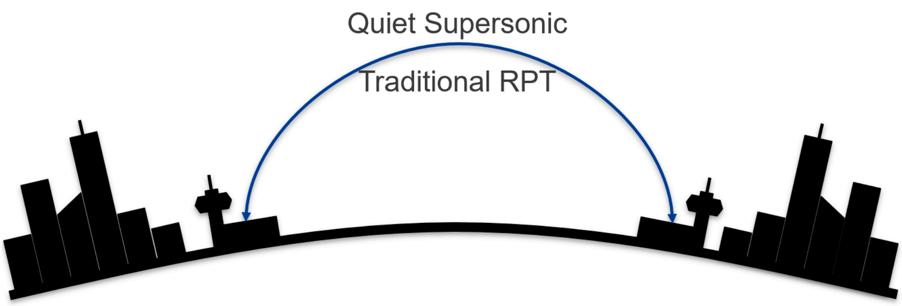


Figure 9. Intracontinental aviation.

3.4. Intercontinental

Intercontinental travel is about moving from one country to another, typically spanning an ocean, technically from one continent to another. For example, this would include flying from Australia to North America, or from North America to Europe. This typically involves crossing a body of water, as in long-range international flights serviced by international airlines utilizing large twin-aisle wide-body aircraft (B747 and A380, etc.). Since these flights cross an ocean, they are not limited to quiet supersonic solutions; hence, traditional supersonic aircraft would be able to service this industry [64]. There is potential in the future for hypersonic vehicles [64], although the cost–benefit in terms of the actual economics of operating an airline that can move so fast is still debatable. A simple argument is that at some point in time, someone will find it cost-effective to fly at such high speeds. These intercontinental modes of air travel are illustrated in Figure 10.

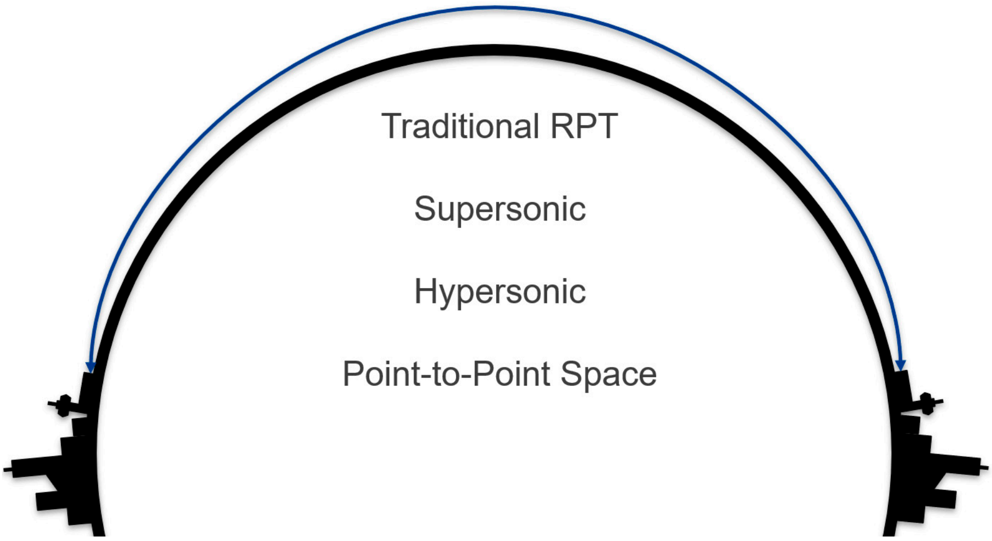


Figure 10. Intercontinental aviation.

What is more disruptive is the transition from intercontinental aviation to space as a form of aerospace transportation, specifically point-to-point space travel [66]. If SpaceX can realize its proposed point-to-point space travel, as it suggested several years ago, it would be a game changer in terms of the economics and the speed of moving from one place to another, literally from one side of the globe to the other.

3.5. Space

Point-to-point space travel clearly segues to all space transport. The space system is effectively made up of three aspects for the transportation of passengers and/or goods. First is suborbital space tourism, which involves short hops up into the atmosphere or to the edge of the atmosphere, to the Kármán line or the 100 km mark. In recent years, suborbital space tourism has become mainstream, with Virgin Galactic and Blue Origin accomplishing commercial flights [67]; there are more space tourism initiatives planned in the suborbital regime. Here it should be noted that point-to-point transportation is a suborbital activity. The distinction between the two is that space tourism typically necessitates being returned to the departure port, while for transportation this is not the case.

Next comes low Earth orbit (LEO). The International Space Station at 400 km is in low Earth orbit. It is hoped that there will be many opportunities for people to travel to LEO, such as to hotels, etc. [68], participating in orbital space tourism [69]. There is also a burgeoning space manufacturing industry, looking to make use of microgravity due to the improvements that such an environment would provide for certain specialty products. An example of this is the fabrication of ZBLAN optical fibers [70]. Microgravity is also beneficial for certain types of experiments, and hence future space activities will involve more R&D on-orbit. There are those in emerging industries looking for opportunities to set up in low Earth orbit who need affordable, reusable launch options so that they can undertake regular on-obit activities and operate profitably. Further into space, there is geostationary orbit, and further afield, the Moon, Mars, and others. These various scales of travel are illustrated in Figure 11. There is potential for space-mining asteroids and other activities [71], all of which begins to approach science fiction territory; however, there are many possibilities in the future aerospace transportation system that involve space.

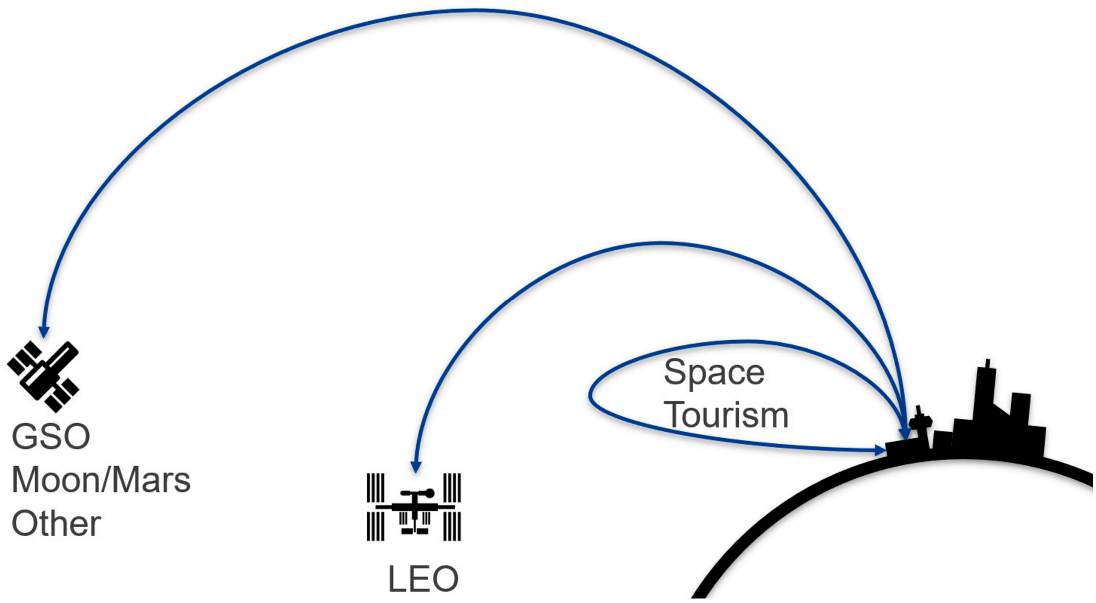


Figure 11. Space scales, suborbital tourism, sustained low Earth orbit, geostationary orbit, and beyond.

3.6. Aerospaceports

An important feature of the future aerospace transportation system is what can collectively be called aerospaceports. The concept of the aerospaceport includes airports [72], spaceports [73], and vertiports or skyports [74]. There are many different ways and means by which aerospace vehicles will interact with people on the ground, necessary for passengers to board and alight. Each of these—the vertiport, the spaceport, and the airport—may be described as an aerospaceport (depicted in Figure 12). There will be some cases where these ports are adjacent to each other, enabling passengers to fly in on one type of vehicle and fly out on another. For example, when SpaceX showed its proposed point-to-point space travel, the spaceport was floating on a barge. Instead of a boat moving people to the barge and back, UAM could fly passengers out to the barge in the middle of a body of water. That is, passengers can utilize UAM to get out to that spaceport and then take off on their scheduled suborbital rocket flight, traveling from one side of the world to the other in less than two hours.

Figure 12. Aerospaceports (generated with Microsoft Designer): (**a**) a traditional airport, (**b**) a vertiport, and spaceports (**c**) inspired by spaceport America and (**d**) SpaceX's point-to-point service.

4. Urban Aviation

4.1. Historical Development

As noted in the Introduction, early visions of flying cars and personal aircraft were depicted in science fiction, such as *The Jetsons* and *Blade Runner*. The concept of UAM really does begin in the early literature as flying cars, although the modern industry definitely opposes this historic term [75]. This concept of the flying car was formalized to PAVs at some point around the year 2000, likely by NASA [76]. The modern idea of an intelligent transportation system begins slightly after this with research by Moore [77] (who was then at NASA and is now CEO of Whisper Aero). In this early work, the term on-demand transport was utilized, or on-demand aircraft [78], which had all the elements associated with UAM. The term ODM, or on-demand mobility, was used by Moore [79] in 2006, which later became ODAM around 2012 [80], specifying the aerial nature likely due to surface mode research and developing similar technologies. With further technological developments, the concept has evolved into AAM [81], or advanced air mobility, which offers a greater scope than just urban. AAM as a term appears to become common from 2020 [82]. The transition from ODM through UAM to AAM reflects the broadening vision of integrating air mobility solutions not just within urban environments but also in regional and rural settings, enhancing connectivity and accessibility on a larger scale.

Glass [3] gives a detailed history of flying cars, beginning with early visions and prototypes in the early 20th century. Pioneers like Gustave Whitehead and Trajan Vuia made initial attempts with their Condor and Aéroplane-Automobile, respectively. In 1917, Glenn Curtiss introduced the Autoplane (Figure 13a), one of the first serious efforts to create a roadable aircraft. The 1930s brought Waldo Waterman's successful Arrowbile (Figure 13b). The 1940s featured Theodore P. Hall's ConvAirCar (Figure 13c), and Robert Fulton's Airphibian in the post-war period could convert from plane to car in minutes (Figure 13d). The 1950s saw Moulton B. Taylor's iconic Aerocar, which remains a symbol of the flying car concept (Figure 13e). Early flying cars were very literal vehicles, showcasing very different approaches from modern UAM. Also of note is the infamous Moller Skycar [83].

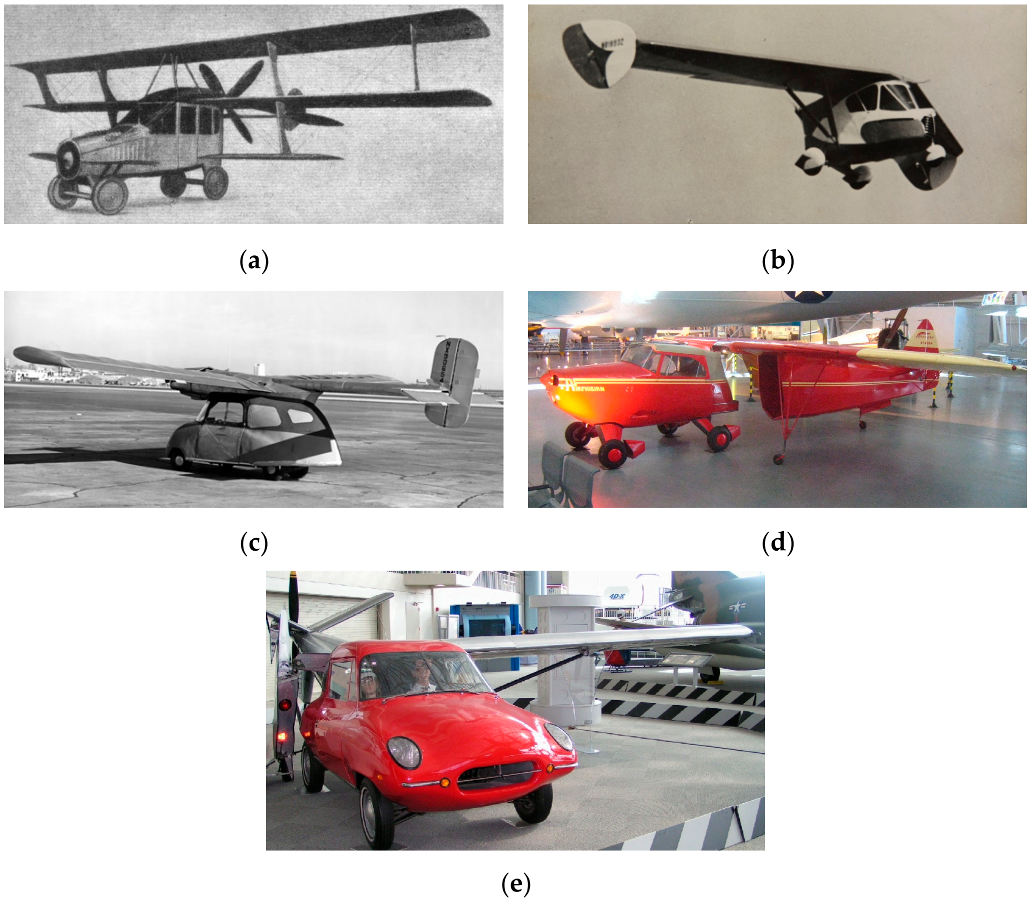


Figure 13. Historic flying cars: (**a**) the Autoplane, (**b**) the Arrowbile, (**c**) the ConvAirCar, (**d**) the Airphibian, and (**e**) the Aerocar. (Creative Commons, Wikimedia).

Interestingly, DeLaurentis, et al. [84] suggested in 2002 that PAVs were not GA, nor were they "'Jetsons' like imaginations", rather they were future air vehicles, specifically 30 years away! Now, 23 years later, this demonstrates a conservative estimate for advanced technology, unlike nuclear fusion, which has similarly been 30 years away for the past 60 years [85]. This cautious optimism highlights the significant strides made in aviation technology, driven by advancements in electric propulsion, autonomous systems, and regulatory frameworks. The gradual yet steady progress underscores the realistic potential of UAM becoming a mainstream mode of transportation in the near future. That is, it is not an abstract future technology that will always be decades away, it is rapidly evolving today and should beat DeLaurentis' 30-year prediction.

The influence of these concepts on public imagination and technological aspirations cannot be overstated. Science fiction has long inspired engineers and innovators, turning fantastical ideas into tangible projects. For example, Jeff Bezos at one point intended to call Amazon Makeitso.com [86], the saying of Captain Jean Luc Picard from *Star Trek: The Next Generation*; this highlights the benefits from integration of STEM and arts into STEAM [87]. The public's fascination with flying cars and personal aircraft has fueled investment and research, accelerating the development of UAM technologies. As these concepts move closer to reality, they continue to shape our expectations and aspirations for the future of transportation.

4.2. Enabling Technologies

Current and future UAM platforms are being enabled by many advanced and advancing technologies. To ensure a broad fundamental understanding of UAM systems, it is important to be aware of these technologies. Different technologies will mean a vehicle interacts with the urban environment differently, and each may have different policy implications. These technologies include advancements in airframe materials and structures, engine and propulsion systems, air traffic control and management, infrastructure, safety systems, autonomy, and communication networks that together form the foundation of modern urban aviation.

Airframe and propulsion innovations are at the heart of UAM from the aerospace point of view. eVTOL aircraft are fundamental to UAM, and are versatile, electric-powered vehicles that eliminate the need for runways [88]. Hybrid propulsion systems, which combine electric and liquid/gaseous fuels [16], extend operational range and energy efficiency. Distributed electric propulsion (DEP) [89] utilizes many smaller electric motors across the airframe; this enhances maneuverability and safety by having multiple propulsors located in advantageous locations, providing redundancy. Materials made from lightweight advanced composites, such as carbon-fiber, are necessary to reduce the weight of vehicles, while still maintaining structural integrity [90]. High-energy-density batteries are critical for longer flight endurance [91], while hydrogen fuel cells may become a significant alternative power source for future UAM systems [92].

Avionic systems, such as those for air traffic management and navigation, are needed to safely integrate UAM into urban airspace. UAV traffic management (UTM) systems are necessary for coordinating the flight paths of the large number of UAM vehicles flying around; this will provide automated route planning and rerouting, as well as real-time terrain and traffic avoidance information [93], TAWS and ACAS, respectively. Global navigation satellite systems (GNSS), such as GPS (as well as Galileo, GLONASS, and Beidou) are needed to give high-precision positioning information, especially in dense urban landscapes [94]. Inertial navigation systems (INS), or inertial measurement units (IMUs) for drones [95], will be needed as a backup for navigation, ensuring reliability where satellite signals are weak. Vehicle-to-everything (V2x) communication will facilitate seamless information exchange between UAM vehicles, ground vehicles, and infrastructure [96], improving situational awareness. Airborne collision avoidance systems (ACAS) will use passive and active systems to sense (or detect) and avoid (SAA or DAA) other UAM [97], preventing what are called mid-air collisions (MAC) in the industry [98]. These sensing and detection systems will include passive secondary RADAR, transponders, whereby aircraft share their position and motion information, as well as active onboard sensors. These active SAA such as radar and LiDAR, as well as visible and IR cameras, will detect obstacles and dynamically adjust flight paths, enabling safe operations in complex, cluttered environments [99].

Any substantial UAM system will need to be supported by a significant number of vertiports, the design and development of which will be needed to facilitate regular reliable operations within urban environments. Vertiports will need to be designed to the specific requirements of eVTOLs, and a variety of possible aircraft and propulsion configurations is likely, with different companies vying to use different IP (intellectual property) to compete in different ways. These vertiports, like heliports before them, will need to provide specialized launch pads that incorporate safety features, such as reinforced platforms and any required emergency systems [100]. Of particular importance are fire suppression systems [101], specifically those intended for modern lithium-ion batteries [102]. Energy infrastructure is fundamental to any aerospace transportation system. The aviation industry is literally built on an extensive underground network of pipes that move fuel to countless airports [103]. Similarly, the UAM network, and likely specific to vertiports, will need high-capacity electrical grid connections for rapid battery charging [104], or hydrogen refueling stations in the case of hydrogen-powered vehicles [105]. Automated ground services, such as autonomous docking systems, robotic maintenance, and automatic charging or refueling [106], will ensure the efficiency and scalability of vertiport operations. These elements will also streamline turnaround times, facilitating quick vehicle dispatch while minimizing human involvement, thereby optimizing overall traffic flow.

If UTM and SAA are combined with artificial intelligence (AI)-powered flight systems, this will be transformative; it would enable UAM vehicles to operate without direct human control [107], unlike the current generation of eVTOL aircraft that are piloted. The likely next step is human-in-the-loop, remotely piloted systems [108], freeing up the pilot seat for an additional passenger or for improved range/endurance. The communications technologies noted below and relevant levels of redundance would be needed for remote operations, and they would likely need to have some level of automation available in the event of a major communication failure, similar to the return to home fail-safe mode utilized in many consumer drones [109]. In general, AI will enable fully autonomous flight, including takeoff and landing, while also facilitating advanced automation providing mid-flight adjustments to optimize flight paths, thereby minimizing energy use. In congested airspaces, swarm intelligence—coordinated AI that allows multiple UAM vehicles to navigate in close proximity—will ensure safe, efficient flight [110]. AI will also be important for more general UTM, where predictive analytics can be used to forecast urban traffic and dynamically reroute aircraft to avoid congestion and/or adverse weather [111].

Safety technologies and certification processes form the foundation of public and regulatory acceptance of UAM, given that safety is a key factor for demand [112]. Noting the increasing trend in powerplant failure in aviation [113], redundancy or multiple backup will ensure that vehicles remain operational even in the event of system failures, thus enhancing operational safety. UAM aircraft certification will require rigorous regulatory processes to meet crashworthiness standards, where the goal is to ensure the highest level of passenger survivability in emergencies [114]; that is, UAM aircraft will be treated no differently from other PART 135 operations. Noise abatement technologies will help to minimize the noise pollution from UAM operations, which is a major concern for urban areas [115]. These technologies will including quieter propulsion systems and other acoustic design improvements [39]. In parallel, cybersecurity systems will need to protect UAM platforms from potential hacking [116], ensuring that communication channels are secure, while safeguarding critical flight data [117]. Safety is also intimately linked with airspace management [118].

High-speed, reliable communication links will be essential for any real-time coordination and control of UAM vehicles [119]. Current 5G and future communication networks will provide the necessary bandwidth and low-latency connections for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication, enabling seamless data sharing across the UAM ecosystem [96]. Although it is sensible for UAM to only operate in urban areas with full 5G+ coverage, in areas where this coverage is limited or problematic, satellite communication systems will be needed to provide the control and monitoring of UAM vehicles [120], as well as back-to-terrestrial communications systems. The Internet of Things (IoT) will integrate sensors embedded within both the UAM vehicles and the supporting infrastructure, enabling real-time data exchange to optimize flight performance, support predictive maintenance, and monitor traffic conditions [121]. Clearly the goal will be to piggyback on existing infrastructure like the 5G network, although it would be reasonable to think that a UAM-specific system might be integrated into mobile phone towers and vertiports, using technologies such as optical tracking and LiDAR.

Figure 14 encapsulates all the above discussed enabling technologies for UAM. Central is the vehicle itself, likely an eVTOL, made of lightweight composites; this incorporates a DEP system using hybrid electric power, from both battery storage and hydrogen fuel cells. The avionics provide dead reckoning via an INS/IMU in case of issues with the primary navigation from GNSS (GPS, etc.), which would be highly augmented with ground-based corrections (GBAS) to improve positioning information to submeter accuracy. Avionics would also include safety systems such as ACAS and TAWS to prevent collisions with other traffic and terrain, respectively. This would be supplemented with electro-optical

(EO)-based detect-and-avoid systems using LiDAR and digital cameras. Comms would be via multiple routes, with 5G at the core, as well as satellite links to low Earth orbit constellations such as Starlink; comms would enable V2G and V2V links, which would feed into the other avionic systems (navigation and safety). On the ground, power for the entire system would ideally come from renewable sources of electricity, facilitating recharging, and potentially onsite hydrogen generation by recycling the water exhaust from the fuel cells. While traditional primary RADAR may be included on the ground, EO-based systems are more likely, although limited to use in good visibility (no fog). There would be additional ground safety systems, including fire suppression, and all ground handling and support would need to be autonomous, utilizing robots, etc. (including maintenance). On the cloud (within the systems), there would be countless narrow AI systems, facilitated by big data and analytics, all needing a high level of cybersecurity to ensure safety and reliability.

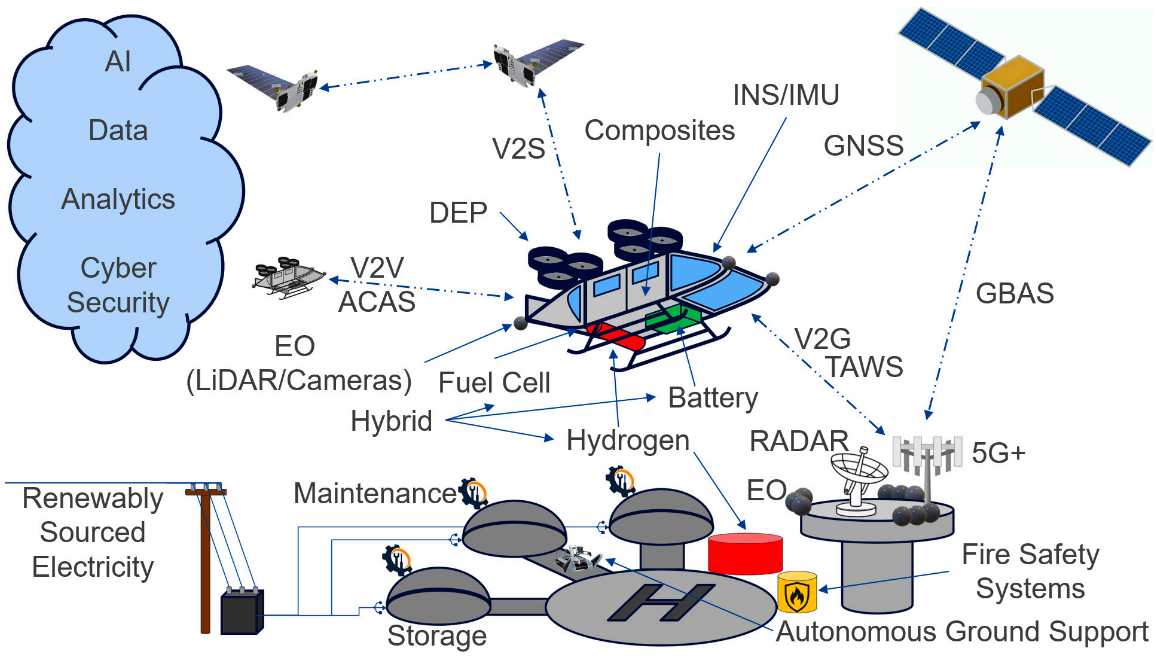


Figure 14. Enabling technologies for eVTOL-based UAM.

4.3. Prototypes and Pilots

The recent development of UAM systems has included various prototypes from major defense and aerospace primes, including Boeing and Airbus, both directly and indirectly. Uber Elevate helped to popularize UAM, planting the idea of air taxis flying around in the imaginations of the general public. Joby Aviation [122], who acquired Uber Elevate in 2020, is now one of the major players; it has made significant progress with its eVTOL aircraft, securing major funding and successfully completing several test trials. Companies like Wisk Aero and BETA Technologies are similarly advancing with designs focused on autonomy and efficiency, while EHang and Volocopter have conducted urban flight demonstrations, particularly in Asia and Europe, showcasing the viability of these technologies [123]. Despite the excitement surrounding these projects, some vehicles have been discontinued as the market matures and consolidates. Figure 15 showcases several current UAM vehicle designs, illustrating the various approaches to solving the challenges unique to urban aviation. A good overview of UAM vehicles is given by Bacchini and Cestino [11] and by Ugwueze et al. [124].

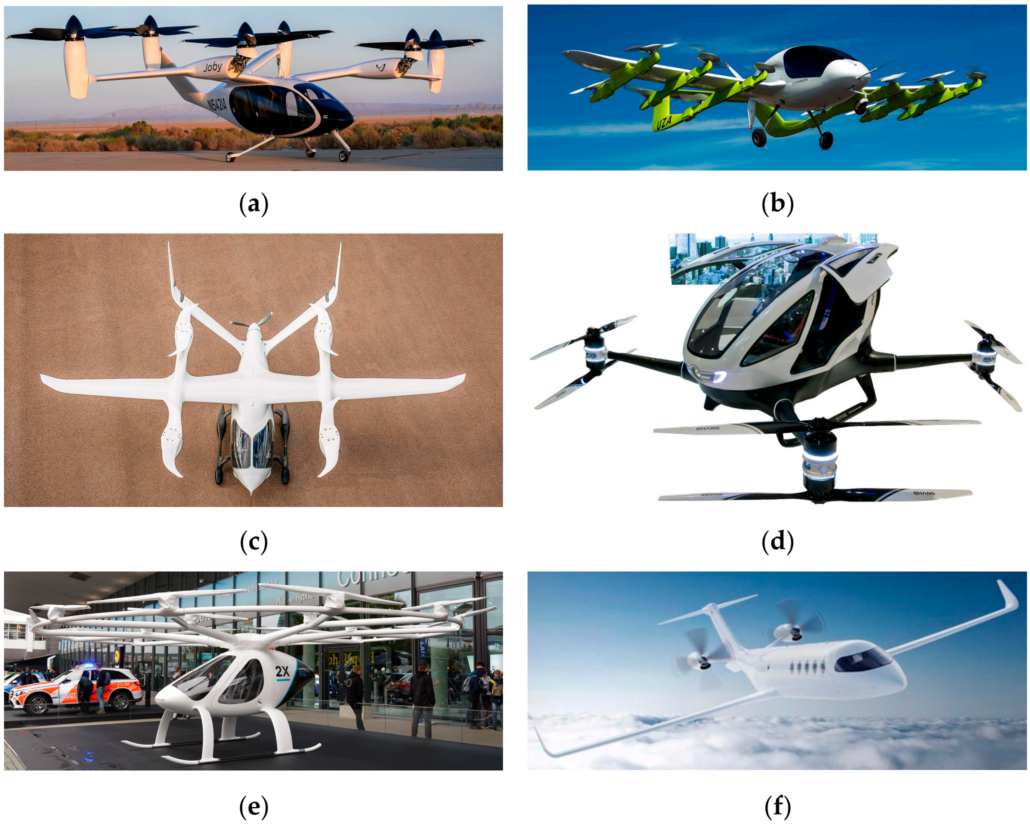


Figure 15. UAM/AAM vehicles from various manufacturers: (**a**) Joby, (**b**) Wisk Aero, (**c**) BETA Technologies, (**d**) EHang, (**e**) Volocopter, and (**f**) Eviation. (Creative Commons, Wikimedia).

Navigating the complex regulatory landscape is an important and necessary safety aspect of UAM development, while it is admittedly resulting in slower progress. While the destructive learning for SpaceX has resulted in leaps and bounds in terms of innovation, it is not the industry norm [125]. Certification processes for eVTOL aircraft are stringent, as noted above, with bodies like the FAA (Federal Aviation Administration) and EASA (European Union Aviation Safety Agency) working to ensure safety while enabling innovation [126]; there can be no wild-west flight test; incidents like the OceanGate Titan could sink the industry before it takes off [127]. The integration of UAM vehicles into existing airspace, likely under different airspace categories, presents another challenge; critically, UAM aircraft must coexist with traditional aviation and small unmanned systems without causing disruptions [128]. Companies like those previously mentioned (Joby Aviation, Volocopter, EHang, Wisk Aero, and BETA Technologies) are advancing the industry, but a fully operational UAM system for use in urban environments will require ongoing regulatory adaptation and international harmonization of standards [35].

5. Urban Science and Design

5.1. Primer

Key aspects of urban science and design that need to be considered are urban planning, transportation infrastructure layout, and land use allocation. These three domains are interrelated, collectively shaping the functionality and sustainability of urban environments. These are underpinned by several guiding principles, encompassing economic, social, and environmental considerations.

Urban planning, generally speaking, is about the strategic organization of land use, infrastructure, and services to enhance the quality of life for urban residents [129]. This takes a systematic approach to managing urban growth that ensures that developments are sustainable as well as meeting the needs of current and future citizens [130]. A core principle of urban planning is the integration of land use and transportation planning, which is needed in order to develop efficient and effective urban spaces [131]. This integration promotes accessibility and mobility, enabling residents to access essential services as well as employment opportunities without having to rely too heavily on private transportation [132].

Transportation infrastructure layout is another important aspect of urban planning that has a direct impact on the patterns of land use [133]. Urban development can either be aided or hindered by the design and configuration of transportation networks [134]. For example, well-designed and planned transit corridors can improve accessibility and connection, which can then contribute to economic growth while also reducing travel times [135,136]. On the other hand, poorly designed and planned transport networks can lead to increased congestion, requiring greater travel distances (longer commutes), as well as contributing to environmental degradation [137–139]. A consistent correlation between the spatial patterns of transportation systems and the socio-economic dynamics that they support has been noted, and needs to be considered [140].

Another key idea in urban planning is land use allocation, which determines how various parts of a city are used [141]. Mixed-use developments, which blend residential, commercial, and recreational areas, can also be encouraged by efficient and successful land use planning [142]. These developments work to reduce environmental impacts by limiting the need for lengthy travel times while at the same time boosting the liveliness of urban areas [143–145]. This is best demonstrated with the concept of transit-oriented development, which encourages the use of higher-density construction close to transit stations in an effort to boost the use of public transportation and reduce reliance on private modes of transportation [146–148].

Sustainability is a general guiding principle that underpins most, if not all, aspects of urban planning, transportation infrastructure layout, and land use allocation [129,149]. Sustainable urban planning aims to minimize the overall ecological footprint while enhancing the livability of urban areas [131,150]. This involves setting up green spaces, encouraging the use of public transport, and establishing policies that support and encourage energy efficiency as well as waste reduction [151]. For example, the use of green infrastructure within urban planning can help to mitigate urban heat islands and enhance biodiversity, contributing to overall environmental health [152,153].

The role of technology in urban planning has increased significantly, becoming more important, particularly with the introduction of data-driven methodologies [154]. Planners can make better decisions by utilizing spatial analysis tools and techniques to evaluate land use patterns and transportation networks [155–157]. These novel resources can be used to pinpoint regions with significant public transport demand, improve routes, and raise the general effectiveness and efficiency of urban mobility systems [130,158]. In addition to this, the application of geographic information systems in urban planning allows for better visualization and analysis of spatial data, aiding in the development of more cohesive urban strategies [159].

Another necessary urban planning component is public participation; this ensures that the opinions and voices of community members are heard during the decision-making process [160,161]. Engaging in planning discussions with residents promotes a feeling of responsibility and ownership, which results in more successful and accepted urban policies [162,163]. This participatory approach can also help to identify the needs and preferences of residents, which can be integrated into transportation and land use plans to create more inclusive urban environments [164,165].

Equity in urban planning is needed to address the disparities that exist in the access to resources and opportunities [166]. Transportation policies must take into account the needs of all demographic groups, particularly any marginalized communities that may face additional barriers to their mobility [167,168]. Urban planners can reduce social inequality and encourage inclusive growth by ensuring equal access to land use and transportation [169].

Climate change adaptation and mitigation strategies are increasingly becoming integral to urban planning [170]. Creating resilient urban environments that can endure the effects of climate change, like flooding and extreme temperatures, is more and more becoming the responsibility of planners [145,171]. This includes promoting energy-efficient building practices, improving green spaces, and putting into place sustainable transportation options [172]. The integration of climate considerations into urban planning processes is needed to create sustainable cities that can endure even in the face of environmental challenges [129,145]. Along with pollution concerns, with urbanization come more general health concerns [173].

The principles of urban planning, transportation infrastructure layout, and land use allocation are interconnected and essential for creating sustainable, livable urban environments. UAM needs to consider all of these facets, not just superficially, but wholeheartedly. The following subsections will investigate these principles further in the context of UAM, through the ideas of urban adaptation, urban exploration, and urban integration.

5.2. Urban Adaptation

A key question for those in the discipline of urban science is, how do urban planning and infrastructure need to adapt for the introduction and likely rapid growth of UAM? The American Planning Association (APA) has addressed this very issue [174].

Cities will need to ensure that zoning codes allow for the construction of vertiports and other UAM infrastructure [175]. This includes designating specific areas for takeoff and landing, which might be on rooftops, parking structures, or other underutilized spaces [100]. There will no doubt be zoning implications due to adding infrastructure on existing structures (height implications, etc.) and changing the purpose of some areas if open spaces are all that is available. Furthermore, the APA notes that there could be other changes to zoning codes due to a reduction in the need for on-street parking; this could feed back to replacing some parking with vertiports at the ground level.

Urban planners will need to ensure that vertiports and other UAM facilities are well-integrated with existing transportation networks [176]. This means creating seamless connections between UAM hubs and public transit, roads, and pedestrian pathways. The APA also notes that "shared UAM companies will also need places to store vehicles during periods of low demand", which is in addition to the vertiports, because vehicles would not be able to wait at vertiports due to space constraints and the need to keep landing slots available for incoming flights. These storage facilities will need to be strategically located for quick access, as well as being equipped with automated systems for efficient vehicle management, including maintenance and charging [177]. Additionally, these facilities should be scalable to handle future growth and integrated into the urban landscape to minimize impact on traffic and local communities.

Urban infrastructure must also adapt to accommodate the technologies that underpin UAM. This includes the development of advanced charging stations for electric aircraft, as highlighted by Thipphavong [178,179], who discussed the available electrical grid power capacity. The integration of smart technologies, such as real-time data analytics and predictive modeling, can optimize the operational efficiency of UAM services, which will be critical for managing power needs to ensure a satisfactory user experience [180]. Additionally, the establishment of dynamic routing systems can improve the responsiveness of air taxi services to fluctuating demand patterns [181].

Addressing noise pollution and environmental impact will be crucial. Urban planners will need to consider the placement of vertiports to minimize noise in residential areas and ensure that UAM operations are environmentally sustainable. Donateo and Ficarella [182] explore the energy consumption and emissions associated with UAM, emphasizing the need for sustainable practices to minimize the ecological footprint of air taxis. The adoption of electric and hybrid-electric aircraft can significantly reduce greenhouse gas emissions, aligning with global sustainability goals [183]. Furthermore, integrating UAM with existing public transport systems can enhance overall urban mobility while reducing reliance on fossil fuels [184].

The introduction of UAM will require rethinking public spaces to ensure safety and accessibility [36]. This includes designing safe pedestrian areas around vertiports and ensuring that emergency services can easily access these sites [185]. Additionally, urban planning must involve the development of comprehensive emergency response protocols for incidents involving UAM, ensuring that emergency services are trained and equipped to handle such situations [9]. For the case of Australia, the significant increase in the number of safety occurrences would quickly overwhelm the ATSB, which is not involved in surface traffic accident investigations; a similar approach may be needed for UAM. Public awareness and education are also crucial; engaging with the community to educate them about UAM operations, safety measures, and privacy protections can help build public trust and acceptance [186]. Intelligent design and planning are essential to create resilient infrastructure that can adapt to the evolving needs of urban air mobility, ensuring that vertiports and related facilities are integrated seamlessly into the urban landscape, utilizing an urban system design [187].

Fundamental to urban planning is engaging with communities to address concerns and gather input; this is essential to avoid unintended "backlash" [188]. Urban planners will need to work closely with residents to ensure that UAM developments meet the needs and expectations of the community [58].

5.3. Urban Exploration

It is possible for UAM infrastructure to enhance public spaces through "placemaking" [189], which focuses on creating public spaces that promote the health, happiness, and well-being of the people that use them. Vertiports have the potential to be integrated into modern vibrant public spaces, fostering both utility and social value. Human-centered design can be used to ensure that vertiports serve both functional and social purposes, prioritizing the human experience in their location as well as aesthetic integration [190], and not just function. Community participation is important [191]; public workshops or interactive platforms can gather community feedback on vertiport and drone corridor designs, aligning with best practices in urban planning.

UAM will need to be integrated with existing smart city infrastructure through data-driven smart urban management [192], or what is called urban informatics, where data are used to plan and manage cities. IoT, AI, and real-time analytics can optimize vertiport and drone corridor usage, to improve efficiency and ensure safety. The concept of transit-oriented development (TOD) focuses on maximizing access to public transport [193]; by integrating vertiports with existing and planned public transport hubs, creating seamless multimodal connections, UAM can embody TOD. Resilience planning addresses the need for urban systems to withstand and adapt to challenges [194], with UAM infrastructure providing new, flexible transportation options that will promote resilience planning. Sustainable urban mobility plans (SUMPs) ensure integrated, sustainable transport systems, highlighting the need for environmentally friendly and long-term urban mobility strategies [195]; in the context of UAM, the entire thinking is rooted in SUMP, with modern sustainable aviation practices facilitated by electrification [196].

UAM systems can be designed to work with existing transportation networks, improving multimodal connectivity through what are called "complete streets", where the focus is on designing streets for all users, not just cars [197]. Similarly, vertiports can be incorporated into a city's overall transportation infrastructure, making UAM accessible alongside other modes of transport; that is, vertiports can be part of major surface mode interchanges. Utilizing the ideas of context-sensitive solutions (CSS) [198] will ensure that vertiports are contextually adapted to various environments, preserving or enhancing the aesthetic and cultural fabric of cities. Mixed-use development combines different land uses, with beneficial outcomes [199], and by integrating vertiports and drone corridors into dynamic, efficient urban areas, these benefits may be enhanced.

Policy and regulatory considerations for UAM include zoning and land use; urban planners will be best suited to determine how these need to evolve to include UAM. For example, vertiports and drone corridors will likely require new zoning definitions, with flexible zoning needed to accommodate new UAM technologies as the art dynamically evolves. Another important policy (and procedure) dimension to be considered is environmental impact assessment (EIA), to ensure sustainability [200]. EIAs will be critical for vertiports and UAM systems to meet standards of green building, noise mitigation, and energy-efficient design. Cofone, Sabato, Di Rosa, Colombo, and Paglione [200] note the expansion of EIAs to include the health dimension in an integrated environmental and health impact assessment (IEHIA). The implementation of these procedures will ensure that UAM and vertiports are understood in terms of their public health impact, which is intimately linked to their safety considerations. These will then collectively assess noise pollution [201], safety standards [202], and air quality, with safety regulations and noise abatement strategies minimizing UAM's impact on residents.

5.4. Urban Integration

For urban planners, the priority should be the creation of mobility hubs [203], which are centralized locations where different modes of transportation converge. Vertiports or drone corridors would ideally be part of these hubs, ensuring smooth transitions between air and ground transport modes (buses, trams, trains, etc.). Urban planners will need to explore how vertiports could physically integrate into transport hubs, with a focus to reimagine underutilized urban spaces [204], both the current underutilized spaces and those that may result from the implementation of UAM (parking structures), as future mobility hubs. This direct urban integration would enhance the efficiency of both passenger and freight transport in spaces where they are both needed, and welcome a degree of urban revitalization or regeneration [205]. It is critical that this is considered in a proactive way, as UAM will result in underutilization of some existing urban infrastructure for ground modes of transportation. If these spaces can be repurposed, then there will be a net positive impact from the future integration of UAM.

Planners will need to focus on solving the challenge of first- and last-mile transport [206], that is, ensuring a seamless connectivity from a traveller's origin to their destination, over the all-important and often difficult first and last mile. UAM also makes aviation available for traffic relief [207], offering a potential solution for longer, congested commutes. As previously discussed, this aligns with the goal of urban mobility hubs to integrate UAM with existing public transportation, facilitating efficient and effective transportation mode switching for passengers. There are a number of modal interchanges urban planners can aim to optimise for, giving first- and last-mile solutions; specific examples include electric scooters [208], autonomous vehicles [209], and on-demand ridesharing services [210], each of which could be linked to vertiports to ensure continuous connectivity for passengers.

Urban planners must manage the interaction between public and private transportation providers [211]. UAM could be developed and operated by private entities (e.g., Joby, Volocopter), but this must align with public infrastructure and urban planning objectives. Similarly, UAM must be integrated with public transportation networks to enhance [177], rather than compete against, public transport systems. Time savings and efficiency will also likely influence UAM adoption [212]. Creating public–private partnerships or introducing policy frameworks to ensure that UAM harmonizes with municipal goals for mobility, affordability, and accessibility is critical [213].

As noted in the preceding section, smart cities rely on real-time data analytics [192], which help to manage transportation systems, and the integration of UAM will require similar systems to ensure smooth operation [111]. Urban planners and designers will need to consider how UAM systems could be integrated into smart mobility platforms [214] used for urban mobility management, in terms of track traffic flows, to optimize routes and predict demand for transport services. This will ensure that UAM is part of the broader city infrastructure, helping to manage congestion, reduce wait times, and maintain transport efficiency.

Finally, UAM should be viewed not in isolation but as part of a broader future-oriented planning and decision-making, which for the urban transportation ecosystem might include [215] autonomous vehicles, underground tunnels, or even Hyperloop systems [216]. Urban planners need to ensure that the integration of UAM does not inhibit future transport innovation. Importantly, urban planners will need to consider how cities can maintain flexibility in their planning frameworks to accommodate future developments alongside UAM, and thus help convey a holistic approach [217].

6. Limitations and Challenges

6.1. Regulatory Barriers

Through the analysis in Section 5, it is clear that the successful implementation of UAM faces many regulatory barriers that cover various aspects of aviation and urban planning. These barriers can be categorized as aircraft certification, air traffic management, infrastructure development, pilot and operator certification, safety and security standards, and legal and liability issues. Each of these elements plays an important role in shaping the operational landscape for UAM; as such, understanding them is important to facilitate the integration of aerial vehicles into urban environments.

6.1.1. Aircraft Certification

One of the main regulatory challenges for UAM is the certification of new aircraft types, which for UAM mostly involves vertical takeoff and landing aircraft [218], specifically eVTOL vehicles [219]. The FAA and other global aviation authorities (EASA, etc.) face the difficult task of defining the necessary certification standards to ensure the safety and reliability of these new UAM aircraft, as they do for all aircraft [220]. The challenge of certifying eVTOLs stems from their unique operational characteristics, which differ greatly from standard aircraft [221]. For example, the FAA has begun developing a new regulatory framework expressly for eVTOLs, which will take into account their design, performance, and operational capabilities [222]. In addition to this, the integration of autonomous systems into these vehicles complicates the certification process, necessitating rigorous testing and validation to ensure that these systems can operate safely not only with people on board but also in urban environments [223,224]. This work will need to be done in a variety of global contexts [225].

6.1.2. Air Traffic Management

Current ATM systems are not equipped to handle the anticipated influx of UAM operations [226]. Current ATM systems are designed for traditional aircraft and operations, and the introduction of numerous small, autonomous aerial vehicles poses significant challenges for airspace management [227]. The development of a new air traffic management approach, previously identified in Section 4 as UTM, is needed to ensure the safe and efficient operation of UAM [228]. This includes the creation of dedicated airspace corridors, real-time traffic monitoring, and advanced communication systems to facilitate coordination among the multitude of operators [229,230]. The integration of UAM into the broader airspace system requires collaboration among various stakeholders, including aviation authorities, urban planners, and technology developers, to establish a cohesive operational framework [231].

6.1.3. Infrastructure Development

The establishment of appropriate infrastructure, such as vertiports, is essential for the successful deployment of UAM [228]. These facilities must be strategically located and designed to accommodate the unique operational needs of eVTOLs, including takeoff and landing requirements, passenger boarding, and maintenance services [232]. However, the regulatory landscape surrounding the construction and operation of vertiports is still evolving [233]. Local zoning laws, land use regulations, and building codes must be adapted to facilitate the development of this new infrastructure [234]. Additionally, the integration of vertiports into existing urban environments presents logistical challenges, including the need for seamless connections to ground transportation systems [235–237].

6.1.4. Pilot and Operator Certification

The certification of pilots and operators for UAM is another significant regulatory barrier [228]. Traditional pilot training programs may not adequately prepare individuals for the unique challenges associated with operating eVTOLs in urban settings [238]. Regulatory bodies must establish new training and certification standards that reflect the specific operational requirements of UAM [239], including the use of advanced avionics and autonomous systems [224]. Also, the potential for fully autonomous operations raises questions about the necessity of human pilots and the implications for regulatory oversight [240].

6.1.5. Safety and Security Standards

Ensuring the safety and security of UAM operations is essential [238]. Regulatory frameworks must address potential risks associated with the operation of eVTOLs [241], including mechanical failures [242], cybersecurity threats [243,244], and the implications of operating in densely populated urban areas [186]. The development of comprehensive safety management systems [245], which include risk assessment protocols and incident reporting mechanisms, is essential for fostering a culture of safety within the UAM ecosystem [186]. Additionally, the establishment of security standards to protect against unauthorized access and potential threats is critical for gaining public trust and ensuring the viability of UAM operations [246,247].

6.1.6. Legal and Liability Issues

The legal landscape surrounding UAM is still largely undefined [248], presenting challenges related to liability and insurance [249]. As UAM operations become more common, questions will arise around who is liable in the event of an accident or incident involving eVTOLs [250]. Regulatory bodies must develop clear guidelines that delineate the responsibilities of operators, manufacturers, and other stakeholders in the event of a safety occurrence [251]. Furthermore, the integration of UAM into existing legal frameworks, including airspace rights and property laws, is necessary to address potential conflicts and ensure the smooth operation of aerial vehicles in urban environments [252]. The privacy dimension that must also be considered, with UAM transiting overhead [253], and the general concept of airspace ownership [254].

6.2. Public Acceptance

UAM's successful implementation relies significantly on public acceptance [255], which also faces limitations and challenges. The relevant factors are safety, noise, socio-economic implications, infrastructure, and public awareness and education programs. Understanding these factors is important for stakeholders involved in the development and deployment of UAM systems.

6.2.1. Safety

While there are safety challenges in the regulatory context noted in the previous subsection, there is also the public perception of safety for UAM [256]. Research indicates that public confidence in the safety of aerial vehicles is a significant determinant of acceptance [257]. The introduction of new technologies often raises concerns about reliability and the potential for accidents [258], particularly in urban environments where the risk of collisions with buildings and other aircraft is increased, with potentially disastrous consequences [259]. Studies have shown that the public's perception of safety will be affected by their familiarity with existing air travel systems and the perceived technological maturity of

UAM vehicles [31,260]. Thus, extensive public education and transparent communication about safety measures and technological advancements are needed to mitigate fears and improve acceptance [31,261]. Much of the research into safety for UAM is being led by NASA and its System-Wide Safety Project [262,263], with ongoing contributions presented regularly at AIAA (and other) conferences [264–266].

6.2.2. Noise

Noise is a key concern that affects public perception of UAM [267]. The operation of eVTOL aircraft is expected to generate noise [268], which could disrupt urban environments and affect the quality of life for residents [115,269]. Research indicates that communities are particularly sensitive to noise levels [270], and any increase in ambient noise could lead to public opposition against UAM initiatives [269,271]. Therefore, addressing noise concerns through effective design and operational strategies, such as optimizing flight paths and using quieter technologies, is key in terms of gaining public support. On the topic of noise, substantial work has been undertaken by the NASA-led UAM Noise Working Group [272], with sessions annually as part of the various AIAA (and other) conferences [273–275].

6.2.3. Socio-Economic Implications

Another significant barrier to acceptance are the socio-economic implications of UAM [228]. The potential for UAM to increase social inequalities is a concern, as access to these services may be limited to wealthier individuals, thereby widening the gap between different socio-economic groups [276,277]. Public acceptance is likely to be influenced by perceptions of fairness and equity in access to innovative services [278], including UAM. Policymakers must ensure that UAM systems are designed to be inclusive and accessible to all segments of the population, potentially through subsidies or partnerships with public transportation systems [279]. Ultimately, socio-economic factors will influence the success of UAM, and studies have shown that demographic differences exist in the general public's willingness to pay for UAM services [280].

In terms of socio-economic considerations, it is relevant to discuss the market potential and cost of UAM, because as noted, willingness to pay is important [280,281]. Clearly, market demand is a key factor [282]. This will be driven by the types of business models utilized for UAM [283]. Along with these general insights, specific modelling and analysis are needed for individual markets to assess economic feasibility [284,285]. There are also niche applications of UAM that can be explored, such as airport shuttles [286] and medevac [287]. Cost will also depend on the technology implemented in the UAM vehicles [288]. If the predicted cost of "27 US-$ to 46 US-$ per requested trip" can be achieved [289], then there is hope for affordable UAM that is accessible to a broad range of socio-economic groups. However, it has also been noted that there are other factors that influence consumer willingness to pay [290].

6.2.4. Infrastructure

As with safety, infrastructure challenges are multifaceted, with the regulatory aspects discussed previously, and now we must consider the public acceptance of UAM infrastructure [291]. The integration of UAM into existing urban transportation networks requires substantial investment in infrastructure, such as vertiports and urban air traffic management systems [292,293]. The public's perception of the government's ability to effectively manage these changes will influence acceptance levels [294]. Transparency in regulatory processes and active involvement of community stakeholders in planning and decision-making can foster trust and enhance public support for UAM initiatives [292,295].

6.2.5. Public Awareness and Education

Public awareness and education programs are needed to address misconceptions and provide accurate information about UAM [296]. Individuals may lack a clear understanding of how UAM operates, the associated benefits, and the potential risks [297,298].

Research indicates that informed communities are more likely to support innovative transportation solutions [299,300]. Educational initiatives should focus on demystifying UAM technologies and highlighting their potential contributions to urban mobility and sustainability [301].

6.3. The Environment

The integration of UAM into existing urban environments poses significant challenges, particularly concerning its environmental impact, not to mention the actual operation environment of urban spaces. These include air pollution, noise pollution, land use, and energy generation impacts. Here, current literature is used to explore the limitations and challenges associated with UAM, focusing on its environmental implications.

6.3.1. Air Pollution

One of the primary concerns regarding UAM is its potential contribution to air pollution [302]. While UAM aims to reduce ground traffic congestion, the environmental benefits are contingent upon the energy sources utilized by air vehicles [303]. The eVTOL aircraft is often highlighted as a sustainable alternative to traditional combustion engines [304]. However, the environmental footprint of UAM is influenced by the entire lifecycle of these vehicles, including manufacturing, operation, and end-of-life disposal [305]. Studies indicate that the overall emissions from eVTOLs can still be significant, particularly if the electricity used for charging is derived from fossil fuels [306]. Therefore, the transition to UAM must be accompanied by a broader shift towards renewable energy sources to genuinely mitigate air quality issues [307].

6.3.2. Noise Pollution

Noise pollution is another key environmental challenge associated with UAM, and the concept was addressed in the previous subsection from the public perspective. The introduction of numerous eVTOLs operating in urban airspace raises concerns about noise levels, which can adversely affect urban populations [26]. Research indicates that noise from aircraft can lead to various health issues, including stress and sleep disturbances, particularly in densely populated areas [308,309]. Moreover, the acoustic footprint of UAM operations is compounded by the need for frequent takeoffs and landings, which are inherently noisier than cruising flight phases [310]. As urban areas are often already burdened by noise from ground transportation, the addition of aerial traffic could exacerbate existing problems, necessitating stringent noise regulations and community engagement in planning processes [311,312]. As noted in the previous subsection, the NASA-led UAM Noise Working Group has undertaken substation work in this area [272–275].

6.3.3. Land Use

Notably, traditional aviation offers a significant advantage over surface transportation in terms of impact around land use. The physical runway area for the 370 major airports in the continental United States comprises approximately 325.6 million square meters (~5500 m by ~80 m, with two runways per airport). In contrast, the road system for the United States covers an area of approximately 107 billion square meters, four orders of magnitude greater.

The integration of UAM into urban environments also raises questions about land use and urban planning [313]. The establishment of dedicated vertiports, landing and takeoff sites for eVTOLs, requires careful consideration of spatial planning to avoid conflicts with existing land uses and to minimize environmental impacts [234]. Urban planners must account for the potential displacement of green spaces and residential areas, which could lead to increased urban heat island effects and loss of biodiversity [314]. Also, the construction and operation of vertiports could contribute to local air quality issues if not managed properly, particularly if construction activities disturb existing pollutants or if the facilities are not designed with sustainability in mind [315].

6.3.4. Energy Generation

Another significant challenge is the potential for increased energy consumption associated with UAM operations [91,316]. While eVTOLs are designed to be more energy-efficient than traditional aircraft [317,318], the overall energy demand could still rise dramatically if UAM services are widely adopted [319]. This is particularly concerning in urban areas where energy infrastructure may already be strained [178,179]. The increased energy demand could lead to higher greenhouse gas emissions if the energy is provided using non-renewable sources, which would undermine the sustainability goals of UAM initiatives [320,321]. Therefore, comprehensive energy assessments are needed to ensure that UAM contributes positively to urban sustainability efforts [322].

6.3.5. Weather

Real-time weather data will be essential for UAM operations [323]. The urban landscape, referred to as urban canyons, presents weather hazards such as enhanced wind shear and turbulence [324]. Traditional meteorological issues may also be exacerbated in the UAM context, such as icing and visibility reduction [325,326]. An assessment of Chicago suggests that in winter, almost 50% of UAM trips could be impacted by weather [327]. It is not surprising then that passenger perception of UAM in adverse weather conditions is a key factor [325,326]. There are a wide range of elements needed for safe UAM operations in terms of weather, which include measurement, analysis, modeling, forecasting, decision support, dissemination, and overarching policy [328]. All of these will need dedicated research, likely in every city to utilize UAM. In addition to these natural weather phenomena, UAM will create its own weather-like effects, such as downwash and outwash, that also need to be understood [329].

6.4. Autonomous Future

Joby Aviation, arguably a leader in the space, has made it clear that they are pursuing certification in a conventional aviation context, which will necessitate a pilot onboard an aircraft [330]. However, it is clear that the aviation of the future will be fully autonomous. Below is a timeline that is based on Year 0 being 2025, although this technically represents when commercial operations commence.

6.4.1. Year 0 to 5: Initial Autonomous Capabilities

A modern airliner is highly automated, to a level such that minimal inputs are needed from pilots during all phases of flight [331]; in principle, human pilots are in the cockpit to deal with critical safety situations in real time. The word autopilot is part of our everyday vernacular, but represents a real system onboard an aircraft, along with autothrottle and autoland systems [332]. As such, any modern aircraft will be developed with the same level of "limited autonomous functions" under supervised conditions, with pilot-assistance systems. That is, these systems are currently certified today, with a pilot in the loop, or on the loop, depending on the specific architecture of the system. As such, all initial UAM flights will involve regulatory frameworks for semi-autonomous operations in urban environments. In fact, it would be effectively impossible to certify an aircraft for operations in urban environments that do not adopt this concept of operation. Studies have shown that for uncrewed systems in wind shear situations, autonomous systems can maintain a position or trajectory hold while human pilots cannot [333], with potentially disastrous consequences.

This period in UAM operations will be crucial in terms of data collection. The underlying question will be, when was pilot intervention needed? There will also need to be an accounting of what tasks current regulations require pilots to engage in, and an assessment of what level of automation can be applied to each of those. The final key self-reflection aspect here will be to assess what proportion of those pilot interventions and regular tasks can be done remotely by an operator, that is, a pilot operating the UAM vehicle from a ground station.

6.4.2. Year 5 to 10: Pilot Optionality in Controlled Urban Environments

Assuming that the initial data collected in the first phase are favorable, the second stage is likely to implement a teaming approach. This would involve a ground-based operator doing everything the pilot would do (or did in phase 1), while a pilot is in the vehicle in case there is an issue with the secure communications link. This will give regulatory bodies the ability to understand pilot-optional flights in well-mapped urban corridors with high infrastructure support, while a pilot is still onboard to meet current certification requirements. This also provides a chance to increase public acceptance of autonomous functions, with these routine semi-autonomous flights reinforcing trust. Also during this phase, infrastructure such as vertiports and autonomous traffic management systems may reach a level of reliability that mitigates some urban flight risks. A current example of this is the ease with which we can autoland with zero visibility at many airports using GBAS [334]; however, due to limitations in taxiing in zero visibility, it is not possible at some airports [335]. That is to say, if vertiports integrate more sensing systems, this will facilitate higher levels of autonomy.

6.4.3. Year 10 to 15: Scaling Autonomous UAM Operations

As technology, regulatory frameworks, and public confidence converge, we could see fully autonomous, pilotless operations becoming more common in specific cities that pioneer UAM infrastructure. By this time, operational metrics and data from semi-autonomous flights will support a compelling safety record for fully pilotless flights (no pilot onboard, exclusively ground control). Insurance and economic models may begin to align with autonomous services, and public adoption could increase, assuming there have been no significant incidents that would erode trust, as accidents in innovative aerospace endeavors can result in significant consequences [336].

6.4.4. Year 15 to 25: Widespread Pilotless UAM Services

In phase 4, fully autonomous UAM operations could become standard in major urban areas, depending on the rate of adoption and success of earlier phases. At this point, advanced autonomous systems, supported by well-integrated infrastructure and a stable regulatory framework, would likely enable regular, reliable, and cost-effective pilotless UAM services. Importantly, there would still be ground operators, but unlike in earlier phases, this would not be a one-to-one function where a single ground controller is responsible for a single aircraft; instead, we would be at the stage of one-to-many, where a single controller supervises many UAM trips and intervenes when needed. The broad adoption in this phase would still vary globally based on local regulatory and infrastructural conditions, as well as public acceptance trends.

6.4.5. Year 25 Onwards: Fully Autonomous

While the trust in autonomous systems is a point of contention [337], it is an objective fact that the speed of digital processing greatly outpaces that of human cognition [333]. As such, it is clear that the ultimate future will be one of fully autonomous operations. While there will still undoubtedly be some level of one-to-many supervision, the sheer size and scale of what is predicted for UAM ultimately limits the usefulness of real-time human decision-making [338]. Consider the highway scene from Steven Spielberg's *Minority Report* (2002); the improvements in efficiency with every car simultaneously moving away from the red light that turns green instantly is not something we mere humans can achieve. Autonomous vehicles can achieve this with flocking algorithms [339]. Unfortunately, human and autonomous drives in this context do not mix; putting a human-controlled vehicle in the middle of that scene would be problematic; the result would be autonomous vehicles avoiding and moving around and away from the source of unpredictable behavior. This, in principle, is what makes the task of autonomous cars more challenging [340], while the lack of any current UAM traffic means the procedures can be designed and developed today knowing that automation is the future. I have said to my students for the last decade, your grandchildren will one day exclaim to you, "They used to let people fly planes", just like we scoff at the medical practices of centuries past.

7. Analysis

Techno-optimism [341] fuels much of the excitement for UAM, with proponents envisioning a future where electric, autonomous aircraft reduce urban congestion, shorten commute times, and create greener cities. The optimistic view around UAM rests on the belief that these technologies can deliver significant improvements in urban mobility and quality of life; that is, UAM embodies technological determinism [342]. However, this vision must be balanced with a realistic assessment of the social, regulatory, and infrastructural challenges, given that aviation activities must be integrated into existing urban environments, where they have traditionally been avoided or excluded (with the exception of some helicopter operations). While technology can be a driving force for "progress", the success of UAM will also depend on soft metrics, specifically, how well it is aligned with equitable, sustainable, and well-regulated urban planning.

It is the purview of urban planners to make sure that new transportation systems are sustainable, equitable, and accessible. A comprehensive approach to sustainable urban transportation includes five dimensions; these are affordability, inclusivity, accessibility, satisfaction with public transport, and the quality of public spaces [36].

While elements of sustainability were mentioned in the preceding sections, in terms of both renewable energy and green design, social equity is another important consideration. How will UAM services be made accessible to diverse populations, including lower-income communities? What about traditionally underserved urban pockets? This section will consider these questions and discuss how cities can use policies to prevent UAM from being a luxury service that increases social inequality.

7.1. Equity

Ensuring that UAM services are accessible to all, regardless of socio-economic factors, is needed to prevent the emergence of 'airspace inequality'. That is, it is crucial to ensure that UAM does not contribute to gentrification [343]. Hence, strategies need to be developed to make UAM not only accessible but affordable to a wide range of income groups [344]. Strategies may include subsidies or tiered pricing models, the implementation of which will ensure that lower-income groups can also benefit from any advantages that a UAM system may bring [295]. Inclusive planning is essential, involving diverse community stakeholders in the planning and implementation of UAM to ensure that the benefits are equitably distributed [345]. Unsurprisingly, community engagement is necessary; it will help to understand and address the needs and/or preferences of all residents, ensuring that the implementation of UAM does not exacerbate social inequalities [346]. Also, developing UAM in conjunction with additional improvements to existing public transportation will help integration with the broader urban mobility network; this is essential so that the UAM system does not replace or overshadow the more affordable and common surface modes.

With a focus on affordability and inclusivity, cities can prevent UAM from becoming a luxury service that exclusively serves the wealthy, which would only serve to increase social inequality. This focus would also help to ensure that UAM does not contribute to urban displacement [347]. Continuous monitoring and regulation will be needed to help mitigate potential negative implications for housing prices, while also ensuring that UAM makes a positive contribution toward urban development. Fundamentally, the aim is for UAM to be a tool for enhancing urban mobility for all.

7.2. Sustainability

Assessing the environmental impact of UAM is needed to develop sustainability strategies that go towards a reduction in emissions, energy consumption, and noise pollution [348]. The integration of UAM in the urban environment must focus on the utilization of sources of renewable energy to minimize the associated carbon footprint [317]. Emissions reduction strategies must also include optimizing the environmental impact of UAM operations [349], in terms of both emissions and noise. Other strategies for noise pollution reduction are necessary to ensure that UAM aircraft do not excessively disrupt the urban environment in which they operate [26]; this requires the development and adoption of noise reduction technologies [350]. The development of UAM infrastructure and vehicles needs to incorporate sustainable design practices, specifically emphasizing green design [27]. While the emissions from electric vehicles can be readily understood, a full lifecycle analysis of any and all UAM vehicles, from production to disposal, is required to fully understand the total environmental impact of UAM [351]; this would also facilitate the planning and implementation of any mitigation strategies needed. By addressing these sustainability challenges, it is hoped that UAM will contribute to a greener and more sustainable urban transportation system: green urban aviation.

7.3. Philosophical and Human Geography Perspectives

The literal rise of UAM, along with all autonomous systems, can stoke concerns that are rooted in neo-luddism [352], the belief that technological advancements threaten jobs and societal stability. Just as automation has changed the manufacturing and service industries, the arrival of autonomous UAM may put traditional transportation jobs at risk. Considering the satirical cry from Stone and Parker's *South Park*, "They took our jobs", these concerns reflect a broader anxiety in society about how automation encroaches on human labor [353]. This fear is exacerbated by general techno-pessimism [354]; this belief draws the focus, regardless of any promise of efficiency and convenience UAM may bring, to the fact that it also risks further alienating those whose livelihoods depend on manual, human-operated systems.

Social constructivism [355], which emphasizes that knowledge and understanding are developed through social interactions and cultural context, would suggest that a UAM system's success is not simply a matter of technical feasibility; success requires societal acceptance and adaptation, and thus what is termed societal buy-in is essential [356]. Hence, the implementation of UAM needs to be carefully balanced with strategies for workforce transition [357]; this will help to ensure that the benefits are equitably distributed, while simultaneously avoiding the dystopian fears associated with unchecked technological progress, like the job-taking AI voice assistants from the aforementioned *South Park*.

Communitarianism is a philosophy that emphasizes the importance of community and social cohesion [358]. From this viewpoint, UAM could be used to promote community bonds and ensure equity for all members of society. Community-centered planning, involving local communities in the planning and decision-making processes for UAM infrastructure and services, would ensure that the needs and preferences of residents are prioritized. Ensuring that UAM services are affordable and accessible to all community members, regardless of income level, can help prevent social inequalities. UAM can be used to improve connectivity between different parts of a city, especially underserved or remote areas, integrating these areas more fully into the urban fabric and promoting social and economic inclusion. Similarly, the prioritization of environmentally friendly technologies and operations in UAM further aligns with communitarian values of sustainability and the stewardship of shared resources. Also, local economies could be supported by involving local businesses in the development and operation of UAM services; this would help to ensure that the economic benefits of UAM are distributed within the community.

Given that the intended aim of UAM is to revolutionize how people navigate and move through cities, these systems align with the Situationists' idea of negation [359]. That is, UAM will challenge the traditional ways people move through urban spaces. UAM can be seen as a modern extension of Debord's "quest of another use of the urban landscape" [360], where the aim was to find new and unconventional ways to use and experience urban landscapes. By introducing the third dimension to mobility, above the city streets, UAM changes the current ways people navigate, interact with, and move through urban environments. That is, UAM aligns with the Situationists' idea of breaking free from the prescribed norms and exploring cities in more dynamic and creative ways [361].

Deleuze and Guattari's geophilosophy is an interesting lens through which to view UAM [362]. UAM represents a form of deterritorialization, breaking traditional boundaries of urban transportation; opening the urban airspace is then the simultaneous reterritorialization. Furthermore, UAM challenges conventional perceptions of urban space and mobility just as geophilosophy rethinks subjectivity beyond phenomenological constraints. UAM will require new ways of thinking about movement, space, and the human experience within urban spaces. The integration of UAM involves aesthetic and design practices that reshape our interaction with urban spaces. This echoes the geophilosophical emphasis on art and aesthetics in refiguring subjectivity and engaging with the unthought forces of the earth. Finally, geophilosophy's call for a "new earth" and "new people" aligns with the innovative and forward-thinking nature of UAM. It encourages us to envision new possibilities for urban living and mobility that transcend current limitations.

8. Discussion

8.1. Key Findings

The future aerospace transportation system aims to establish an integrated, sustainable, and efficient network that can effectively address current transportation challenges like congestion, pollution, and accessibility. Advancements in areas such as electric propulsion, autonomous systems, and air traffic management will help to enable the system, providing the potential to revolutionize transportation within and between cities. This future aerospace transportation system encompasses various scales of transport, from intracity UAM and drone deliveries to intercontinental and even space travel.

This review focused on the urban science perspective of UAM, an area not comprehensively covered in previous reviews, with previous studies heavily focused on engineering aspects. UAM has evolved from early visions of flying cars and personal aircraft, progressing through concepts like PAVs (personal air vehicles) and on-demand mobility, to the modern concept of AAM (advanced air mobility), which includes a broader scope beyond the concept of urban aviation.

The realization of UAM depends heavily on enabling technologies, including electric propulsion, autonomous flight, advanced materials, and communication, navigation, and surveillance systems. These technologies are needed to create safe, efficient, and sustainable UAM operations. Prototypes and pilot programs are currently under development, with key industry players like Boeing, Airbus, Joby Aviation, Wisk Aero, BETA Technologies, EHang, and Volocopter leading the way, showcasing the progress and potential of UAM.

Successfully integrating UAM into urban environments requires careful consideration of urban design and infrastructure adaptations. Vertiports, designated landing and takeoff areas for UAM vehicles, will need to be seamlessly integrated into urban landscapes, considering aspects like noise reduction, visual impact, and efficient passenger flow.

Significant limitations and challenges stand in the way of UAM implementation. Regulatory barriers, such as aircraft certification, air traffic management, infrastructure development, pilot and operator certification, and safety and security standards, pose challenges to the seamless integration of UAM. Public acceptance is also an important factor, with concerns regarding safety, noise, socio-economic implications, and the impact on infrastructure.

Environmental impacts require consideration, particularly the potential for air and noise pollution, land use implications, and the energy generation needed to support the anticipated UAM operations. While electric propulsion offers a cleaner alternative, a thorough lifecycle analysis of UAM vehicles is necessary to evaluate their overall environmental impact, not to mention that eVTOLs are only as clean as the source of electricity.

Despite the challenges, the potential benefits of UAM, including reduced congestion, improved connectivity, and economic growth, are substantial. The social equity considerations of UAM must be addressed, ensuring equitable access and preventing UAM from becoming a luxury service that is accessible only to the wealthy.

8.2. Interpretation of Results

8.2.1. Primary Research Questions

What are the key challenges and opportunities associated with integrating UAM into existing urban transportation networks? Integrating UAM into existing urban transportation networks offers both opportunities and challenges. Some key opportunities are:

- Reduced congestion: UAM can alleviate traffic on roads, leading to shorter commute times.
- Improved connectivity: UAM can connect areas that are not well-served by existing transportation.
- Economic growth: UAM can create jobs and stimulate economic growth.

However, there are significant challenges to consider:

- Regulatory barriers: There are several regulatory hurdles to overcome, including aircraft certification, air traffic management, infrastructure development, and safety standards. These regulations are needed to ensure the safety and efficiency of UAM operations.
- Public acceptance: Public acceptance of UAM is crucial for its success, but there are concerns about safety, noise, and socio-economic implications. Educating the public about UAM technology, safety features, and benefits is vital to gain wider acceptance.
- Environmental impact: The environmental impact of UAM, particularly in terms of air and noise pollution, needs to be carefully considered.

What are the requirements for UAM in terms of urban design and infrastructure? Successfully integrating UAM into urban environments requires a shift in urban design and infrastructure considerations. The key requirements are:

- Vertiports: These specialized landing and takeoff areas for UAM vehicles need to be seamlessly integrated into urban landscapes. They require reinforced platforms, emergency systems, and potentially fire suppression systems for lithium-ion batteries.
- Charging infrastructure: Extensive high-capacity electrical grids are necessary to support the rapid charging needs of electric UAM vehicles, mirroring the fuel distribution network for traditional aviation.
- Drone corridors: Designated airspace for UAM operations needs to be established to ensure safety and efficiency.
- Integration with existing transportation: UAM should be integrated with existing transportation systems to provide seamless connectivity for passengers. This involves incorporating vertiports into transportation hubs and optimizing connections with other modes of transportation, including electric scooters, autonomous vehicles, and public transit.

What are the potential social equity and sustainability implications of UAM? The implementation of UAM raises important social equity and sustainability considerations. Key concerns are:

- Equity of access: UAM services should be accessible to all members of society, regardless of income level. Implementing strategies like subsidies and tiered pricing models can prevent UAM from becoming an exclusive service for the wealthy, thereby promoting social inclusion.
- Environmental sustainability: Minimizing the environmental impact of UAM is paramount. This involves using renewable energy sources to power vertiports and UAM vehicles, optimizing flight paths to reduce emissions and noise, and adopting sustainable design practices for infrastructure and vehicles.
- Community engagement: Transparent communication and active community engagement are essential to address concerns, build trust, and ensure that UAM aligns with community values and needs.

8.2.2. Secondary Research Questions

How can the challenges be addressed while maximizing the potential benefits? Addressing the challenges associated with UAM is essential to fully realize its potential benefits. This involves a multi-faceted approach:

- Developing clear regulatory frameworks: Addressing regulatory barriers early on is crucial for facilitating investment and innovation in the UAM sector.
- Building public trust: Public acceptance is critical for the successful integration of UAM. This can be achieved by conducting public awareness campaigns, showcasing safety protocols, and demonstrating the societal and economic benefits of UAM.
- Prioritizing sustainability: Mitigating the environmental impact of UAM requires a focus on renewable energy, efficient flight operations, and sustainable design practices for infrastructure and vehicles.
- Ensuring equitable access: Designing UAM systems to be inclusive and accessible to all income groups is crucial for social equity. Implementing policies that promote affordability can prevent UAM from exacerbating social inequalities.

How can UAM be implemented to minimize negative impacts on existing public spaces and urban design? Minimizing the impact of UAM on existing public spaces requires a thoughtful approach to urban planning and design. Key strategies include:

- Integrating vertiports seamlessly: Vertiports need to be designed to blend into the urban landscape, minimizing visual impact and noise pollution.
- Utilizing underutilized spaces: Reimagining existing underutilized spaces, such as parking structures, as potential vertiport locations can minimize the need for new construction and potentially revitalize these areas.
- Engaging with communities: Early and continuous community engagement is essential for understanding concerns and ensuring that UAM infrastructure aligns with community needs.

What strategies can be implemented to ensure its accessibility, affordability, and minimal environmental impact? Ensuring the accessibility, affordability, and sustainability of UAM requires strategic planning and policy implementation. Strategies to consider are:

- Subsidies and tiered pricing: Providing subsidies for low-income users or implementing tiered pricing models based on income can make UAM services more affordable to a wider range of the population.
- Integration with public transport: Seamless integration with existing public transportation networks can make UAM more accessible to those who rely on public transit.
- Renewable energy sources: Using renewable energy sources to power vertiports and UAM vehicles can significantly reduce the carbon footprint of UAM operations.
- Efficient flight operations: Optimizing flight paths to reduce travel distances and implementing technologies that minimize noise pollution can contribute to UAM sustainability.
- Lifecycle analysis: Conducting a thorough lifecycle analysis of UAM vehicles, from manufacturing to disposal, can help identify areas for improvement and implement strategies to reduce the overall environmental impact.

8.3. Comparison with Previous Studies

Moradi et al. [9] provide a good holistic overview that aligns with many of the major points discussed in this work. They discuss routing and scheduling, infrastructure planning, safety and security, and the efficiency–sustainability tradeoff. Similarly, Wang et al. [28] cover most if not all of the technological aspects covered in this review. Their review is given from a systems architecture perspective, and as such considers many aspects of the system of systems that UAM will ultimately represent.

8.3.1. Technology

Bridgelall [363] has a recent review of the aircraft innovations trends for AAM, which highlights a range of similar technological advancements important to the development of VTOL aircraft. Bridgelall's use of patent analysis is particularly insightful as it provides concrete examples of the engineering currently being undertaken, such as improving transition efficiency between hover and forward flight, enhancing control systems using AI, and managing energy use and heat dissipation from batteries. The review by Kiesewetter et al. [27] concentrates on a detailed analysis of different AAM aircraft configurations, their technological readiness, and their performance across various criteria, providing a comprehensive overview of the aircraft themselves, the key aspects of which are summarized herein. Similarly, Zhou et al. [44] focus on evaluating and comparing different VTOL technologies for both manned and unmanned aerial vehicles, giving a detailed and complete overview. Materials for UAM vehicles were also discussed in this work, and these were reviewed in detailed by Choi et al. [34].

Engine-related aspects were also mentioned in the review of technological aspects of UAM. A more comprehensive review is provided by Doppler et al. [22]. Aspects of rotors are reviewed by Atci et al. [24], while other reviews related to UAM have been presented for rotors [364] and propellers [365]. Also crucial to the powertrain of eVTOL vehicles for use in UAM is the source of energy/power, as noted in the technological review. This can include batteries [41] as well as fuel cells [92,366], which, as noted, have been reviewed in relation to UAM.

8.3.2. Operations

A critical operational (and technological) aspect discussed was ATM for UAM, or UTM. DLR has had a long history of research in this area [33]. For example, its HorizonUAM project looked at a safe, efficient, and sustainable UAM ecosystem in Germany [367]. Other reviews have been provided by Aldemir and Ucler [38], which looked to swarming solutions, as well as by Zhang et al. [40] in the context of China, and by Li et al. [43]. Routing is a clearly important aspect of UTM, given that it can have significant influence on energy consumption [10].

There are also two reviews that deal with more general operations. Liao et al. [25], in addition to UAM, reviews aspects of management and operational considerations, similar to those common to other parts of the aviation industry. Other similar operational scenarios were explored in the review by Maia and Lourenço da Saúde [42].

8.3.3. Environment

Steiner [45] gives a great primer on the need for the "weather community" to engage more with UAM research, noting that more fine-grain information will be needed. This is clearly illustrated by other reviews that show how important wind is in urban canyons to the safe and efficient operation of UAM [23,37].

The other critical aspect of the environment is the impact UAM operations will have upon it. While there are clearly studies dealing with bigger-picture environmental impacts from UAM [348], there is a notable lack of reviews of these kinds of studies. What has been studied more is the noise aspect. This includes measurement and perception of noise [26], as well as sound propagation and mitigation [39].

8.3.4. Urban Science Dimensions

Several reviews have investigated the regulatory and policy aspects of UAM. Fakhraian et al. [29] looked at compliance of UAM in terms of European Union regulations. The review by Mazur et al. [35] gives a broader context in terms of regulatory frameworks for UAM. Similarly, the review by Raghunatha et al. [32] considers policy and governance for the three dimensions of the vehicle, infrastructure, and adoption, part of which aligns with the urban science dimensions. A more tactical approach was explored by Biehle [36], developing indicators for affordability, inclusivity, accessibility, and satisfaction. Also, acceptance was investigated by Tepylo et al. [31]; here, public acceptance of advanced aviation technologies like drones and urban air mobility was found to be influenced by perceived risk, technological reliability, and the perceived benefits compared to existing technologies.

The review by Sieb et al. [30] is also relevant here, as well as to technology. Noting the previously mentioned reviews around policy, regulation, and governance, airworthiness is a critical aspect, directly related to aviation. Safe operations will rely on both good initial airworthiness (certification) and continued airworthiness (maintenance).

8.4. Implications and Future Research

The integration of UAM into existing urban transportation systems presents a unique opportunity to revolutionize urban transportation, but it also presents several challenges that must be carefully considered. The successful implementation of UAM depends on a multi-faceted approach that addresses regulatory barriers, fosters public acceptance, prioritizes sustainability, and ensures equitable access.

A proactive regulatory framework is needed to foster innovation and investment in the UAM sector. Existing regulations for traditional aviation need to be adapted to accommodate the unique characteristics of UAM operations, including aircraft certification, air traffic management, infrastructure development, and safety and security standards. A streamlined, transparent regulatory process that keeps pace with technological advancements will be critical for the industry's growth and sustainability.

Public acceptance of UAM is important for its successful implementation. Addressing public concerns about safety, noise, and socio-economic implications through public awareness campaigns and transparent communication is essential. Showcasing safety protocols, technological advancements, and the potential societal and economic benefits of UAM can help foster trust and mitigate potential opposition. Community engagement initiatives, including workshops, surveys, and advisory boards, can provide valuable input and ensure that UAM development aligns with community needs and values.

Prioritizing sustainability in UAM development is essential to minimize its environmental impact. This includes the integration of renewable energy sources to power vertiports and UAM vehicles, optimizing flight paths to reduce emissions and noise pollution, and adopting sustainable design practices for infrastructure and vehicles. A thorough lifecycle analysis of UAM systems, from production to disposal, is necessary to identify areas for improvement and implement strategies to reduce the overall environmental impact.

Ensuring equitable access to UAM services is crucial for social equity. Strategies to prevent UAM from becoming an exclusive service for the wealthy, such as subsidies and tiered pricing models based on income, should be considered. Seamless integration with existing public transportation networks can further enhance accessibility for those who rely on public transit.

The analysis of existing research reveals several areas where further investigation is needed. The long-term environmental impact of UAM requires comprehensive research. This includes examining the impact of UAM operations on air quality, noise levels, and land use. Conducting a full lifecycle analysis of UAM vehicles and infrastructure, considering factors like emissions from manufacturing and disposal, is crucial to fully assess its environmental footprint. A meta-analysis of existing studies on the environmental impacts of UAM would provide valuable insights and predictive power to guide future development and policy decisions.

Research into human factors and non-technical skills (NTS) in urban environments is lacking. Understanding how pilots will adapt to the complexities of operating in urban airspace is essential for ensuring safety. Studies examining pilot workload, situational awareness, and decision-making processes in urban settings are crucial for developing effective training programs and mitigating potential risks. Research into the impact of UAM operations on the well-being of residents, including potential stress and sleep disturbances from noise pollution, is also necessary.

The review also points to the need for more nuanced research on the social and economic implications of UAM. This includes investigating the potential for job displacement in traditional transportation sectors and exploring strategies for workforce retraining and adaptation. Further research is needed to assess the distributional effects of UAM on different income groups and communities, and to ensure that it contributes to a more inclusive and equitable transportation system.

Community engagement should be a central focus of future research initiatives. Developing methodologies for effective community consultation and participation in UAM planning and decision-making is crucial. Exploring the role of community advisory boards, public surveys, and interactive platforms for gathering feedback on UAM infrastructure design and operation can help ensure that UAM aligns with community priorities and mitigates potential negative impacts.

The integration of UAM into urban environments holds immense promise for enhancing urban mobility, but careful planning and consideration of its broader implications are paramount. By addressing these research gaps and implementing proactive policies that prioritize sustainability, equity, and community engagement, we can ensure that UAM contributes to a more efficient, equitable, and sustainable urban transportation system for the future.

9. Conclusions

To quote Steve Jobs, "design is how it works" [368]. In which case, the design for UAM involves a lot of urban science and planning. Designing UAM to work in the urban environments they are intended to service, in terms of importance, is on par with the aerospace engineering responsible for the materials, structures, and powerplants. The future of aerospace transportation, as explored herein, must balance cutting-edge technology with the complex needs of urban spaces and their people.

The future aerospace transportation system spans a wide spectrum, from GA to RPT on international airlines, while the literal rise of drones and RPAS reshapes aviation today. With the aviation scales as defined from intracity to space, the challenges and opportunities at each level are not insurmountable. UAM for intracity and AAM for intercity (and beyond) are emerging as significant technological developments; they will fundamentally alter the thinking around intercity and intracity travel, both for people and goods.

The historical evolution of UAM has included numerous prototypes, demonstrated by flight tests from companies like Joby Aviation and Volocopter. Despite early challenges, the rapid progress in terms of enabling technologies (from electric propulsion and autonomy to digital air traffic management) has laid a solid foundation for future operational success. However, achieving the ultimate goal of UAM requires more than just technological innovations; it requires careful urban planning and policy making that must support these developments, sustainably.

The role of urban science and planning is important to the future of UAM. Presented were the three aspects of adaptation, exploration, and integration, to ensure that UAM aligns with broader urban mobility goals. This involves the adaptation of existing urban landscapes, the exploration of creative land use configurations, and the integration of multimodal transport networks. Planners must carefully consider how vertiports and drone corridors are integrated into public spaces, while working with the surrounding architecture and landscape, as well as seamlessly connecting to other modes of transport.

By offering a novel way to experience and move through cities, UAM could help realize human geographers' vision of a more dynamic and engaging urban life while also addressing social equity and sustainability concerns through inclusive and community-centered approaches. Importantly, UAM should not compound existing social or economic divides, nor should it become an exclusive mode of transportation for the rich. Instead, thoughtful design and policy must prioritize affordability, accessibility, and environmental responsibility, ensuring that UAM is implemented for broad societal benefit.

While this work highlights the importance of a collaborative approach to UAM integration, it is also crucial to acknowledge and address the potential social and environmental implications of this emerging technology. Noise pollution from eVTOL operations, for example, is a significant concern that must be mitigated through quieter technologies, strategic vertiport placement, and ongoing community engagement. Furthermore, ensuring equitable access to UAM services is paramount to prevent the exacerbation of existing social inequalities. Strategies like subsidies, tiered pricing models, and seamless integration with existing public transportation networks are vital to make UAM affordable and accessible to a wide range of income groups, ensuring that its benefits are equitably distributed.

Continued research is also necessary to fully understand the long-term impacts of UAM and to guide responsible implementation. This includes investigating the environmental effects of UAM operations, examining human factors and pilot performance in urban airspace, and developing effective methodologies for community engagement in UAM planning and decision-making. By proactively addressing these challenges and opportunities, UAM can become a truly transformative and inclusive part of the future aerospace transportation system, contributing to a more sustainable and equitable urban environment.

To conclude, the future of urban aviation is by no means simply an engineering challenge but a multidisciplinary endeavor, requiring the collaboration of aerospace engineers, urban planners, policymakers, and communities. By addressing the array of key factors, UAM can become a sustainable, inclusive, and transformative part of the future aerospace transportation system. Critically, this work is not intended as technocratic idealism, rather as a means for urban planners and designers to be informed and make better decisions than would be achieved by engineers or other technocrats, to ensure positive outcomes for society.

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