# TECHNOLOGY REQUIREMENTS FOR THE DEVELOPMENT OF AIRCRAFT FOR URBAN AIR MOBILITY – STATUS QUO

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### Abstract

Urban Air Mobility (UAM) refers to the transportation of people and goods using vertical takeoff and landing (VTOL) aircraft in urban areas. It is seen as a potential solution for the increasing traffic congestion and transportation challenges in cities. The concept of UAM involves a network of skyports, where passengers can transit between ground-based transport, such as cars and trains, to VTOL aircraft. This has the potential to provide faster and more efficient transportation, while reducing greenhouse gas emissions and noise pollution. Despite its potential benefits, UAM faces various regulatory and technical challenges before it can be widely adopted and integrated into existing transportation systems. Due to the operating conditions for urban aircraft being fundamentally different from the existing mature ones such as passenger airplanes, important aspects for their development need to be considered. The research from this paper explores the major high- and low-level technology requirements for achieving airworthiness of urban aircraft. From the selection, five main requirements for successful aircraft operation in urban airspace have been condensed. These are safety, scalability, performance, cybersecurity, and interoperability. The research shows that the success of UAM relies on the development of innovative technologies to design and manufacture aerial vehicles that are safe, efficient, and sustainable. Regulators must also establish a clear legal framework for the certification of aerial vehicles and operators, ensuring safety, security, and interoperability.

## 1. INTRODUCTION

Urban Air Mobility (UAM) is a fast-evolving concept that has gained significant attention in recent years. The idea behind UAM is to enable air transport within urban areas, allowing people and goods to travel quickly and efficiently while reducing congestion on the ground.

The concept of UAM has its roots in the early days of aviation. In the late 19th century, early pioneers of aviation, such as the Wright Brothers, experimented with different forms of aircraft that could fly short distances. The first commercial air service started in 1914 when a biplane flew a route between St. Petersburg, Florida, and Tampa, Florida. It was around that time when the idea of *flying cars* (Ref. 1) surfaced. Examples of such flying cars are the Ford Flivver from the 1920s, the Aerobile from 1937, or the Airphibian from the 1940s. Many of the early efforts to develop hybrid planes failed because of fatalities (Ref. 2) and lack of funding (Ref. 3, 4). Initially funded by the Canadian Government, the Avrocar is considered the first early vertical takeoff and landing (VTOL) aircraft designed for military use. However, it was abandoned due to high costs. In 1958, the U.S. Army and Air Force took over the project, but the flying-saucer-shaped aircraft faced thrust and stability problems. As a result, the project was terminated in 1961 (Ref. 5). None of these early concepts of urban aircraft achieved commercial success.

From the 1950s until the 1980s, a number of operators began offering UAM services using helicopters in various cities including Los Angeles, New York City, and the San Francisco Bay Area. For example, New York Airways began providing passenger service between Manhattan and LaGuardia in the mid-1950s. These early passenger helicopter services were made possible through a combination of helicopter subsidies, which were terminated in 1966, and airmail revenue in the United States (Ref. 6). Over the next few decades, aircraft designs advanced as technology improved, leading to the development of more mature VTOL aircraft and other novel forms of flying vehicles.

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The concept of UAM, as we know it today, emerged in the early 2000s with the adoption of drone concepts into novel aircraft for cargo and passengers (Ref. 7). As the technology improved, drones began to be used for a wide range of applications, including aerial photography, agriculture, and search and rescue. Around the same time, increased urbanization and population growth led to rising traffic congestion in cities worldwide, leading researchers and transport providers to consider using drones and other aircraft to provide transport services within urban areas. In 2017, the US Federal Aviation Administration (FAA) established the Unmanned Aircraft System Integration Pilot Program (IPP), which sought to explore the feasibility of integrating drones and other UAM vehicles into existing transport infrastructure (Ref. 8). This program was followed by numerous governmental initiatives around the world, e.g. Ref. 9, 10, aimed at utilizing the potential of UAM in providing efficient and sustainable public transport in urban areas.

Since then, many companies, including Uber, Boeing, and Airbus, have entered the UAM market, investing heavily in the development of VTOL vehicles (Ref. 11, 12). These vehicles use advanced electric propulsion systems, which offer several advantages over traditional aircraft, such as reduced noise pollution and fewer emissions. As the technology continues to advance, UAM could soon provide a fast, efficient and sustainable transport solution for people and goods in urban areas.

Today, UAM is defined "as an air transportation system for passengers and cargo in and around urban environments [...], offering the potential for greener and faster mobility solutions" (Ref. 13). Several whitepapers by Volocopter (Ref. 14), TTI TE Connectivity (Ref. 15), the National Aeronautics and Space Administration (NASA) (Ref. 16) and others (Ref. 17–19) have been published over the last few years, illustrating the topicality of UAM in this day and age. However, there are certain requirements which need to be met in order for UAM to be a certifiable and acceptable means of transport for the public.

The remaining work is structured as follows: In chapter 2, the status quo and research developments for UAM are discussed. In the main part, chapter 3, five major technology requirements for the development of UAM are presented. The requirements and their implication in UAM are discussed in chapter 4, before the paper is concluded in chapter 5.

## 2. RELATED WORK

Related work regarding the requirements for next-generation avionics in UAM is sparse. As the technology is just now starting to thrive, mostly high-level requirements and constraints, such as social acceptance and infrastructure regulations are discussed in current publications.

Two important publications discussing the status quo and current research in UAM are from Straubinger (Ref. 20) and Pons-Prats (Ref. 21). In her paper, Straubinger provides a comprehensive overview of various aspects related to UAM. The paper covers topics such as concepts of operation, market actors, integration into existing transportation systems, and UAM transport modeling and simulation. Overall, Straubinger provides valuable insights into the current state of UAM research and highlights the challenges and considerations involved in its implementation. Pons-Prats shows the need for new mobility concepts and UAM as disruptive technology filling this need. The authors discuss the importance of technological advancements, particularly in batteries and electric and distributed propulsion systems. Technological advancements facilitate the design of novel aircraft types with VTOL capabilities. The paper mentions challenges to the deployment of UAM. However, these challenges are not further specified.

The authors of the paper Ref. 22 present an analysis of the operational constraints that may affect the implementation and scale-up of UAM services in Los Angeles, Boston, and Dallas. The objective of the study is to identify potential challenges and limitations that could impact the growth and viability of UAM systems. Five major overarching constraints were identified. The constraints indicate that proposed UAM operations may face similar hindrances as the previous helicopter air carrier operations despite advancements in technology and business models. Examples for such hindrances are safety issues and rejection of access to saturated airspace.

The paper Ref. 23 by Reiche explores the advancements and potential applications of UAM systems for passenger and air cargo transportation within urban areas. It discusses the challenges and potential barriers related to adverse weather conditions and provides a weather analysis methodology used to develop a climatology for UAM operations. It highlights the need for further research and analysis to identify potential weather barriers and their effects on safety, cost, and efficiency in UAM operations.

In Ref. 24, Stelkens-Kobsch and Predescu from the German Aerospace Center (DLR) emphasize the need to address security concerns in the development and implementation of UAM systems. The paper highlights the harmonization of different states' legacy approaches to enable a seamless flow of traffic and the inclusion of various types of vehicles in controlled airspace. The main focus with the security task of the project is on identifying primary and supporting assets, listing threats, and identifying vulnerabilities that could be exploited in urban airspace.

Athavale et al. discuss the chip-level considerations required to enable dependability for VTOL and UAM systems in their paper (Ref. 25). It covers the critical drivers in future mass-produced VTOLs, the integration of modern commercial off-the-shelf computing and communications technology, and the impact on air traffic control systems and UAM avionics. The conclusion of the work states that advancements in Artificial Intelligence (AI) and communications technologies, along with functional safety strategies, are making it possible to enable capabilities for VTOL and Urban Aircraft Systems (UAS). The core of any VTOL operation is an efficient, safe, secure, scalable, and cost-effective air traffic control system.

Much of the presented literature either covers high-level requirements or specific technologies required for UAM operations. Some examples are high-level security concerns, operational constraints, and integration into existing transportation. The paper at hand makes a contribution to the research field of UAM by compiling a broad but precise spectrum of technology requirements for supporting aircraft operation in urban airspaces.

## 3. REQUIREMENTS FOR URBAN AIR MOBILITY OPERATIONS

Requirements for UAM systems can be categorized into five points. A large part, which will especially be relevant for certification, are safety guarantees. There are several safety considerations which aid in tackling safety concerns. Further, the systems need to scale well with different types and sizes of aircraft. This especially applies to the performance of the aircraft regarding their avionics architecture. A modular avionics design facilitates their application in different types of aircraft. Likewise, aircraft need to have interoperability in the complex system of systems information web for collision avoidance and air-ground communication. This information web is located in an urban environment near ground stations which leads to heightened security concerns. These conditions make aircraft operating in urban environments particularly susceptible to attacks. The five requirements safety, scalability, performance, interoperability, and cybersecurity will be discussed in more detail in the next subsections. At the end of each subsection, the particular requirement that needs to be met to achieve airworthiness for UAM is defined in the form of a recommendation.

### 3.1. Safety

Safety in the domain of aviation can be defined as the state of being safe from harm or danger during the operation of an aircraft. Safety is a significant factor in the development and use of aircraft. The aviation industry remains the leading force in driving rigid safety standards for transportation. Some recent reports covering the topic are Ref. 26–28. The operating conditions of UAM systems give additional significance to the discussion of safety. The current industry vision is for UAS to operate in urban airspace which is crowded, accompanied by a high frequency of passengers, and which requires increased takeoffs and landings, as partly discussed in Ref. 22.

Some of the challenges in terms of safety for UAM are discussed in Ref. 6, 29. Specifically the question emerges how new technology concepts for UAM, such as simplified flight controls or automated subsystems, can be assessed for safety. The aircraft systems covering the aircraft itself, the pilot, flight controls, avionics, and so forth need to be evaluated with new integrated evaluation methods. UAS are envisioned to operate along with the full range of manned and unmanned aircraft currently found in the airspace, possessing different capabilities and operating under specific rules (Ref. 30). In addition to the high-density traffic scenarios, fully automated AI-based applications and ground segment events with direct impact on the flight operations will assume a role in UAM. In Ref. 31, EASA proposes a general qualitative approach from Annex C and Annex D of their Specific Operations Risk Assessment to tackle the lack of safety data and field experience for manned and unmanned aircraft operated in the U-space[1] airspace. According to Ref. 32, however, these methodologies currently do not suffice to cover safety assessments for the operational domain and previously mentioned operating conditions.

Specific examples for operating challenges of UAS are for instance their restrictions to limited airspace, as described in Ref. 33. Aircraft cannot enter forbidden airspace, which could, for instance, be avoided with geofencing. The limited space in urban areas alongside the crowded airspace will make precise and safe fencing of aircraft a challenging task. Another example is the heavy influence of weather conditions on the motion stability of UAM technologies such as VTOL, as discussed in Ref. 34. The authors stress the necessity of thorough testing for safety certification of future UAM technologies. Ref. 35 suggests that operational certificates for UAS operating under low or moderate airspeed conditions will be carried out similar to the 14 CFR Part 135 certification (Ref. 36). Methodologies aiding in the testing and certification process for UAM technologies are for instance scenario-based testing and the precise definition of the systems' adaptive operational design domain (Ref. 37). Regulatory frameworks for the certification of safe and airworthy UAS are still in their infancy. The earliest rules for operation of urban aircraft have been published by EASA in June 2022 in their Notice of Proposed Amendment (Ref. 38). The regulatory framework for the operation of drones covers objectives to "ensure a high and uniform level of safety for UAS subject to certification [...]" and "enable

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[1] As defined by the European Comission: "U-space is the European term used for Unmanned [or Urban] Traffic Management (UTM), a set of new services relying on a high level of digitalisation and automation of functions, and specific procedures designed to support safe, efficient and secure access to airspace for large numbers of drones."

operators to safely operate manned VTOL-capable aircraft [...]". Other publications from regulatory organizations for aviation, such as Ref. 39 from the International Civil Aviation Organization or Ref. 40 from FAA, can be seen as more general guidances. Other noteworthy documents are EASA's means of compliance with VTOL (Ref. 9) and commission implementing regulations 2021/664, 2021/665, and 2021/666 (Ref. 41–43) with requirements for the air traffic management and manned aviation operating in U-space airspace. With increasing maturity of UAM, more regulatory frameworks with safety and certification considerations can be expected.

In the context of safety, UAM shall adhere to a comprehensive set of regulations and guidelines to ensure the highest level of safety for passengers, operators, and the general public.

## 3.2. Scalability

Scalability refers to "the ability of a system to maintain its performance and function, and to retain all its desired properties when its scale is increased greatly, without causing a corresponding increase in the system's complexity" (Ref. 44). To operate UAS, scalability is a vital aspect that aircraft operators need to consider. As demand grows, they must quickly and proficiently scale up their operations, which involves expanding the fleet, infrastructure, air traffic management systems, and logistical aid to ensure smooth operations. UAS are designed to thrive in densely populated urban areas with high traffic volume, which poses a challenge in handling numerous flights and passengers while maintaining safety and efficiency.

Architecturally, common system components of future UAM systems need to scale well with different aircraft types. Envisioned are UAM systems which serve different purposes. Examples are urban air taxis or urban medical aircraft. These aircraft have different capabilities, nevertheless, safety requirements should be applicable to all of them, independent of their size and functionality. Two of NASA's concept aircraft are shown in Figure 1 as reference. The Tiltduct (left) and Multi-Tiltrotor (right) vehicles are fundamentally different aircraft. Nevertheless, the systems components and the aircraft themselves need to scale well in the urban environment they operate in. Solutions for the avionics architectures shall be effective in the sense that the required functionalities for UAM can be achieved. At the same time the systems are under the constraint of efficiency in the sense that the execution of functionalities is performant independent of the type of application.

Standardizing the necessary safety regulations and certifications for different UAS with highly variable operational scenarios to achieve the technologies' airworthiness can pose a challenge. Current safety standards applicable to conventional aircraft assume relatively mature and consistent operations and procedures. The environment for future UAM technologies, with an increased density of aircraft and potentially unforeseeable flight scenarios, requires a precise and partially new definition of standards.

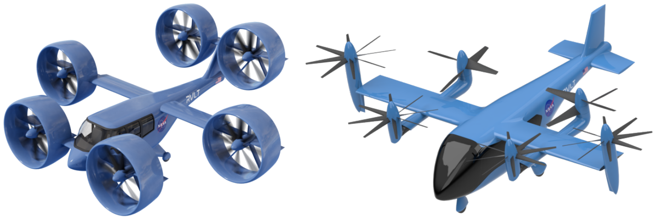

Figure 1: Selection of NASA's concept aircraft for UAM (Ref. 45)

Some of the challenges for pilots operating with UAM technologies are presented in Ref. 46. With the introduction of automation systems such as AI-based applications for autonomous flight, personnel operating future UAS face additional load during system operation. In addition, operating different aircraft with changing operational conditions will add to the operational complexity and make scalability in terms of system utilization harder.

In the context of scalability, UAM shall possess the capacity to seamlessly accommodate a significant increase in demand and effectively handle a growing number of users, infrastructure, and services without compromising safety, efficiency, or overall performance. This includes the ability to efficiently scale up operations, infrastructural support, and technological capabilities in order to meet the evolving needs of an expanding urban air transportation system.

## 3.3. Performance

Performance refers to the resource-efficiency of UAS for their intended use and its implication in the type of systems used for propulsion, computation, and so forth. A significant issue for discussion for applications such as urban air taxis is the economy within their scope of application. An example is the avionics system, which plays a crucial role in the development of performant UAS. Distributed Integrated Modular Avionics (DIMA) architectures pose the preferred choice for avionics systems in UAS. DIMA is an avionics architecture concept in which several processing nodes are placed throughout an aircraft. Each processing node is responsible for specific functions and communication with other nodes which are integrated via a high-speed digital network, typically an avionics full-duplex switched Ethernet (AFDX) network. Not only their high performance in the scope of function execution but also the decreased number of required components and therefore reduction in weight makes DIMA favorable (Ref. 47).

As discussed in Ref. 20, the demand for low noise emissions and the willingness to pay are significant factors for public acceptance and the success of UAM vehicles. Other factors are the restrictions caused by weather, time of day, and capacity restrictions by urban infrastructure. Electric propulsion shows high potential for use in UAM technologies, tackling some of the demands mentioned above. UAS are by nature sensitive to vibrations and require a lightweight design. Electric propulsion with fewer moving parts, reduced noise, and being suitable for lightweight vehicles represents a superior solution for UAM (Ref. 48), compared to conventional propulsion such as turbine. Still, further development is needed to support the high performance and functionality requirements existing in UAM (Ref. 49).

The development of new network technologies is a major focus of the aviation industry, and Avionics Wireless Networks (AWN) is a significant part of this effort. Wireless networks play a crucial role in the transportation industry by reducing the amount of wiring needed in vehicles, thus decreasing weight and increasing efficiency, resulting in significant cost savings (Ref. 50). In particular, the aviation industry benefits from technologies such as Wireless Avionics Intra-Communication (WAIC), which simplify wire installation and promote safety-critical concepts such as dissimilar component redundancy and improved system reconfigurability (Ref. 51, 52). Features such as route segregation and redundant radio links ensure dissimilar redundancy and help to mitigate risks of single points of failure (Ref. 51). One possible application of WAIC is for spatially distributed controllers, actuators, and sensors, replacing current fieldbus technologies (Ref. 52). Network technologies used in next generation UAS are discussed in detail in Ref. 15. With the increase in digital and wireless system solutions in future aircraft such as VTOLs, there will, however, also be an increase in cybersecurity demands.

In the context of performance, UAM shall provide efficient transportation solutions, with reduced travel times and increased accessibility, enabling swift and convenient urban mobility. UAM should demonstrate minimal environmental impact, with the adoption of sustainable technologies and practices.

### 3.4. Cybersecurity

As defined by the International Air Transport Association in Ref. 53, "aviation cyber security may be considered as the convergence of people, processes, and technology that come together to protect civil aviation organizations, operations, and passengers from digital attacks." The proximity of urban aircraft to ground stationed attackers and the adoption of new communication technologies, such as WAIC, make the systems more susceptible to cyberattacks. Tackling these problems in the already heightened safety-critical environment these technologies operate in will be a demanding endeavour. This is particularly apparent when identifying the data links in the UAM environment, as illustrated in Figure 2.

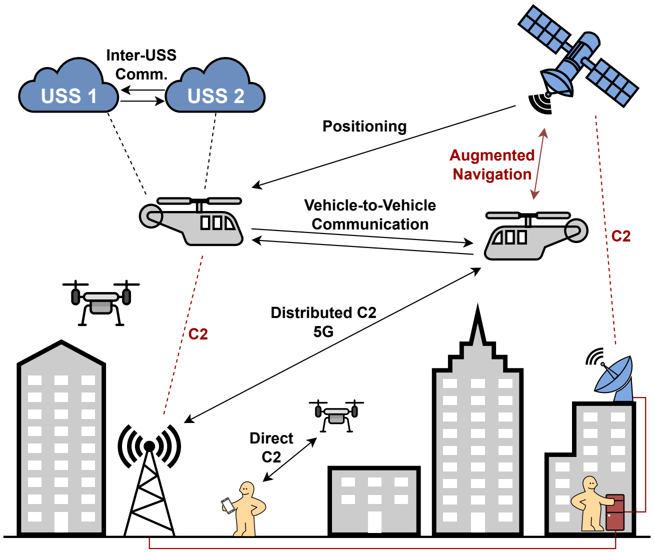

Figure 2: Urban aircraft system communication and data links (Ref. 54, 55)

Additionally to the existing data links found in commercial aviation, there are supplementary communication networks in UAM. Some of the core technologies found in future UAM systems are augmented navigation with Command and Control (C2)[2] links, as well as Unmanned Aircraft Systems Service Supplier (USS)[3]. Common vulnerabilities of the systems, which need to be addressed for safety regulations and certifiability, are jamming – interrupting targeted RF signals, spoofing – sending of illegitimate information, interception – manipulating video transmission, and Denial of Service (DoS) – undermining controls and transmission (Ref. 58). All of these threats are magnified due to advancements in internet connectivity of aircraft over the years and the proximity of UAS to urban spaces and ultimately ground attackers. Some of the current research areas for the operational environment of UAM technology which are relevant for cybersecurity are communication, navigation, and surveillance. The development of more robust vehicle

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[2] As defined in Ref. 56: "Command and Control (C2) datalink is the element of the command and control function that provides the interface between the [Remotely Piloted Aircraft] (RPA) and the Ground Control Station for the purposes of commanding and controlling the flight."

[3] As defined in Ref. 57: "A USS is an entity that provides services to support the safe and efficient use of airspace by providing services to the operator in meeting [Unmanned Aircraft System Traffic Management] (UTM) operational requirements."

designs for UAM which can manage cybersecurity threats will be of high priority (Ref. 30, 59).

In the context of cybersecurity, UAM shall prioritize the implementation of robust and comprehensive security measures to ensure the safe and secure operation of aerial transportation systems. This includes secure communication, intrusion detection and prevention, and secure software development.

### 3.5. Interoperability

Interoperability refers to the seamless ability of distinct systems to function together, even when they are developed and constructed by divergent organizations. In the context of UAM, interoperability is crucial in ensuring that various UAM systems and vehicles can safely and efficiently communicate with each other, share data, and coordinate their operations. Figure 3 illustrates the crammed airspace and need for seamless interoperability for different types of aircraft in a UAM scenario. In the presented scenario, drones and other small unmanned vehicles operate in the low-level airspace up to 150 m. Between 150 m and 2 km, VTOLs for UAM operate in different zones in the UAM corridor. The commercial airspace for airplanes is between 2 and 8 km. The figure shows a UAM corridor with a vertical passing zone for UAM vehicles. However, a horizontal passing zone is also conceivable. Vertical and horizontal passing zones in UAM corridors are described in Ref. 40 in more detail.

Interoperability is highly significant for UAM for several reasons. First, UAM systems and vehicles need to communicate with one another in real-time, requiring a high level of data exchange and coordination to avoid collisions and other safety risks. Second, guaranteeing interoperable aircraft can enhance the efficacy of UAM systems by streamlining their operations, reducing delays, and increasing their reliability. Last, an interconnected system can help ensure that aircraft remain accessible and affordable by creating a more open and competitive market, which can lower costs and increase the availability of UAM services in various regions.

To address the need for interoperability in UAM, several initiatives and projects are underway worldwide, including:

- The development of standards and protocols for UAM systems, created by aviation regulatory bodies such as EASA and FAA.
- New testing and certification programs for UAM vehicles and systems to ensure that they function together safely and effectively.
- New partnerships and collaborations between different UAM organizations, companies, and regulators with the aim of promoting greater communication, information sharing, and interoperability within the UAM industry.

As described in Ref. 61, two fundamental obstacles need to be tackled for the safe and reliable development of interoperable aircraft in urban environments:

(a) Operation planning for aircraft guaranteeing safety and performance, and

(b) real-time airborne collision avoidance for an elevated number of aircraft sharing the airspace without a priori approval of all flight plans.

Specifically when talking about collision avoidance systems and air-ground communication between humans and/or aircraft in urban and crowded airspaces, the interoperability of subsystems will play a crucial role in the adoption of UAM technologies. Standardized hardware and software systems will have the potential to increase operability of different types of aircraft in urban environments. The smaller airspace margins as well as aircraft sizes and the need for higher maneuverability in urban airspaces will call for computationally performant avionics solutions (Ref. 25).

In the context of interoperability, UAM shall adhere to a set of requirements to ensure seamless integration and effective collaboration among various stakeholders involved in the operation and management of urban air transport systems. These requirements encompass standardized protocols, compatibility with existing infrastructure, and integration of systems and services.

## 4. PUTTING IT ALL TOGETHER

Five major requirements for accomplishing operations of UAS have been identified. They are safety, scalability, performance, cybersecurity, and interoperability. These requirements are highly interdependent and crucial for achieving airworthiness for future UAS.

One of the key findings of this paper is that safety is a critical requirement for UAS due to their operation in urban environments with high population densities. Therefore, advanced safety features such as hazard analysis techniques need to be incorporated into the avionics systems to ensure safe operation. Another key finding is that scalability is an important feature that future urban aircraft need to fulfill. The systems need to scale well with different types and sizes of aircraft. Technological advancements, particularly in batteries and electric as well as distributed propulsion systems, are of high importance. They facilitate the design of novel aircraft types with VTOL capabilities and tackle some of the aforementioned requirements.

One interpretation of these findings is that the targeted developments for UAM are a complex and challenging task that requires a multidisciplinary approach. The interdependence of the presented requirements highlights the need for a holistic approach to UAS development that takes into account the unique operating conditions of UAM. Achieving

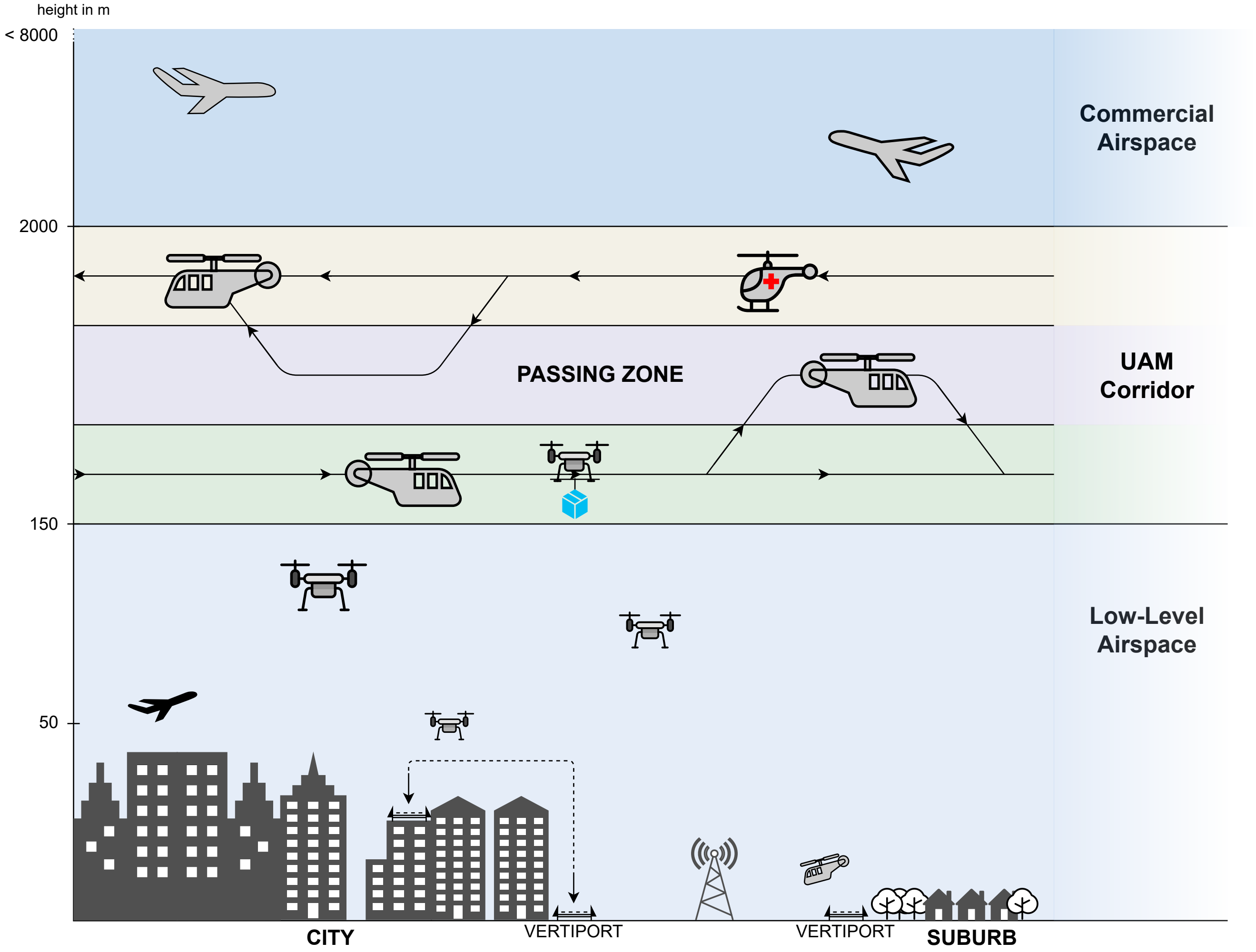

Figure 3: UAM scenario with different types of aircraft operating in and above cities and suburbs (Ref. 40, 60)

airworthiness and acceptance for UAM will enable the safe and efficient operation of urban aircraft, which have the potential to revolutionize urban mobility.

## 5. CONCLUSION

In recent years, the concept of UAM has garnered considerable interest as a rapidly developing field. UAM aims to make air travel accessible within urban areas, offering fast and efficient transportation of people and goods while simultaneously alleviating congestion on the ground. This technology has the potential to revolutionize urban mobility by providing more sustainable and quicker transport solutions. Overall, the emergence of new technologies such as UAM offers solutions to some of the current challenges in transportation. However, the adoption of these technologies also adds additional constraints to their aircraft development. Five major requirements have been identified for the development of UAS, namely safety, scalability, performance, cybersecurity, and interoperability. As presented, the areas are highly interdependent and need to be thoroughly researched to achieve airworthiness for future UAS. One limitation of this paper is that it does not provide detailed information for some of the challenges and solutions to the deployment of UAM. Further research is needed to identify and address these points, and achieve a full technical coverage of necessary requirements for UAM. Within the scope of this research more detailed specifications for the development needs of UAM technologies will be investigated.

## References

1. Chana, W.F., A. *Flying Automobiles: Are They for Real?* https://books.google.de/books?id=pqT%5C_xwEACAAJ (AIAA, 1996).
2. Bryan, F. *Beyond the Model T: The Other Ventures of Henry Ford* ISBN: 9780814322369. https://books.google.de/books?id=DMu1AAAAIAAJ (Wayne State University Press, 1990).
3. James R. Chiles. *Flying Cars Were a Dream That Never Got Off the Ground* https://books.google.de/books?id=pqT%5C_xwEACAAJ (AIAA, Feb. 1989).
4. Leary, W. M. Robert Fulton's Skyhook and Operation Coldfeet. *CENTRAL INTELLIGENCE AGENCY WASHINGTON DC CENTER FOR THE STUDY OF INTELLIGENCE.* https://www.cia.gov/static/Robert-Fulton-Operation-Coldfeet.pdf (Jan. 1995).
5. Fedrigo, D. F. G., Gobato, R. & Gobato, A. *Avrocar: a real flying saucer* 2015. arXiv: 1507.06916 [physics.pop-ph].
6. Cohen, A. P., Shaheen, S. A. & Farrar, E. M. Urban Air Mobility: History, Ecosystem, Market Potential, and Challenges. *IEEE Transactions on Intelligent Transportation Systems* **22,** 6074–6087. https://doi.org/10.1109/TITS.2021.3082767 (2021).
7. Petit, Y. L. & Islam, K. *Urban Mobility Next 8, Expectations and success factors for Urban Air Mobility in Europe* tech. rep. (European Institute of Innovation & Technology, Nov. 2022). https://www.eiturbanmobility.eu/wp-content/uploads/2022/11/EIT-UrbanAirMobility.pdf.
8. Federal Aviation Administration. *UAS Integration Pilot Program* (2017). https://www.faa.gov/uas/programs_partnerships/completed/integration_pilot_program.
9. European Union Aviation Safety Agency. *Special Condition for VTOL and Means of Compliance* (June 2023). https://www.easa.europa.eu/en/document-library/product-certification-consultations/special-condition-vtol.
10. Radio Technical Commission for Aeronautics. *Advanced Air Mobility (AAM)* (2023). https://www.rtca.org/about/technical-initiatives-aam/.
11. Urban air mobility: A comprehensive review and comparative analysis with autonomous and electric ground transportation for informing future research. *Transportation Research Part C: Emerging Technologies* **132,** 103377. ISSN: 0968-090X. https://doi.org/10.1016/j.trc.2021.103377 (2021).
12. Schweiger, K. & Preis, L. Urban Air Mobility: Systematic Review of Scientific Publications and Regulations for Vertiport Design and Operations. *Drones* **6.** ISSN: 2504-446X. https://doi.org/10.3390/drones6070179 (2022).
13. McKinsey & Company. *Study on the societal acceptance of Urban Air Mobility in Europe* tech. rep. (European Union Aviation Safety Agency, May 2021). https://www.easa.europa.eu/en/downloads/127760/en.
14. Volocopter. *PIONEERING THE URBAN AIR TAXI REVOLUTION* (June 2019). https://www.volocopter.com/wp-content/uploads/Volocopter-WhitePaper-1-01.pdf.
15. Cullen, M., Moore, R., Schlosser, C. & Benton, M. *Connecting The Future of Flight White Paper* tech. rep. (TTI TE Connectivity, 2021). https://www.ttieurope.com/content/dam/tti-europe/resources/Literature/SupplierGuides/TTI-TE-Connecting-The-Future-of-Flight-White.pdf.
16. Johnny T. Doo and Michael A. Tsairides and Marilena D. Pavel and Michael Smith and Arnaud Didey and Edward Bennet and Craig Hange and Michael Bromfield and Nathan P. Diller and Jessie Mooberry. *NASA Electric Vertical Takeoff and Landing (eVTOL) Aircraft Technology for Public Services – A White Paper* tech. rep. (National Aeronautics and Space Administration, Sept. 2021). https://ntrs.nasa.gov/api/citations/20205000636/downloads/2021-08-20-eVTOL-White-Paper-Final_V48.pdf.
17. Vertical Aerospace *et al. The Future of Advanced Aerial Mobility* tech. rep. (Vertical Aerospace, Oct. 2021). https://vertical-aerospace.com/wp-content/uploads/2021/10/The-Future-of-Advanced-Aerial-Mobility.pdf.
18. EHang. *White Paper on Urban Air Mobility Systems* (Jan. 2020). https://www.ehang.com/app/en/EHang%20White%20Paper%20on%20Urban%20Air%20Mobility%20Systems.pdf.
19. Kay Plötner and Anna Straubinger and Lukas Preis and Michael Shamiyeh. *Putting Urban Air Mobility into perspective* tech. rep. (Bauhaus Luftfahrt, June 2023). https://www.ehang.com/app/en/EHang%20White%20Paper%20on%20Urban%20Air%20Mobility%20Systems.pdf.
20. Straubinger, A. *et al.* An overview of current research and developments in urban air mobility – Setting the scene for UAM introduction. *Journal of Air Transport Management* **87,** 101852. ISSN: 0969-6997. https:

//doi.org/10.1016/j.jairtraman.2020.101852 (2020).

21. On the understanding of the current status of urban air mobility development and its future prospects: Commuting in a flying vehicle as a new paradigm. *Transportation Research Part E: Logistics and Transportation Review* **166.** https://doi.org/10.1016/j.tre.2022.102868 (2022).
22. Vascik, P. D., Balakrishnan, H. & Hansman, R. J. *Assessment of Air Traffic Control for Urban Air Mobility and Unmanned Systems* in *8th International Conference for Research in Air Transportation (ICRAT)* (MIT International Center for Air Transportation (ICAT), June 2018). http://hdl.handle.net/1721.1/117686.
23. Reiche, C., McGillen, C., Siegel, J. & Brody, F. *Are We Ready to Weather Urban Air Mobility (UAM)?* in *2019 Integrated Communications, Navigation and Surveillance Conference (ICNS)* (2019), 1–7. https://doi.org/10.1109/ICNSURV.2019.8735297.
24. Stelkens-Kobsch, T. H. & Predescu, A.-V. *Contribution to a secure urban air mobility* in *41st IEEE/AIAA Digital Avionics Systems Conference, DASC 2022* (Oct. 2022). https://elib.dlr.de/191044/.
25. Athavale, J., Baldovin, A., Mo, S. & Paulitsch, M. *Chip-Level Considerations to Enable Dependability for eVTOL and Urban Air Mobility Systems* in *2020 AIAA/IEEE 39th Digital Avionics Systems Conference (DASC)* (2020), 1–6. https://doi.org/10.1109/DASC50938.2020.9256436.
26. Debyser, A. *AVIATION SAFETY* tech. rep. (European Parliament, Mar. 2022). http://www.europarl.europa.eu/ftu/pdf/en/FTU_3.4.9.pdf.
27. Safety Intelligence & Performance Department. *ANNUAL SAFETY RECOMMENDATIONS REVIEW* tech. rep. (European Union Aviation Safety Agency, Sept. 2022). https://doi.org/10.2822/199328.
28. Operations, Safety and Security. *2021 Safety Report* tech. rep. (International Air Transport Association, Apr. 2021). https://www.iata.org/contentassets/bd3288d6f2394d9ca3b8fa23548cb8bf/iata_safety_report_2021.pdf.
29. Holbrook, J. *et al.* *Enabling Urban Air Mobility: Human-Autonomy Teaming Research Challenges and Recommendations* in *AIAA AVIATION 2020 FORUM* (2020). https://doi.org/10.2514/6.2020-3250.
30. Thipphavong, D. P. *et al.* *Urban Air Mobility Airspace Integration Concepts and Considerations* in *2018 Aviation Technology, Integration, and Operations Conference* (June 2018). https://doi.org/10.2514/6.2018-3676.
31. European Union Aviation Safety Agency. *High-level regulatory framework for the U-space* (Mar. 2020). https://www.easa.europa.eu/en/downloads/111303/en.
32. Castro, D. G. & García, E. V. *Safety Challenges for Integrating U-Space in Urban Environments* in *2021 International Conference on Unmanned Aircraft Systems (ICUAS)* (2021), 1258–1267. https://doi.org/10.1109/ICUAS51884.2021.9476883.
33. Schuchardt, B. I. *et al.* Air Traffic Management as a Vital Part of Urban Air Mobility - A Review of DLR's Research Work from 1995 to 2022. *Aerospace* **10.** ISSN: 2226-4310. https://doi.org/10.3390/aerospace10010081 (2023).
34. Takacs, A. & Haidegger, T. Infrastructural Requirements and Regulatory Challenges of a Sustainable Urban Air Mobility Ecosystem. *Buildings* **12.** ISSN: 2075-5309. https://doi.org/10.3390/buildings12060747 (2022).
35. Graydon, M., Neogi, N. A. & Wasson, K. *Guidance for Designing Safety into Urban Air Mobility: Hazard Analysis Techniques* in *AIAA Scitech 2020 Forum* (Jan. 2020). https://doi.org/10.2514/6.2020-2099.
36. Code of Federal Regulations. *PART 135 - OPERATING REQUIREMENTS: COMMUTER AND ON DEMAND OPERATIONS AND RULES GOVERNING PERSONS ON BOARD SUCH AIRCRAFT* (Feb. 2023). https://www.ecfr.gov/current/title-14/chapter-I/subchapter-G/part-135.
37. Girija, A. A., Stefani, T., Mut, R., Krüger, T. & Durak, U. *USING OPERATIONAL DESIGN DOMAIN FOR SAFE AI IN URBAN AIR MOBILITY* in *ASAM International Conference 2022* (Nov. 2022). https://elib.dlr.de/192568/.
38. European Union Aviation Safety Agency. *Notice of Proposed Amendment 2022-06* (June 2022). https://www.easa.europa.eu/en/downloads/136705/en.
39. International Civil Aviation Organization. *LEGAL AND SOCIETAL STAKES FOR THE EMERGING AIR MOBILITY IN METROPOLITAN AREAS* (Aug. 2022). https://www.icao.int/Meetings/a41/Documents/WP/wp_110_rev_en.pdf.
40. Federal Aviation Administration. Urban Air Mobility (UAM) Concept of Operations. https://www.faa.gov/sites/faa.gov/files/Urban%

20Air%20Mobility%20(UAM)%20Concept%20of%20Operations%202.0_0.pdf (May 2023).

41. European Union Aviation Safety Agency. *COMMISSION IMPLEMENTING REGULATION (EU) 2021/664* (Apr. 2021). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32021R0664.
42. European Union Aviation Safety Agency. *COMMISSION IMPLEMENTING REGULATION (EU) 2021/665* (Apr. 2021). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32021R0665.
43. European Union Aviation Safety Agency. *COMMISSION IMPLEMENTING REGULATION (EU) 2021/666* (Apr. 2021). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32021R0666.
44. IFAR, A. W. G. *et al. Scientific Assessment for Urban Air Mobility (UAM)* tech. rep. (Mar. 2023). https://elib.dlr.de/195379/.
45. Whiteside, S. & Pollard, B. Conceptual Design of a Tiltduct Reference Vehicle for Urban Air Mobility. *Aeromechanics for Advanced Vertical Flight.* not yet published (Jan. 2022).
46. Bauranov, A. & Rakas, J. *Urban air mobility and manned eVTOLs: safety implications* in *2019 IEEE/AIAA 38th Digital Avionics Systems Conference (DASC)* (Sept. 2019), 1–8. https://doi.org/10.1109/DASC43569.2019.9081685.
47. Annighöfer, B. *Model-based Architecting and Optimization of Distributed Integrated Modular Avionics* ISBN: 9783844034202 (Shaker Verlag, Aachen, 2015).
48. Patterson, M. D., Antcliff, K. R. & Kohlman, L. W. *A Proposed Approach to Studying Urban Air Mobility Missions Including an Initial Exploration of Mission Requirements* in *AHS International 74th Annual Forum & Technology Display* (2018).
49. Markov, A. *A Framework for Integrating Advanced Air Mobility Vehicle Development, Safety and Certification* Dissertation (Georgia Institute of Technology, May 2022). http://hdl.handle.net/1853/66598.
50. Elgezabal Gómez, O. *Fly-by-wireless: Benefits, risks and technical challenges* in *CANEUS Fly by Wireless Workshop 2010* (2010), 14–15. https://doi.org/10.1109/FBW.2010.5613788.
51. Uwe Schwark. *Wireless Avionics Intra-Communication (WAIC)* https://www.sae.org/binaries/content/assets/cm/content/attend/2017/aerospace-standards-summit/waic.pdf. SAE Aerospace Standards Summit Spring 2017. Apr. 2017.
52. Lukic, B., Ahlbrecht, A., Friedrich, S. & Durak, U. *State-of-the Art in Engineering Integrated Modular Avionics and the Way Ahead* in *42nd IEEE/AIAA Digital Avionics Systems Conference, DASC 2023,* not yet published (Oct. 2023).
53. International Air Transport Association. *Aviation Cyber Security* (May 2020). https://www.iata.org/contentassets/e55ae27b2fc34343a1143fca5129c8dd/aviation-cyber-security-position.pdf.
54. Johnson, R. D. *Unmanned Aircraft System Traffic Management (UTM) Project* in (2018).
55. Bae, J., Lee, H. & Lee, H. *A Study on Communication Technologies for Urban Air Mobility* in *2022 13th International Conference on Information and Communication Technology Convergence (ICTC)* (2022), 2235–2240. https://doi.org/10.1109/ICTC55196.2022.9952749.
56. European Union Aviation Safety Agency. *SC-RPAS.C2, RPAS Command and Control (C2) Datalink* tech. rep. (May 2016). https://www.easa.europa.eu/en/downloads/20784/en.
57. Joseph L. Rios and Irene S. Smith and Priya Venkatesen and Jeffrey R. Homola and Marcus A. Johnson and Jaewoo Jung. *UAS Service Supplier Specification* tech. rep. (National Aeronautics and Space Administration, Oct. 2019). https://ntrs.nasa.gov/api/citations/20200000512/downloads/20200000512.pdf.
58. Tang, A. C. *A Review on Cybersecurity Vulnerabilities for Urban Air Mobility* in *AIAA Scitech 2021 Forum* (2021). https://doi.org/10.2514/6.2021-0773.
59. Jordan, A. *et al. Systematic Evaluation of Cybersecurity Risks in the Urban Air Mobility Operational Environment* in *2022 Integrated Communication, Navigation and Surveillance Conference (ICNS)* (2022), 1–15. https://doi.org/10.1109/ICNS54818.2022.9771507.
60. Shrestha, R., Oh, I. & Kim, S. *A Survey on Operation Concept, Advancements, and Challenging Issues of Urban Air Traffic Management* in *Frontiers in Future Transportation* (2021).
61. Rodionova, A., Pant, Y. V., Jang, K., Abbas, H. & Mangharam, R. *Learning-to-Fly: Learning-based Collision Avoidance for Scalable Urban Air Mobility* 2020. https://doi.org/10.48550/ARXIV.2006.13267.