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WHITE PAPER

A Future with Autonomous Urban Air Mobility

Preparing Cities and Citizens

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Foreword

The Aviation Studies Institute, based at the Singapore University of Technology and Design, has been established to address the needs of aviation stakeholders and advance the development of aviation in the Asia-Pacific region. In this paper we focus on one of the much publicised yet still developmental dimensions of the industry: autonomous flight for urban mobility.

There has been growing attention to autonomous aircraft over the last year, with a greater industry push to make this new mode of passenger transport a reality – with a focus on proving new technology and establishing new markets. A significant amount of work has and continues to go into this area across industry and government agencies. The solution is not just about technology – there is a fundamental need to getting people onboard too. Autonomy in transport is not new either. There are plenty of autonomous transit systems in the world, but autonomous cars not yet mainstream.

We have commissioned this work to gain insights from previous research into autonomous ground vehicles to find out what lessons can be translated into urban air mobility and save re-discovery. This paper is produced by our colleagues from the Lee Kuan Yew Centre for Innovative Cities who have previously undertaken various research into the public adoption of autonomous ground vehicles.

We hope that you find the analysis and recommendations provided useful and thought provoking.

Mr Jamie Bloomfield

At the Aviation Studies Institute we are keen to utilise research to solve real-world challenges and work with industry partners to translate our outcomes into industry-wide capabilities. If we have capabilities you want to leverage, if there is an improvement you would like us to investigate, a partnership opportunity you would like to explore, or a way we can help aviation in Asia-Pacific to develop further, please get in touch:

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You can also find more details on our website: https://asi.sutd.edu.sg/

On behalf of the Aviation Studies Institute, Assistant Professor Nuno Ribeiro recently completed research into Airfield Management and Economics.

If you are keen to learn more about this work, please let us know.

Assistant Professor Nuno Ribeiro

Assistant Professor Nuno Ribeiro has an interest in developing and applying operations research methods, such as optimisation, machine learning and simulations to support the decision-making processes in transportation system management.

His work has received attention from academia and industry stakeholders reflected in several research awards, such as the Anna Valicek Medal by the AGIFORS in 2018, best PhD dissertation by INFORMS-AAS in 2019 and the best paper award by INFORMS-AAS in 2020.

Nuno received his Ph.D. in Transport Systems in 2019 from the University of Coimbra (Portugal). During his stints as a Ph.D. student, he also held visiting research positions in MIT and Carnegie Mellon University.

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Dr Samuel Chng

Dr Samuel Chng is Senior Research Fellow and heads the Urban Psychology Lab in the Lee Kuan Yew Centre for Innovative Cities at the Singapore University of Technology and Design. He is also Deputy Lead for the Future-Ready Society programme and leads the Insights, Implementation and Impact Evaluation Unit in the programme.

With the majority of the world's population residing in cities today, fostering urban lifestyles that contribute towards creating low-carbon, resilient, healthy and equitable cities become ever more critical. An applied social psychologist, his interdisciplinary work focuses on developing research-informed policies and initiatives to accelerate this transition in Singapore and the wider Asian region.

His research in the Urban Psychology Lab includes a focus on the perception and adoption of mobility-related innovations in cities, including autonomous vehicles and electric vehicles.

He is a firm believer in translating academic research and capacity building, and so actively collaborates with partners in government, industry, the labour movement and media in this endeavour.

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Merna Alzurikat

Merna Alzurikat is an Architect with six years of experience in the architecture and engineering field in Jordan. She has worked on a variety of projects, including healthcare, educational, and multi-use developments across the Middle East. Currently, Merna is a Research Assistant at the Lee Kuan Yew Centre for Innovative Cities (LKYCIC) and is pursuing a Master's of Science in Urban Science, Policy and Planning (MUSPP) at the Singapore University of Technology and Design (SUTD).

Prior to joining MUSPP, Merna was a core team member at the Jordan Space Research Initiative (JSRI). Together with the core team, she created a Roadmap for Jordan's participation in the Moon Village, focusing on Analog Missions for the Moon & Mars. This initiative led to the establishment of JSRI, with the goal of establishing an analog facility in Jordan to benefit life on Earth and align with national priorities.

Within JSRI, Merna was responsible for Community and Stakeholder Engagement, where she plans and implements projects, initiates partnerships with different educational institutions and private companies, and researches the benefits of space exploration in enhancing life on Earth. She also explored the intersection of smart city development and space technology, seeking innovative solutions to urban challenges.

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Executive Summary

Ground Transportation Systems in cities face various contemporary challenges, like traffic congestion, lack of space for the required infrastructure, pollution, and the frequency of accidents, this has ultimately led to the questioning of the system's efficiency and sometimes to its failure.

Urban Air Mobility (UAM) are innovative and disruptive technologies that offer a safer and more efficient solution to the existing traditional transportation systems in cities that emerged to cater to the contemporary needs of cities and address the prevailing challenges to eventually enhance the existing transportation services and ensure the efficiency of the urban mobility system.

Currently, ongoing global efforts are exerted towards the incorporation of UAM in cities as they transition towards the efficient utilization of urban airspace. From here arises the urgent need for well-thought-through plans and strategies for implementing and integrating these new mobility innovations in existing urban ground transportation systems.

These strategies should consider the gradual introduction of the technology into existing urban transportation systems to allow the different stakeholders to monitor, assess, and adapt to the different variables and risks emerging throughout implementation. More importantly, this would assist in building social acceptance and gradual familiarity with the technology.

To integrate UAM safely and efficiently into the existing urban transportation systems and network, it is necessary to identify and properly address the expected challenges for its smooth implementation.

The following challenges are identified for the integration of UAM into cities:

- As UAM technology advances, adapts to new variables, and adopts new systems and designs, regulatory frameworks and standards must be consistently re-evaluated and updated to respond to these developments.
- Complexity of operations, as UAM introduce new aerial vehicles to an existing crowded airspace and complex air traffic system.
- For the proper operation of the UAM vehicles, new specialized types of infrastructure need to be provided and incorporated in the city such as vertiports for take-off and landing of air vehicles, charging stations, and maintenance facilities.
- Highly dependent on socio-economic factors, and the acceptance of UAM by the public.
- UAM is expected to be disruptive and change existing urban transportation services dynamics and structures.

The latest development in UAM, autonomous technology is gaining prominence and has led to great interest in Autonomous UAM (UAM) and its potential to accelerate the introduction of UAM in cities. Much like the case with ground transportation systems, the UAM market is expected to initially be dominated by piloted aircraft, eventually leading to fully autonomous vehicles with advanced collision avoidance and real-time route maintenance capabilities.

However, as AUAM offers a potentially exciting new and sustainable mobility solution to cities, it is vital to understand the various urban situations and cases where AUAM could potentially be the alternative solution. The following roles, as identified in this paper, are where the potential of AUAM is highlighted:

- Cities have limited land available for urban expansion, a crucial resource for urban growth and development. As AUAM proposes the utilization of urban airspace for transportation, this would allow city planners to allocate less land area for new roads since AUAM does not require this type of infrastructure to function and thus provide more space for other urban features and functions and reducing the environmental impact of establishing the infrastructure.

- AUAM can have the flexibility to operate in a wide range of scenarios in the urban context. AUAM is expected to be used in different types of operations like emergency medical services, law enforcement, natural disaster relief, firefighting, tourism and entertainment, cargo delivery, passenger transportation (scheduled or on-demand), and sub-regional transport (between transport hubs, regularly to feed scheduled flights).

Based on identified similarities between AUAM and autonomous vehicles (AV; e.g., disruptive mobility innovations with high levels of autonomy that unlock new ways people transverse spaces), a few key transferrable learnings from the last two decades of AV research are brought to attention in this paper to speed up the learning curve of how AUAM could be successfully implemented.

- The need to foster trust and manage the differences between perceptions and reality.
- Presence of a layered mental model of autonomous mobility.
- Geographical differences increase the challenges of transboundary services.
- Identify who is most trusted to lead the development and implementation.

The integration of UAM and AUAM should, ideally, strengthen the seamless flow and uninterrupted connectivity of the transportation services provided within a city and between cities. Hence, Environmental, Socio-economic, Political, Safety and Security, Urban Planning, and Regulatory Framework considerations are discussed to ensure that this integration is possible.

The growing role of space technology in the field of urban planning in general and UAM in specific also highlights the mutual benefits in research and development in these adjacent fields and the natural cross-collaboration.

Ultimately, the successful implementation of UAM and AUAM relies heavily on the active participation and support of various communities and stakeholders. Open and transparent dialogue with governments, residents, businesses, and experts is crucial to addressing concerns, building trust, and tailoring UAM and AUAM solutions to meet specific community needs.

Key players and stakeholders for the emergence and integration of UAM and AUAM which is crucial for fostering collaboration and ensuring the efficient implementation of strategies and technologies are also identified and discussed.

While UAM and AUAM can potentially bridge gaps in the existing ground transportation networks unlocking different types of services and contributing to the interconnectedness of cities reaching remote areas that are underserved by traditional infrastructure, challenges in developing services that are accepted by the public remain.

Hence, this white paper recommends the development of a comprehensive user-centric strategy for preparing the public and cities for the testing and introduction of (autonomous) urban air mobility in cities.

This would require stakeholders from the public, private and academic sectors to collaboratively engage in research and development, as well as continuous dialogues when developing UAM and AUAM technologies and services that meet the needs of our cities and society.

Recommendations

Principal Recommendation

- Develop a comprehensive, user-centric strategy for preparing the public and cities for the testing and introduction of (autonomous) urban air mobility in cities.

Related Recommendations

- Address the current limited understanding of public acceptance and readiness for the testing and introduction of (autonomous) urban air mobility in cities with systematic investigations and engagements with lay citizens, community groups and relevant stakeholders.

- City and transportation authorities need to prepare an implementation roadmap for (autonomous) urban air mobility in cities.

- Technical requirements and standards, and operation parameters regulating the development of (autonomous) urban air mobility services in cities to ensure they do not negatively impact the quality of life in cities need to be developed to support the development of (autonomous) urban air mobility services by the industry.

Introduction – The Regional Landscape

As overground and underground Transportation Systems in cities face various contemporary challenges, negatively impacting the general comfort and affordability of the provided service, like traffic congestion, lack of space for the required infrastructure, pollution, and frequency of accidents, this has ultimately led to the questioning of the efficiency and sometimes to the failure of the system.

Hence, the need for innovative and disruptive technological solutions arises to cater to the contemporary needs of cities and address the prevailing challenges to eventually enhance the existing transportation services and ensure the efficiency of the urban mobility system as a whole.

Urban Air Mobility (UAM), where airspace is utilized for passenger travel and transportation of goods within the urban context, offers a safer and more efficient solution to the existing traditional transportation systems in cities.

This paper focuses on the Autonomous Urban Air Mobility (AUAM) solutions where unmanned aircraft are employed to address urban transportation challenges. It will also explore the various urban considerations that should be taken when integrating the newly introduced system into the urban fabric, like environmental, socio-economic, political, cyber security, safety, infrastructural, and urban planning considerations.

Illustration 1 - UAM: Urban Air Mobility Means A Safe And Efficient System For Vehicles, Piloted Or Not, To Move Passengers And Cargo Within A City

Source: NASA

However, UAM, in its manned and autonomous forms, is considered a relatively recent idea that is still under experimentation in urban development. Thus, only a limited number of case studies and previous research are available.

To understand and forecast how UAM and AUAM will impact cities, we need first to explore the potential behind adopting this novel technology and its implications on existing and future urban infrastructure, policies, and planning. The deployments of piloted aerial vehicles (e.g., helicopters) in urban settings as early as 2010, such as the helicopter transfers in New York City, are the earliest form of UAM (Cohen et al., 2021) that provide an opportunity to examine the early applications of UAM for learning.

Thus, this paper will focus on the potential role of AUAM in cities and discuss its opportunities and challenges when integrating into existing urban transportation systems and infrastructure, utilizing urban airspace, and supporting the development with the right policies.

As the developments and aspirations in UAUM parallel those of autonomous road transportation today, we will also seek to apply transferable learnings and lessons, particularly in managing potential conflicts between unmanned traffic and manned traffic and the public.

Overview of Urban Air Mobility

Introduction to Urban Air Mobility

Urban Air Mobility (UAM) is gaining prominence as a newly introduced transportation system utilizing urban airspace to transport passengers and cargo through safe, secure, and more sustainable manned and unmanned aircraft systems (European Union Aviation Safety Agency, 2024).

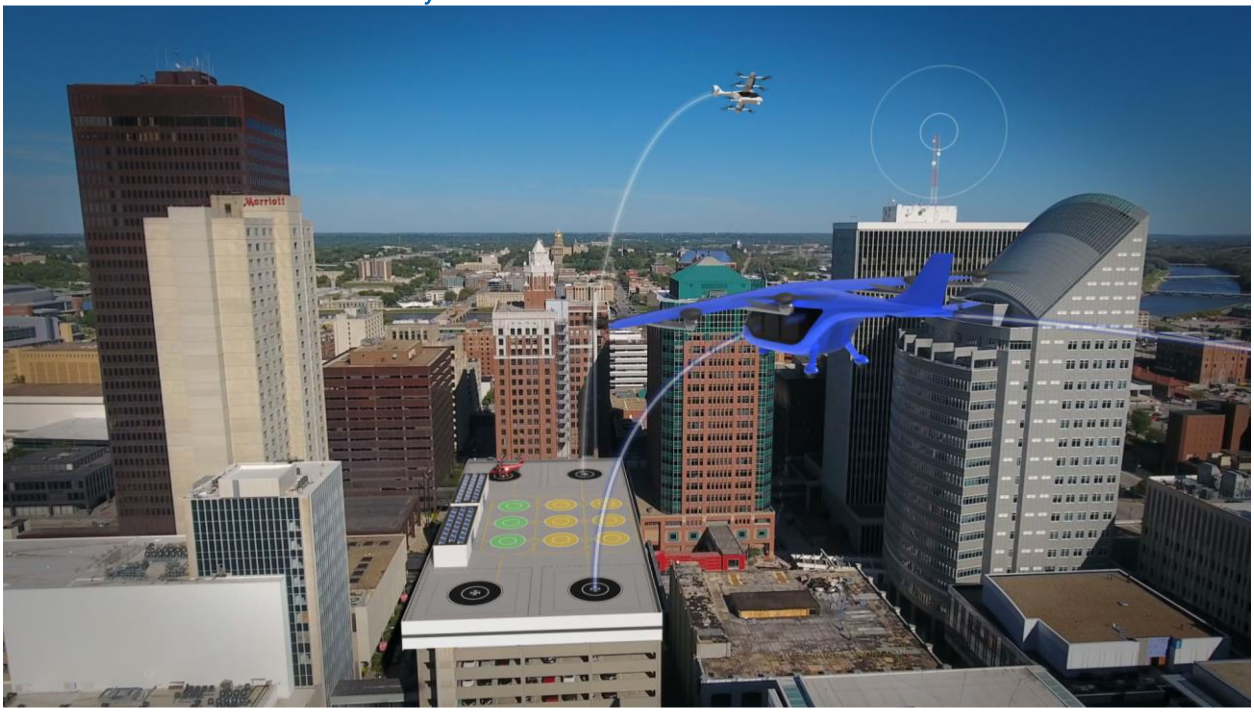
Enabled by new technologies and integrated into the existing ground and underground transportation systems, UAM is expected to increase the efficiency of the urban transportation system. This is achievable due to UAM's capacity to offer direct and rapid on-demand connections between urban locations, bypassing the limitations of ground infrastructure (Markets and Markets, 2023).

The novel transportation system, commonly performed by electric Vertical Take-Off and Landing (eVTOL) aircraft, a helicopter, for example, offers a combination of onboard/ground-piloted (manned) and increasingly autonomous (unmanned) operations (European Union Aviation Safety Agency, 2024; Markets and Markets, 2023), presents a sustainable opportunity and solution for urban travel as it employs electric propulsion systems, "reducing dependence on fossil fuels and minimizing greenhouse gas emissions" (Markets and Markets, 2023).

Currently, UAM is relentlessly under the research and development of multiple industry, academic, and governmental entities. These efforts hope to develop technological breakthroughs in automation, lightweight materials, and battery and energy management systems that will further contribute to creating a more sustainable urban air mobility system (Markets and Markets, 2023).

It is anticipated that once UAM is completely integrated into the urban transportation system and is fully operational, it will significantly alter how consumers and goods move within and between cities and enhance current levels of connectivity. UAM, when made available in a similar manner through ride-hailing apps such as Uber today, might also provide consumers with greater transportation alternatives, and provide faster point-to-point travel journeys at lower cost (Garrow et al., 2021).

Illustration 2 - Advanced Air Mobility Aims To Shorten Travel Time



Source: NASA

The Urban Air Mobility Market Report published by Markers and Markets in 2023 estimates that the UAM market will grow from USD 3.8 billion in 2023 to USD 28.5 billion by 2030, at a Compound Annual Growth Rate (CAGR) of 33.5% from 2023 to 2030. This shows the significant potential the UAM has as a new disruptive market to grow, driven by the need for fast and effective transportation as well as environmental concerns.

However, this raises the important question of whether cities and their citizens are ready for Urban Air Mobility. Even if the number of UAM original equipment manufacturers (OEMs) and operators are investing their resources to develop the technology and business, urban infrastructure, policy and planning have to be in place to support the successful growth and adoption of UAM in cities.

Adoption of UAM

Early adoption of UAM can be traced back to the 1940s in the United States where Vertical Take-Off and Landing (VTOL) vehicles, and helicopters at the time, were operated for commercial purposes within cities (Thipphavong et al., 2018).

From 1947 to 1971, Los Angeles Airways used helicopters to transport people and mail between locations in Los Angeles, including between Disneyland and Los Angeles International Airport. Also, from 1953 to 1979, New York Airways used helicopters to fly passengers between heliports in Manhattan and the three major airports in New York City (Newark Liberty International Airport [EWR], LaGuardia Airport [LGA], and John F. Kennedy International Airport [JFK]) (Garrow et al., 2021; Thipphavong et al., 2018).

However, both services Los Angeles Airways and New York Airways were suspended due to safety concerns after tragic accidents caused the death of many passengers as a result of mechanical failures in the helicopters (Garrow et al., 2021; Witkin, 1979).

This proved the need to urgently address challenges of the utilization of air vehicles for transport in the urban context and the necessity to further develop the technology before adopting this new solution to be safely operated in the urban airspace.

Amidst more efforts focusing on making the technology safer to operate in the urban airspace, more countries are rapidly advancing towards adopting UAM in their cities.

Currently, São Paulo, Brazil is already using air taxis for passenger transport (Bulanowski et al., 2023), 170 cities, regions, and states in 55 countries around the world are developing plans for Advanced Air Mobility (AAM) and Urban Air Mobility (UAM) aviation services, according to the latest edition of the Global AAM/UAM Market Map (News, 2023). In the USA, there are 46 city/regional UAM programs underway, 20 in Germany, 15 in China, and 13 in Brazil (Urban Air Mobility News, 2023).

This illustrates the ongoing global efforts applied towards the incorporation of this novel transportation solution in cities as they transition towards the efficient utilization of urban airspace. From here arises the urgent need for well-thought-through plans and strategies for implementing and integrating UAM in existing urban transportation systems, both above ground and underground. Several of such efforts are currently underway.

Cities in the European Union (EU) have adopted the strategy of gradually introducing UAM through multiple projects and initiatives focusing on a user-centric approach. The EU-funded project AURORA (sAfe Urban aiR mObility for euRopeAn citizens) has addressed the results of stakeholder involvement (Bulanowski et al., 2023) as it realizes the importance of community engagement as well as interdisciplinary and cross-organizational collaboration for the successful implementation of UAM. The project also suggested that public acceptance appeared higher for applications in health and safety domains, proposing that the integration of UAM could begin with emergency-related services (Bulanowski et al., 2023).

Similarly, the Urban Air Mobility Initiative Cities Community (UIC2) focused on engaging European cities in discussions to address the benefits and challenges of utilizing urban airspace (Bulanowski et al., 2023). Furthermore, EU cities are expected to initially integrate UAM through the delivery of goods using drones or the transport of passengers using piloted aircraft (European Union Aviation Safety Agency, 2024).

Illustration 3 - Advanced Air Mobility Aids In Healthcare

Source: NASA

Thus, it is essential to realize that strategies made for the integration of UAM in the urban context should carefully consider the gradual introduction of the technology into existing urban transportation systems. This can be achieved through early-stage stakeholder and community engagement activities, slow injection of air vehicles into the urban airspace, and initial limitation of UAM services to specific routes of air traffic and tasks performed.

These strategies would support the following:

- Allowing policymakers to test the newly issued regulatory frameworks for UAM and consequently adjust to new inputs in a timely manner.
- The emergence of well-planned and efficient new infrastructure while the existing infrastructure develops and adapts to meet the new loads.
- Allowing technology developers to assess the performance of their systems and designs in real scenarios and redevelop accordingly to meet identified variables.
- Allowing unforeseen risks to safely emerge while also providing the time required to assess and mitigate these risks.
- Indicating a more realistic market demand for the technology or service at an early stage of implementation.
- Building social acceptance and gradual familiarity with the technology.

All of which, are important factors that ensure the safe and effective adoption of UAM in cities, whilst also allotting time for the different stakeholders to adapt and adjust to the different variants and unforeseen conditions faced during operation and ultimately mitigating risks that could emerge as a result. However, the introduction and adoption of UAM in cities is not without its own unique set of challenges.

Challenges of Integrating UAM

As an emerging and disruptive transportation solution, and much like other new technologies employed in cities, UAM is facing many operational, technological, social, economic, environmental, and regulatory barriers (Bulanowski et al., 2023). To integrate UAM safely and efficiently into the existing urban transportation systems and network, it is necessary to identify and properly address these challenges by setting out effective strategies, plans, and frameworks that assist in the smooth implementation of UAM.

These challenges are summarized into the following:

1. Continuous development of the UAM technology

As UAM technology continues to advance, adapt to new variables, and adopt new systems and designs, regulatory frameworks and standards need to be consistently re-evaluated and updated to respond to these developments (Chomsky, 2023). Policymakers are therefore required to constantly monitor, assess, and revise the issued regulatory frameworks as well as to communicate and coordinate with the technology developers to keep up with development plans. This dynamic environment may result in delays in fully implementing UAM as well as may require a significant amount of resources.

2. Complexity of operations

The urban airspace is mainly used for the operation of traditional piloted aircrafts and helicopters. This presents a challenge for the integration of UAM as it is introducing new aerial vehicles to an existing crowded airspace and complex air traffic system. Thus, successful integration of UAM in the urban airspace will require high levels of coordination and the development of a new air traffic control system (Chomsky, 2023).

Furthermore, different operation systems of the UAM vehicles may exist at simultaneously in the same urban airspace, i.e. manned (pilot on board or remotely piloted from a ground station) and unmanned (onboard control system; Lourenço da Saúde & Maia, 2021), further contributing to the complexity of coordinating and regulating air traffic, and standardizing protocols.

3. Specialized infrastructure

For the proper operation of the UAM vehicles, new specialized types of infrastructure need to be provided and incorporated in the city such as vertiports for take-off and landing of air vehicles, charging stations, and maintenance facilities (Chomsky, 2023). These advanced technologies and infrastructure would also require a labour force and economy equipped with the requisite new types of skills and knowledge to design, construct and operate them.

4. Highly dependent on socio-economic factors

For the integration of the UAM services in cities to achieve its initial purpose of providing a more efficient and sustainable transportation solution, there must be user demand for this service. This demand is created only when citizens of the city have social acceptance of the technology and are willing to pay for such services in their city (Chomsky, 2023; Sengupta et al., 2023).

5. UAM as a disruptive technology

UAM is expected to have a disruptive nature that will change existing urban transportation services dynamics and structures (Smith, 2022). This has prompted companies and operators, both existing and new, to consider and experiment with UAM to gain first mover advantage in this new disruptive market. However, it is unclear how much and when UAM technology would realize this anticipated potential.

These challenges surrounding the implementation of UAM are significant but not insurmountable. Overcoming them would require close collaboration between industry stakeholders, government agencies, and the public (Chomsky, 2023).

In the latest development in UAM, autonomous technology is gaining prominence and has led to great interest in Autonomous UAM (UAM) and its potential to accelerate the introduction of UAM in cities.

Autonomous Urban Air Mobility (AUAM)

The concept of autonomy in technology is used to describe the machine's ability to make real-time decisions based on its surrounding environment as it utilizes artificial intelligence, sensors, and data analytics. Autonomy is widely used in the field of transportation and air mobility in particular is witnessing a revolution in autonomous transportation (Estrellado, 2023).

"Autonomous flight involves aircraft that do not have a pilot on board nor are remotely piloted from a ground station in non-segregated airspace. Rather, the aircrafts are exclusively controlled by onboard systems" (Lourenço da Saúde & Maia, 2021).

Much like the case with ground transportation systems, the UAM market is expected to initially be dominated by piloted aircraft, eventually leading to fully autonomous vehicles with advanced collision avoidance and real-time route maintenance capabilities (Sengupta et al., 2023).

Thus, the introduction of AUAM is thought to significantly improve the operational safety of UAM compared to (eVTOL) (Yang & Wei, 2020) as well as making it a more attractive choice for adoption in the urban context as AUAM can be applied to more use cases without the reliance on manned vehicles (Garrow et al., 2021).

Illustration 4 - Assured Vehicle Automation (AVA) - Hazard Perception And Avoidance

Source: NASA

Amazon Prime Air is testing autonomous delivery drones to revolutionize the logistics industry. These drones, designed to navigate through complex airspace autonomously, could significantly expedite the delivery of goods while reducing the carbon footprint (Estrellado, 2023), further showcasing the capabilities of adopting autonomous technologies for air mobility.

However, it is important to point out that social resistance might present a challenge to the adoption of this autonomous technology as members of the public might be concerned with boarding an air vehicle without a human pilot (Sengupta et al., 2023). Therefore, adopting a user-centric approach and building social familiarity with the technology through gradual implementation of AUAM as well as community engagement activities to build trust and public participation are essential for successful integration.

The Potential Role of Autonomous Urban Air Mobility

AUAM offers a potentially exciting new and sustainable mobility solution to cities, which could potentially address the perennial challenge of traffic congestion that most cities experience, amongst other promises. However, it is vital to understand the various urban situations and cases where AUAM could potentially be the alternative solution.

Utilization of Urban Airspace

Cities have very limited land available for urban expansion which is a very crucial resource for urban growth and development. This means that setting aside land for overground and underground transportation comes at an opportunity cost or may be constrained by the lack of available land.

AUAM proposes the utilization of urban airspace for transportation. The significance of utilizing this vertical space in cities cannot be overstated when land is highly sought after in cities and most often prioritized for a host of non-transport infrastructure and amenities including housing, industry, commerce and recreation.

The potential application of AUAM solutions for transportation in cities in this case, on different levels and scales of intervention, would allow city planners to allocate less land area for new roads since AUAM does not require this type of infrastructure to function and thus provide more space for other urban features and functions and reducing the environmental impact of establishing the infrastructure.

AUAM solutions could also be employed when transportation services are needed but where the construction of roads or traditional transportation systems is not possible or is too expensive. This can be due to certain existing natural limitations like harsh terrain and geographical features, or due to the presence of environmentally protected areas, locations that include heritage features, and historical ruins that should be conserved, thus, overground and underground intervention is not possible. From here arises the potential to consider addressing the connectivity needs using AUAM solutions that are relatively lighter in infrastructural requirements and more adaptable than traditional transportation options (Bulanowski et al., 2023).

Ultimately, utilizing the three-dimensional airspace for the integration of AUAM in cities maximizes the use of existing overground and underground infrastructure by meeting fringe mobility needs and taking on some demand from the traditional transportation system.

Operational Scenarios for AUAM

As a consequence of utilizing both autonomous technology (no human pilot on board) and urban airspace, AUAM can have the flexibility to operate in a wide range of scenarios in the urban context. AUAM is expected to be used in the following types of operations as identified by Lourenco da Saude and Maia (2021):

- Emergency medical services
- Law enforcement
- Natural disaster relief
- Firefighting
- Tourism and entertainment
- Cargo delivery
- Passenger transportation (vertiport to vertiport):
    - Scheduled
    - On-Demand
- Sub-regional transport (between transport hubs, regularly to feed scheduled flights):
    - Vertiport–regional airport

- Vertiport–international airport

It is important to note that the use cases and scenarios where AUAM illustrates high potential go beyond the above list as the technology matures. This potential essentially lies in the nature of its operation as it utilizes autonomous technology (no human pilots needed) and urban airspace.

AUAM has the potential to bridge gaps in the existing overground and underground transportation networks as it unlocks different types of services like emergency traffic, optimizes transportation infrastructure and services, and contributes to the interconnectedness of cities reaching remote areas that are underserved by traditional infrastructure.

Transferrable Learnings from Autonomous Vehicles

The introduction of AUAM is part of many countries' drive to digitalize and automate existing mobility services and technology on the way to becoming smart and sustainable cities. AUAM is latest of the full spectrum of transportation systems that are being digitalized and automated.

In the last two decades, many countries have been investing in the introduction of autonomous on-road vehicles (AVs). The last decade saw an increasing number of public trials currently underway for both the eventual deployment of AVs as private transportation and public transportation.

While AV technology has not yet matured, it is only a matter of time before the technology is ready for mass deployment. Thus, transport authorities and academics have been actively involved in research and public engagement to understand the perceptions and attitudes towards AVs and critical factors that will contribute to their successful implementation.

Given the similarities between AUAM and AVs (e.g., disruptive mobility innovations with high levels of autonomy that unlock new ways people transverse spaces), there are a few key transferrable learnings from the last two decades of AV research to speed up the learning curve of how AUAM could be successfully implemented.

1. The need to foster trust and manage the differences between perceptions and reality

Advanced autonomous mobility technology like AVs and AUAM is more likely than not to be foreign to most of the population even if they might have heard of them. This comes despite the increasing prevalence of automated features in vehicles (e.g., lane assist, cruise control) and the presence of automated trains in many cities today (Chng et al., 2021).

AV acceptance research suggests that the higher the level of vehicle automation, the lower the trust and acceptance of the autonomous technology even as greater extent of automation has the potential to improve safety through the reduction of human errors (Chng et al., 2021). This might seem counterintuitive and irrational but lay citizens seem to perceive that with greater automation, the technology gets increasingly difficult, complex, and thus potentially dangerous.

This concern is compounded by concerns surrounding potential safety concerns arising from interactions between humans, human-driven vehicles and autonomously-driven vehicles. However, it is likely that it is the lack of knowledge, experience and exposure to autonomous technology and uncertainty on how these autonomous technologies will be deployed that underpins this anxiety (Becker and Axhausen, 2017).

These highlight the need for further investigation into how trust and acceptance are related to the perception and understanding of automation and their deployment in vehicles on the road or in the air, and how automation should be communicated to citizens more effectively.

2. Presence of a layered mental model of autonomous mobility

Even as lay citizens might know little about autonomous technologies like AVs and AUAM, they often possess a multi-layered mental model of these autonomous mobility technologies that needs to be considered during development, trial and implementation (Chng et al., 2021).

At the core of this multi-layered mental model is the micro or individual-centric focus on the understanding, familiarity and perception of the technology. Issues such as the safety and reliability of autonomous technologies in AVs and AUAM will be key issues (Hulse et al., 2018).

The next meso level will see the individual focus on issues surrounding the implementation of autonomous technology. This concerns whether the individual is able to comprehend and envision how the technology might be deployed in their cities and what this development means for them. Arising questions for the individual would include: Does this improve my life in this city?

At the final, macro, level, individuals deliberate on the extra-personal impacts of the introduction of these autonomous technologies. This includes economic, social and environmental impacts and debates about who within society should oversee its development and implementation.

The presence of this multi-layered mental model highlights the need for a systematic and phased approach when introducing autonomous mobility innovations to the public, starting from enhancing individual knowledge and familiarity before introducing how they will be deployed to the benefit of the city and society.

3. Geographical differences increase the challenges of transboundary services

It is important to note that the perception and acceptance of autonomous technologies like AVs and AUAM will differ between cities even within a country, across countries and across regions. In addition, infrastructure and policy readiness would also differ. These have implications when planning for AUAM transboundary services that connect different cities or countries.

4. Identify who is most trusted to lead the development and implementation

For AVs, national governments were found to be the most trusted by lay citizens to lead the development and implementation of AVs in cities (Chng et al., 2021). This likely reflects the view that the government will safeguard citizens' interests with integrity while possessing the requisite authority to develop and set standards and regulate the technology (Hamm et al., 2019, Siegrist et al., 2000).

The industry sector (e.g., OEMs) is recognized to possess the financial motivation and technical expertise required to develop safe and effective AV solutions. Nevertheless, there are reservations about whether citizens' interests will be safeguarded or prioritized by this sector.

Similar views will likely be found for AUAM. Hence, governments should seek to instil confidence and trust in industrial developments AUAM through stringent regulation and oversight that serve to safeguard and promote the interests of their citizens.

Integration of (Autonomous) Urban Air Mobility

As a growing community of interest is forming for the concept of Urban Air Mobility, including NASA, Uber, Airbus, Honeywell, and many other entities around the globe, and as over a dozen companies, including Airbus, Bell, Embraer, Volocopter, and Aurora Flight Sciences, are building and testing their Electric Vertical Take-off and Landing (eVTOL) aircraft to make UAM and AUAM a reality (Yang & Wei, 2020), this new transportation solution may soon emerge as a viable transportation service in cities in the near future.

As the UAM market is expected to initially be dominated by piloted aircraft, it will eventually transition to be autonomous, leading to AUAM (Sengupta et al., 2023). To be successful, both UAM and AUAM will need to be integrated with the existing transport infrastructure in cities in ways that are acceptable to local communities while providing service levels that offer time savings over existing modes at a price point that individuals are willing to pay (Garrow et al., 2021).

The integration of UAM and AUAM should, ideally, strengthen the seamless flow and uninterrupted connectivity of the transportation services provided within a city and between cities. Hence, the following considerations that will be discussed next focus on key areas to focus on to ensure that this integration is possible.

Environmental Considerations

Energy Consumption

Most of the UAM aircraft are expected to be electrically powered (Sengupta et al., 2023), which means that during the operation of the aircraft, no local emissions are expected (Bulanowski et al., 2023), reducing the risk of environmental damage resulting from the newly integrated transport system.

As the integration of UAM aims mainly at reducing overground and underground traffic congestion, it will indirectly contribute to the decrease of local emissions resulting from ground vehicles and thus improve the general air quality in cities.

However, when compared to ground vehicles, the power requirements are expected to be much higher for UAM than ground vehicles due to the energy required to hover at a particular place (Sengupta et al., 2023) which also translates into a higher demand for electrical power.

Furthermore, it is essential to recognize the potential of UAM to further develop as a technology to incorporate sustainable energy solutions (Sengupta et al., 2023), some of the possible solutions may include:

- Considering sodium-ion battery-powered vehicles instead of lithium-ion to reduce the impact of lithium batteries and electronic waste of the aircraft on the environment.
- Utilizing solar polar to charge in route.
- Optimization of solar-produced energy through route planning to ensure that the shortest route with sunlight is selected.

Wildlife

As UAM aircraft will be travelling through the urban airspace, it is vital to understand the potential risks these aerial vehicles pose to birds when travelling through the same airspace specifically during migration seasons when numbers of birds in some cities’ skies evidently increase as flocks of migrating birds cross through it. This is important for the conservation of the existing global ecosystem. Any potential of accidents and collisions between aircraft and migrating birds would also inevitably pose safety risk to the passengers onboard the aircraft.

It is possible to mitigate these risks through further development of the aircraft's anti-collision and conflict resolution systems that would permit the autonomous vehicle to recognize the potential risk of collision mid-rout, and immediately reroute to avoid conflict.

This can also be mitigated when the migration of birds is monitored and tracked by specialist agencies within the city, according to which the traffic control system replans routes and reschedules journeys to avoid any potential disruptions.

Noise

Roads have always been a source of noise in cities since they host the urban ground transportation systems where sounds of honks, vehicles speeding up, engines revving, and collisions of accidents disrupt the sound quality of a city and produce noise. Shifting the transportation system into the urban airspace is expected to cause a similar impact through the production of noise resulting from vibrations and air movement due to the propelling force and speed of the aircraft.

To mitigate the impact of produced noise it is important to study the cityscape, identify and assess the existing factors, and understand the different impacts that noise can have on different parts of the city and thus employ UAM and AUAM accordingly. It is also essential to set out and enforce policies and regulations to control the speed and altitude of travel so that the aircraft can keep noise produced at acceptable levels.

Illustration 5 - NASA's Advanced Air Mobility Mission Investigates Noise

Source: NASA

Visual

The integration of UAM and AUAM in cities strengthens the city's image of being at the frontier of technological developments. However, too much air traffic can also result in the distortion of views in the city, this is specifically sensitive within residential areas.

Furthermore, the effect that aircrafts within the city's airspace would have on ground vehicles and pedestrians due to overshadowing which may cause the obstruction of vision is also an important aspect to consider when integrating UAM.

These can be mitigated through effective policymaking and planning of air routes and restricting the number of vehicles allowed in the urban airspace using advanced traffic control systems. However, a comprehensive assessment of the impact of the overshadowing of UAM and AUAM on the city should be conducted to construct elaborate implementation plans and strategies for the integration of UAM into the urban environment.

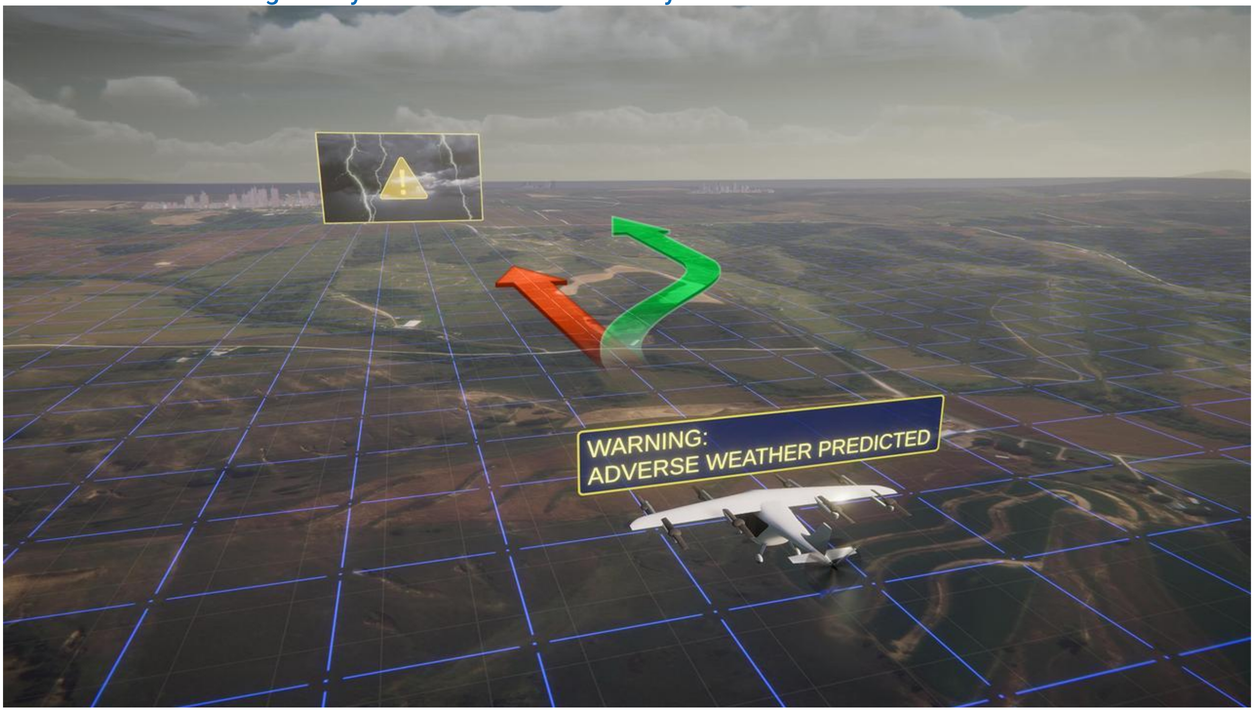
Weather Conditions

Accurate weather predictions are extremely important for the safe operations of UAM and AUAM in urban airspace (Sengupta et al., 2023). Unlike ground transportation, UAM and AUAM vehicles are particularly vulnerable to bad weather conditions. Visual distortions caused by fog, heavy rain, or snow can significantly impair onboard sensors and disrupt communication, increasing the risk of accidents.

Strong winds further heighten the challenge, potentially affecting flight paths and making controlled landings risky (NASA, 2020). In cases of storms, a need to temporarily suspend flights to protect both passengers and infrastructure can arise as per the traffic control system's evaluation of conditions and decisions.

Therefore, robust weather forecasting and real-time monitoring systems are crucial for the safe operation of UAM and AUAM as they operate close to people, buildings, and other air vehicles. Dynamic route planning capabilities that adapt to changing weather conditions will be essential, along with contingency plans for grounding or diverting flights when necessary.

Illustration 6 - Ensuring Safety For Advanced Air Mobility



Source: NASA

Socio-Economic Considerations

Whether UAM and AUAM become a truly disruptive solution in cities depends greatly on building familiarity with the technology with the public to acquire social acceptance and its affordability, particularly for the least resourced in society. The current concept of UAM and AUAM development depends on network design and the eventual cost of the service.

Given the potential for high operating costs and the need for specialized infrastructure, concerns arise about the accessibility of the novel air transport service for those with limited financial resources (Garrow et al., 2021).

To ensure this technology does not exacerbate existing social inequalities, intervention from the public sector may be necessary to make the service economically more accessible to the public (Bulanowski et al., 2023). This could involve subsidies, targeted voucher programs, or even public ownership of certain aspects of the UAM and AUAM network.

It is also essential to involve the public early on in discussions of integrating UAM and AUAM in cities. Similar to most cases that involve the introduction of a new technology, UAM and AUAM will likely be met with public resistance against its integration which can mainly be due to the lack of knowledge and familiarity with this new technology for the public and unspecialized persons.

Therefore, conducting public participation and engagement projects at the earlier stages of implementation of UAM and AUAM will essentially aid in raising awareness and familiarity of the emerging technology. Furthermore, the public will also be able to communicate their needs and concerns to the relevant stakeholders to ultimately assist in providing user-centric UAM and AUAM services (Bulanowski et al., 2023).

Political Considerations

The open nature of the urban airspace presents unique challenges for UAM and AUAM integration. Unlike ground transportation with its defined lanes and borders, the lack of visible boundaries necessitates a robust and precise monitoring and traffic control system to ensure safe and orderly operation.

Slight deviation out of the planned route of the urban airspace cannot be tolerated, requiring advanced algorithms and communication protocols to prevent mid-air collisions. Furthermore, airspace sensitivity must be taken into account. Concerns regarding national security and privacy may demand special permissions for specific aircrafts to fly in certain areas, particularly those overlooking private properties or sensitive military zones.

Additionally, an advanced identification system for foreign aircrafts is crucial to maintain national security and prevent unauthorized intrusions into restricted airspace. Addressing these complexities head-on through technological advancements and regulatory frameworks will be key to safeguarding all stakeholders within the urban airspace.

Cyber Security Considerations

UAM and AUAM will inevitably face concerns regarding cyber security and data protection given the connected and automated nature of the technology. The highly interconnected nature of the newly introduced system, from pilot systems to passenger data, makes it vulnerable to manipulation and unauthorized access. Thus, continued development of technology and safety systems is crucial to mitigate risks of data breaches through intrusion detection. Additionally, precise cybersecurity protocols and data protection regulations need to be implemented to shield against cyber-attacks that will directly affect the in-flight operations of the vehicles, which will lead to safety concerns.

Safety Considerations

Accidents in urban airspace are likely fatal since they happen mid-air at high altitudes and the failure of the piloting system could lead to a risky impact on the ground. Thus, conflict prevention systems in the aircraft should be further developed to reduce the possibility of a collision, also airspace sectorization (a concept widely used in commercial aviation) for which a controller has Air Traffic Control Responsibility over the urban airspace can assist in preventing accidents (Yang & Wei, 2020). This would also require the city to further develop its adopted technologies and safety systems, employed towards emergency responses involving UAM and AUAM vehicles.

Urban Planning Considerations

The seamless integration of UAM and AUAM with existing overground and underground transportation systems is crucial for its success. This requires defining specific operating altitudes within urban airspace, considering zoning regulations and building heights.

Recognizing the diverse functions of urban spaces, vertiports and hubs could emerge as new urban central points, driving urban development around them. The allocation of dedicated mobility space in the sky allows for efficient transportation without impacting road design, potentially leading to reduced traffic congestion.

However, the integration of UAM and AUAM also necessitates additional infrastructure, including hubs and charging infrastructure. The impact of this infrastructure will depend on factors like density, location, and design of these hubs, requiring careful planning to ensure minimal disruption and maximize community benefits (Bulanowski et al., 2023).

Zoning

Utilizing the urban airspace requires strategic land use and zoning practices, aiming to optimize air traffic distribution. This approach involves designating higher air traffic volumes in commercial and recreational zones while minimizing or eliminating flights over residential areas, which typically serve as quieter and safer zones to maintain privacy and safety standards.

Moreover, governing the altitude of travel within the urban airspace should consider zoning regulations and building heights, ensuring compatibility with the existing physical conditions and urban infrastructure. Each zone's unique requirements regarding privacy, altitude, traffic management, air routing, and proximity to transportation hubs should be carefully identified and addressed.

Integrating UAM and AUAM presents an opportunity to utilize existing overground and underground transportation terminals and stations, expanding public transportation options to include UAM and AUAM services. Additionally, exploring the potential of utilizing rooftops, particularly of high-rise buildings, as take-off and landing hubs for UAM and AUAM operations further enhances the efficiency and accessibility of urban air transportation (Sengupta et al., 2023).

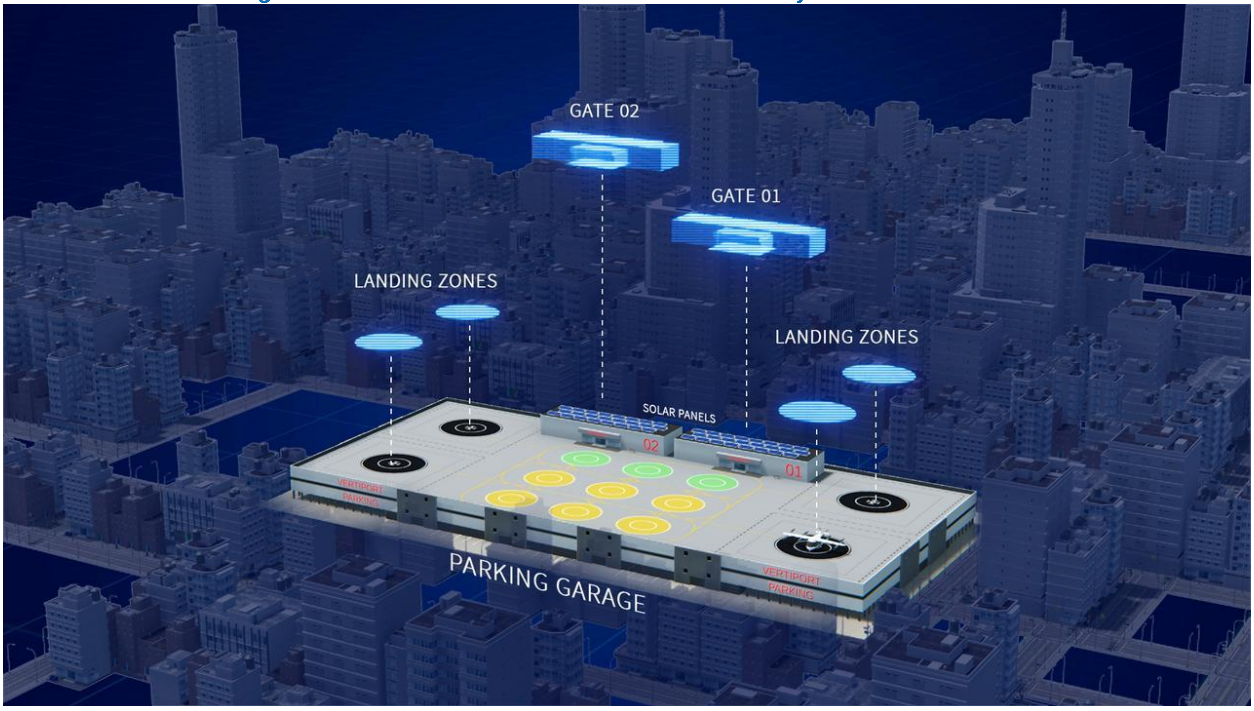
Infrastructure

While UAM and AUAM boasts the potential to revolutionize transportation by eliminating reliance on traditional road infrastructure and utilizing the full potential of urban airspace, its successful implementation depends on the availability of infrastructural support. This encompasses not only the physical vertiports (take-off stations) and landing pads but also the seamless integration with existing transport systems, provision of charging points, transport hubs, and technological infrastructural support as well.

A strong and reliable telecommunication network, incorporating internet access with high-speed data transfer capabilities, is vital for smooth operation as communication systems for air traffic control and conflict resolution systems for example are highly reliant on stable uninterrupted telecommunication service support. This necessitates thorough planning and collaboration between technology providers, city planners, and transport authorities.

Additionally, the specialized skills required to operate and maintain the complex UAM and AUAM ecosystem require focused investment in training programs to ensure a qualified workforce ready to receive this new urban mobility solution. Establishing a strong and comprehensive infrastructure development is a priority for the successful integration of UAM and AUAM into urban environments.

Illustration 7 - Building The Infrastructure For Advanced Air Mobility



Source: NASA

Smart Cities

The potential for integrating UAM and AUAM within smart cities lies in aligning with the needs, operations, and existing infrastructure of a smart city. Both the integration of UAM and AUAM and smart cities into pre-existing urban landscapes share multiple similarities in terms of the necessary infrastructure and considerations for operation. Common infrastructural elements include robust telecommunication network services, comprehensive cybersecurity, and data protection frameworks, as well as the essential knowledge and skills for implementation.

Additionally, community participation and engagement are vital for the social acceptance of both UAM and AUAM and smart city initiatives. Therefore, working towards the advancement of one concept essentially supports the other. Smart cities are well-positioned to seamlessly integrate UAM and AUAM services, facilitating efficient and sustainable urban transportation solutions for the future.

Urban Airspace Division

Airspace Division is an operational approach widely used in commercial aviation to deal with the high demand for aircraft traffic (Yang & Wei, 2020). Integration of UAM and AUAM in the same airspace as other existing aviation services in the city will require UAM and AUAM to adopt the same operational approach.

The International Civil Aviation Organization (ICAO) divides airspace into Classes A-G, with different classes serving commercial and general aviation needs. Compliance with regulations necessitates communication with Air Traffic Control (ATC) before entering controlled airspace. Class F airspace is designated 'uncontrolled' but may still receive ATC assistance (Lourenço da Saúde & Maia, 2021; Thipphavong et al., 2018).

UAM and AUAM operate within urban environments, avoiding Class A airspace (above 18,000 ft) due to its unsuitability for UAM craft. Instead, UAM operations occur in Class E or G airspace, with communication to ATC optional under Visual Flight Rules (VFR). In areas near airports, UAM may navigate within Class B, C, or D airspace, depending on factors like location and constraints (Lourenço da Saúde & Maia, 2021; Thipphavong et al., 2018).

Illustration 8 - Advanced Air Mobility Looks Ahead To Automation

Source: NASA

Phasing

Strategies made for the integration of UAM and AUAM in the urban context should carefully consider the gradual introduction of the technology into the already existing urban transportation system. This allows the time for the urban development to adjust and incorporate changes more safely and contextually. Below are the different phases of the maturity of UAM operations (Thipphavong et al., 2018):

- Emergent UAM operations: Characterized by low-tempo, low-density flights along a small set of fixed routes between a few take-off and landing sites.
- Early expanded UAM operations: Characterized by higher-tempo, higher-density flights in a small network of vertiports feeding a common hub location and managed by UAM operators and third-party services.
- Mature UAM operations: Characterized by high-tempo, high-density flights in a network with multiple hub locations.

Regulatory Frameworks Considerations

Effective regulation of air traffic, incorporating enforcement of laws governing aircraft speed and altitude, is a fundamental requirement for achieving the initial objectives of integrating UAM and AUAM into urban transportation systems.

This requirement highlights the commitment to fostering sustainability, enhancing safety, and optimizing efficiency for the UAM and AUAM systems. Moreover, standardizing services and establishing national and international guidelines for air route design play pivotal roles in ensuring the safety and efficiency of UAM operations.

The European Aviation Safety Agency (EASA) has taken proactive steps in this regard, as evidenced by its plans to develop guidelines for UAM and AUAM route design, aimed at fostering common principles, operational concepts, and best practices while accounting for regional nuances. These efforts, slated for publication in

2024, reflect a concerted push towards harmonizing regulations and enhancing safety standards within the burgeoning UAM and AUAM industry (Butterworth-Hayes, 2024).

Furthermore, the issuance of certificates and permissions for flight operations has critical importance as to exercise better control and oversight over UAM and AUAM activities, thus sustaining safety and regulatory compliance.

The Growing Role of Space Technology

Space technology plays a pivotal role in shaping urban development and monitoring patterns, utilizing satellite imagery and earth observation to provide valuable insights. Recognising this role, there is a growing realization among space agencies of the intersection between space and urban development.

For instance, NASA's Aeronautics Research Mission Directorate (ARMD) has expanded its research focus to include AUAM and Advanced Air Mobility (AAM), highlighting the importance of autonomous concepts initially developed for space exploration in addressing challenges on Earth (Gipson, 2017).

NASA's efforts in UAM and AUAM airspace integration emphasize an active approach, highlighting the importance of cross-collaboration and learning within the UAM community. This collaborative approach aims to refine concepts for both emergent and mature UAM operations and develop the necessary technologies and procedures (Thipphavong et al., 2018).

Satellite technology, integral to telecommunication services, urban planning, and urban development, aids in analysing land use patterns, disaster management, accurate prediction of weather conditions, and optimizing transportation systems through real-time monitoring and tracking. Moreover, it facilitates seamless connectivity and navigation support, enhancing coordination among the different UAM vehicles in the urban airspace.

To fully harness the potential of space technology in urban development, deeper collaborative efforts between governments, space agencies, and technology providers going forward will be essential.

Key Stakeholders for Autonomous Urban Air Mobility

The successful implementation of UAM and AUAM relies heavily on the active participation and support of various communities and stakeholders. Open and transparent dialogue with governments, residents, businesses, and experts is crucial to address concerns, build trust, and tailor UAM and AUAM solutions to meet specific community needs.

This collaborative approach fosters a sense of ownership and ensures that the benefits of UAM and AUAM are equitably distributed, paving the way for a smooth transition and a thriving urban future.

Identifying key players and stakeholders for the emergence and integration of UAM and AUAM is crucial for fostering collaboration and ensuring the efficient implementation of strategies and technologies. It is also vital to understand each stakeholder's distinct roles at various stages of AUAM's introduction into the urban environment.

Furthermore, this understanding facilitates the development of more efficient plans, enables the assignment of tasks, and determines the appropriate phase for involving each stakeholder.

The table below illustrates the identified stakeholders for the integration of UAM and AUAM and their roles and contributions to the technological development.

Table 1 - List of Identified Stakeholders

List of Stakeholders	Type	Role/Task
Governments	Adoption	Adaption of technology within the urban airspace
		Implementing Public transport solutions
		Integration into ground transport systems
		Conducting community engagement activities (i.e., provide training to acquire skills, and ensure public participation)
	Operational	Operation of technology within the urban environment by providing Air Traffic Control (ATC) services
		Collaborating with the private sector and investors on projects for the integration of technology
		Determining guidelines and requirements for the design and implementation of the technology
	Regulatory	Issuing of new regulations and laws
		Law enforcement through providing proper surveillance and punishment schemes
		Implementing ATC services
		Data protection and management
		Setting of control measures
	Policies	Policymaking to mitigate challenges related to environmental, social, economic, security, and safety aspects
	Planning	Integrating technology requirements within the urban fabric through the adoption of novel planning methods, strategies, tools, and concepts for implementation
	Public Safety	Readiness for emergency response to disasters, accidents, and emergencies
Private Companies	Investment	Funding of technology research and development as well as manufacturing
		Driving innovation and competition
	Adoption	Providing services to the end users and other entities through the application of operational scenarios of the technology
		Conducting community engagement approaches
		Integrating safety and security measures
		Collaborating with Governments and other Public and Private companies
		Commitment to data protection and compliance with regulations and standard
Technology Developers	R&D	Receive feedback from technology operators and users
		Design solutions to counter challenges
		Direct contact and collaboration with manufacturers
Technology Manufacturers	Manufacturing	Manufacturing and assembling of technology
		Commitment to achieving design goals that also meet standards
System Integrator	Supplying	New needs introduced would lead to the emergence of a gap in meeting demand
		New skill sets introduced
		Network, communication, and control needed for the operation of technology
End Users	Consumption	Passengers of public transport
		Personal data sharing
		Engagement and participation to ensure user-centric product and services
		Acceptance of the technology and willingness to pay
	Adoption	Use as private vehicles (would require skills and supportive regulations)

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