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ACCEPTANCE SAFETY AND SUSTAINABILITY RECOMMENDATIONS FOR EFFICIENT DEPLOYMENT OF UAM

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Abstract

According to common understanding, Urban Air Mobility (UAM) refers to transportation by air within or between urban areas. The detailed meaning of the notion is not officially defined but an example of UAM definition can be found in the SESAR ATM Master Plan 2019 or in the SESAR VLD203-2020 Programme. For the purpose of the ASSURED UAM project, it was assumed UAM as means of transport of people or goods enabling Door-to-Door (D2D) or near to D2D travel within or to densely populated urban areas. It relates to both manned and unmanned aircraft of different configurations.

ASSURED-UAM project is aiming at development of set of solutions which will assure UAM integration both with ATM and city organization (i.e. transport system) without compromising UAM acceptability, safety nor sustainability.

The project aims are to describe future in terms of probable UAM segment development, assure broad and comprehensive organisational and policy definition support for authorities, policy makers and urban industry organizations, accommodate and propagate aviation best practices, standards, recommendations and organizational solutions into city/municipal administrative and legislative structures, provide recommendations for integration of surface modes under the umbrella of U-Space ATM (SESAR X-TEAM D2D and VUTURA projects) to become first but robust answer on the European Green Deal.

This deliverable D1.1 entitled *Technology readiness review* is aiming to identification and description of the development paths and factors for the most appropriate technology solutions expected to shape future UAM, with reference to the three time horizons considered in the ASSURED-UAM project.

The deliverable is the outcome of Task T1.1 activities, including therefore:

- the review of initiatives and projects aimed at development of UAM, with reference to both aviation and ICT enabling automatic/autonomous vertical transport over populated areas;
- support to the Task 1.4 with appropriate information necessary to build the target use cases.

The deliverable D1.1 consists of three main sections corresponding to the tasks T1.1 dedicated research activities, as outlined below:

- Chapter *3 Main drivers and trends for UAM implementation*, which is devoted to the definition of the main factors and trends for the development and implementation of Urban Air Mobility.
- Chapter *4 Main enabling technologies for UAM implementation*, which is devoted to identification of the main enabling technologies and their differences, for the introduction of the Urban Air Mobility concept, considering also aspects related to Propulsion, Information Communication Technology (ICT), Infrastructures and U-Space.
- Chapter *5 Expected technologies readiness levels in 5, 10 and 15 years*, which is devoted to identification of technological readiness levels expected in the next 5, 10 and 15 years with reference to the enabling technologies for the development of the UAM in urban and peri-urban areas.

Index

List of Tables

List of Figures

1. Introduction

The UAM (Urban Air Mobility) concept is defined by NASA [1] as “safe and efficient air traffic operations in a metropolitan area for both manned and unmanned aircraft systems”. However, existing technologies and regulations only allow the UAM concept be implemented with conventional helicopters now, not as fancy as it sounds. However, based on the last decade publications and recent projects, the UAM will be the future of the metropolitan urban mobility. In fact, many companies already have developed and tested in flight the first UAM vehicles (i.e. EHang 116 and 216, Uber Elevate, Airbus A³ Vahana, Boeing PAV, Lilium Jet, Volocopter VoloCity).

Urban air mobility (UAM) is an aviation industry term for on-demand and automated passenger or cargo-carrying air transportation services, typically flown without a pilot. Traffic is bad these days in urban areas and is getting worse. This creates an opportunity for such services to bring new ways for people to travel around cities and urban areas while reducing congestion [2].

There has been a rapidly increasing interest in providing air transportation services within major metropolitan areas. The combination of increasing congestion and advancements in electric aircraft and automation makes the UAM market more attractive for vehicle manufacturers and transportation companies, so leading to many potential applications for new aircraft [2].

The UAM vehicles will have the best chance at full-scale implementation if they are focused on safety, operated smartly, and are connected under the command of a centralized platform. Safety, of course, always needs to be the first priority, so any UAM vehicle needs to be outfitted with power redundancy and backup systems. Furthermore, UAM vehicles have to be conceived as “smart” vehicles, meaning that they are piloted autonomously, which not only obviates the need for an in-vehicle pilot and the associated costs, but also enhances safety and makes vehicle more controllable.

In the following Figure 1, it is shown the segmentation of the global Urban Air Mobility Market, which is then outlined and commented in the following [2].

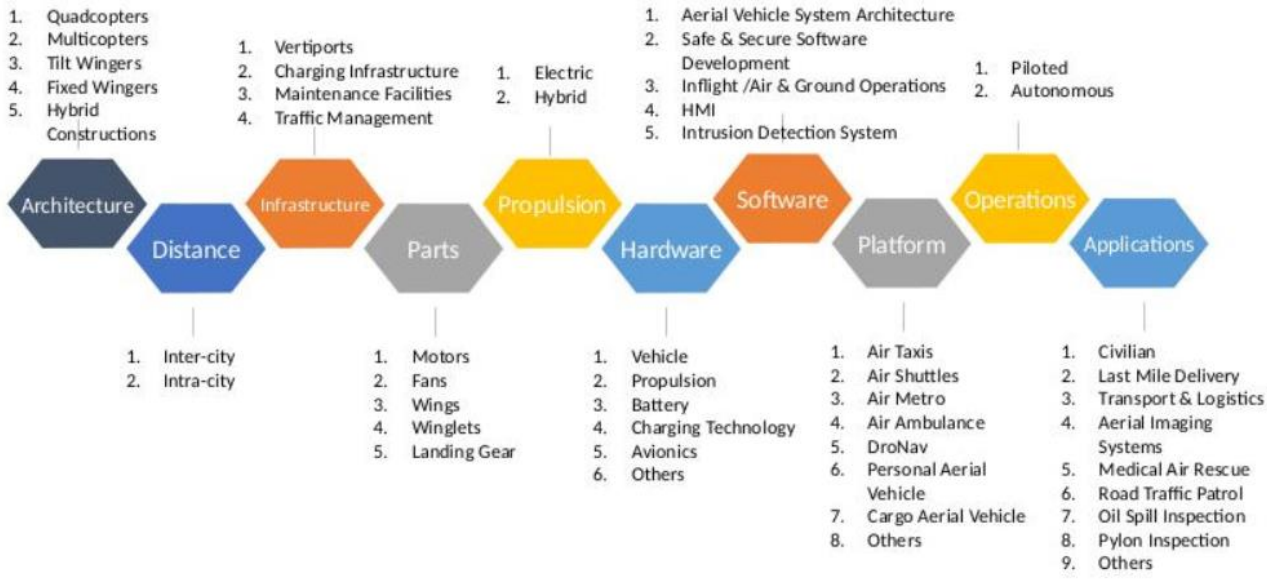

Figure 1: Segmentation of the Global Urban Air Mobility Market [2]

Based on the architecture, the UAM market has been divided into quadcopters, multicopters, tilt wingers, fixed wing, and hybrid constructions. The quadcopter segment is expected to remain the largest segment of the global urban air mobility market during the forecast period. Electric or hybrid-electric quadcopters are going to be the first choice for carrying passengers as they can take-off and land almost anywhere.

On the basis of range, the UAM market has been segmented into inter-city and intra-city. The inter-city segment is expected to be the largest during the forecast period as it is likely to offer short-haul, inter-city flights carrying multiple passengers.

On the basis of platform, the UAM market has been segmented into air taxis, air shuttles, air metro, air ambulances, DroNav, Personal Aerial Vehicles (PAVs), cargo aerial vehicles, and others. The air taxis segment is expected to be the largest during the forecast period. Industry watchers and proponents see air taxis becoming part of the transportation network and generating huge service revenues every year going forward. Airport shuttles and air taxis are expected to grow significantly since the markets are viable with a significant total available market value of USD 500 billion at market entry price points.

By region, North America is expected to remain the largest urban air mobility market during the forecast period and is also expected to register the highest growth rate. In the US, NASA is working on effective partnerships with industry, academia, and the Federal Aviation Administration (FAA) is working to identify and seek solutions to the challenges to accommodate remotely piloted aircraft.

Europe is also likely to offer lucrative growth opportunities to market players in the coming years. Market players aim to mobilize cities and regions across Europe along with a wide ecosystem of stakeholders interested in launching practical mobility demonstration projects with ground and air mobility.

In this document, the current technologies advancements about UAM are described and the technologies that have to be targeted within the next 5, 10, and 15 years are indicated.

1.1. Acronyms

ANSP	Air Navigation Service Provider
ATC	Air Traffic Control
ATM	Air Traffic Management
BLOS	Beyond Line Of Sight
BVLOS	Beyond Visual Line Of Sight
CAAS	Civil Aviation Autority of Singapore
CAGR	Compound Annual Growth Rate
CIRA	Centro Italiano Ricerche Aerospaziali (Italian Aerospace Research Centre)
CNS	Communication, Navigation, Surveillance
DGAC	French Civil Aviation Authority
D2D	Door-to-door
EASA	European Aviation Safety Agency
EIP-SCC	European Innovation Partnership on Smart Cities and Communities
ENAC	Ente Nazionale per l'Aviazione Civile (Italian Civil Aviation Authority)
ENAV	Ente Nazionale Assistenza al Volo (Italian ANSP)
EU	European Union
EVLOS	Enhanced Visual Line of Sight
eVTOL	Electric Vertical Take-Off and Landing
FAA	Federal Aviation Administration
GNSS	Global Navigation Satellite System
IFR	Instrument Flight Rules
IPO	Initial Public Offering
MTOV	Maximum Take-Off Weight
NASA	National Aeronautics and Space Administration
NFZ	No Flight Zone
R&D	Research and Development
SESAR	Single European Sky ATM Research
STOL	Short Take-Off and Landing

PATS	Personal Air Transport System
PAV	Personal Air/Aerial Vehicle
STOL	Short Take-Off and Landing
UAM	Urban Air Mobility
U.N.	United Nations
US	United States of America
UTM	Unmanned (Aircraft Systems) Traffic Management
VFR	Visual Flight Rules
VLL	Very Low Level
VLOS	Visual Line of Sight
V2V	Vehicle to Vehicle

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2. Methodological approach

Urban Air Mobility (UAM) is a novel concept based on the use of Vertical Take-off and Landing vehicles for aerial transportation of people in urban and peri-urban environment.

The methodological approach that has been implemented in the Task T1.1 *Technology Readiness Review* has been based on the execution of sequential study steps, which have been carried out by means of critical literature analysis, involving both material about R&D activities available in literature and material provided by ongoing as well as recently completed international projects.

The study steps have been executed in a sequential way, as indicated below:

- first, the main drivers and trends for UAM implementation have been identified;
- then, based on the identified trends, the technologies that can be considered as main enablers for UAM implementation have been selected;
- finally, dedicated analysis has been carried out in order to forecast, for what it is now reasonably possible, the expected technological readiness levels of the most relevant technologies for UAM implementation, according to the consideration of the three main time horizons that are addressed in the ASSURED UAM project, i.e. within the next 5, 10 and 15 years.

The methodological approach above mentioned is reflected in the organization of this deliverable document, where each of the following sections summarizes the results of each specific study step indicated above.

As indicated above, the outcomes of the studies are based on the literature analysis of papers as well as material from current worldwide UAM research projects, which also led to the definition of a baseline State of the Art (year 2021) on the relevant technologies, from which their future developments can be envisaged. Both EU and US R&D activities have been considered in the studies, being these two areas the ones in which relevant growth is expected in the next years in terms of UAM applications.

3. Main drivers and trends for UAM implementation

3.1 Introduction

The world is becoming increasingly urbanized. Since 2007, more than half of the world's population has been living in cities, and according to the U.N. that share is projected to rise to 60% by 2030 [3]. With a rising population and more cars on the road, travelling across metropolitan areas is increasingly becoming slower and not efficient in terms of energy usage, fuel consumption, and productivity.

This significant urban population growth is expected to create a real need for innovative mobility options, as ground infrastructure becomes increasingly congested. Urban Air Mobility (UAM) can be defined as passenger and/or goods transportation in the proximity of urban settlements using highly automated or fully autonomous passenger and/or cargo drones and is seen as option to provide a safe, sustainable (atmospheric pollution reducing) and convenient transport solution that leverages the airspace above cities.

Furthermore, as the world's urban population grows, traffic congestion has been seriously affecting people's quality of life and taking a toll on general economic growth. For example, according to reference study [4], a U.S. commuter spends 41 hours on average in traffic each year during peak congestion times. An estimate by INRIX[1] (a traffic analysis firm) showed traffic congestions had cost U.S. drivers ~USD 305 billion in 2017, thus implying an average of USD 1,445 per driver. Furthermore, the U.S. Environmental Protection Agency estimated an average passenger vehicle emits 4.7 metric tons of carbon dioxide each year [3].

Also, in the European Union, currently traffic congestion alone costs roughly €100 billion a year [5] and it is expected to increase to roughly €300 billion per year by 2030 [6]. As a result, cities are demanding for efficient and effective mobility solutions.

Efficient and effective urban transport can significantly contribute achieving objectives in a wide range of policy domains for which the EU has an established competence. The success of policies and policy objectives that have been agreed at EU level, for example on the efficiency of the EU transport system, socio-economic objectives, energy dependency, or climate change, partly depends on actions taken by national, regional and local authorities. Mobility in urban areas is also an important facilitator for growth and employment and for sustainable development in the EU areas.

The UAM concept could be further extended into applications in rural areas where the existing ground transportation infrastructure is inadequate. Besides transportation, UAM vehicles can function in specific scenarios in tourism, industrial, emergency medical services, fire control, and other use cases [7].

The idea of aviation in urban mobility is not new, e.g. helicopter taxis have been available for years in mega cities like São Paulo, Mexico City, New York City or Tokyo, as well as in other places in the world such as little cities. However, fast air connections are still associated with high costs and noise levels as well as high energy consumption. The vision of UAM is providing a safe and efficient air transportation system where everything, from small package delivery drones to passenger-carrying air taxis, operate above populated areas.

The push for Urban Air Mobility (UAM) promising market opportunities also emerged thanks to a new class of sustainable and cost-effective aircraft that can be designed based on a hybrid-electrical eVTOL multi-rotor

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[1] INRIX is a private company headquartered in Kirkland, Washington. It provides location-based data and analytics, such as traffic and parking, to automakers, cities and road authorities worldwide, and in turn-by-turn navigation applications like Google Waze. Website: https://inrix.com

architecture, so allowing overcoming most of the drawbacks above outlined associated to the usage of helicopters as air taxis.

3.2 Market overview and trends pre-COVID 19 pandemic

The urban air mobility (UAM) market is expected to witness a CAGR[2] of more than 10% during the forecast period. The increasing of traffic congestion issues, in particular in larger cities globally, is driving the need for faster modes of intracity transportation. For this reason, the UAM concept is assuming growing importance. Many companies are investing in research and development about Urban Air Mobility and there are many startups (e.g. Lilium, Volocopter, Uber Air, EHang etc.) and aerospace players (Airbus, Boeing) that consider this market as high growth potential [8].

Indeed, with the increasing number of vehicles on the road, the problems associated with traffic congestion increase every year. Especially in certain hours of the day, the traffic in the city reaches unsustainable levels, forcing commuters to lose most of their time stuck in traffic on the road, with negative impact also on human health (e.g. stress, nervousness, irritability etc.). The existing roads in many cities (Figure 2 reports the most congested five cities in the world in 2018 [9]) haven't the ability to handle the peak hour load, forcing the commuters to wait in line. This is not just an issue of making citizens waste time in traffic, but also of challenging governments. Moreover, huge quantities of fossil fuels are burned with consequent release of carbon dioxide into the atmosphere, with a significant negative impact on the environment, altering the environment greenhouse gas balance. With traffic congestion and urban road mobility posing a great challenge, governments and technology companies have started to look at UAM as a viable option for the passenger and cargo transport, with significant time savings. Furthermore, air taxis used for the UAM are expected to be mostly electric powered or fuel-cell powered. This can help in reducing atmospheric pollution. Such considerations motivate the effort that many companies are providing by investing significantly in this industry, which is expected to boost the technological advancements in the market in the long run, after the UAM systems enter the commercial usage phase [8].

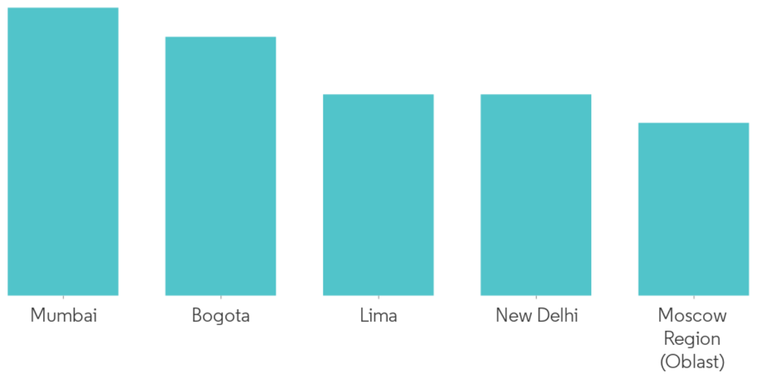

Figure 2: Top 5 Most Congested Cities in The World in 2018 [9]

The UAM concept is projected to penetrate faster in North America and Europe compared to other regions. Many countries are indeed already working towards the commercial adoption of the UAM, however Europe and North America are advancing faster than the other regions in the industry. Aerospace giants from the regions, like Boeing and Airbus, are investing in these technologies and the rise of many startups from both

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[2] Compound Annual Growth Rate (CAGR) is the rate of return that would be required for an investment to grow from its beginning balance to its ending balance, assuming the profits were reinvested at the end of each year of the investment's lifespan.

regions have made them an important market for the industry. In Europe, many cities have been joining the Urban Air Mobility Initiative, which is a part of the European Innovation Partnership on Smart Cities and Communities (EIP-SCC). The abovementioned initiative aims to contribute to the creation of a market for urban air mobility. As part of this initiative, companies with innovative urban mobility solutions are brought together and their solutions are presented and supported for expansion.

The biggest growth in the UAM sector will be made by the Asia-Pacific region which is expected to dominate the market by 2035 with a share of 39.27%. The Asia-Pacific region includes China, Japan, South Korea and Singapore, but China is expected to gain a major share in 2035 due to population growth and traffic [10].

The Asian continent is home to several emerging economies and is seen as the potential market for UAM-based transportation due to increasing urbanization coupled with growing traffic congestion and the rise of high-income groups in the region.

The growth of Asia's UAM market is driven by the fast-paced economies of China, Japan, Singapore and India, and by considerable growth in the transportation sector in general. In addition, Australia, Korea and Taiwan are other countries that contribute to the UAM market, thanks to the significant investments in smart city projects coupled with the increasing urbanization in these countries. Furthermore, the growing e-commerce logistics sector in emerging economies, such as China and India, is expected to be one of the predominant drivers for the growth of Asia's UAM market in the near future.

India is estimated to exhibit a significant growth rate up to 2035. Growing urban population is one of the essential factors that can encourage the demand for urban mobility services in the country. The growing population towards urban cities further raises the traffic congestion, which will create a significant demand for urban air mobility solutions in the country. Along with this, in 2018 HeliTaxi service started in Bengaluru city by the Thumby Aviation Pvt. Ltd. The Helitaxi service will provide quick and seamless transfers to and from airports, at a cost similar to a luxury taxi fare. Additionally, the ride-sharing company Uber is planned to start Uber Air in Mumbai, Delhi, and Bengaluru, i.e. the most congested cities in the country, by 2023. In May 2019, the Indian aviation company VTOL Aviation India Pvt Ltd partnered with IIT Kanpur and planned to build a prototype of the flying taxis in five years in the country, which may have great potential for the urban air mobility services in India [11].

In the meantime, the regulations for the UAM are also being drafted. At the Farnborough Global Urban Air Summit in September 2019, industry and regulatory leaders in UAM highlighted their commitment to meeting the pace of the industry, but highlighting the challenges faced by the market. Therefore, with the premises for the commercial market entry phase in the region, market growth is expected to be greater in Europe than in other regions. Even in North America, the United States is at the forefront of adopting this newer means of transport. Several startups from the United States are working together for developing and implementing these technologies locally. A roadmap is also being laid for bringing the UAM into commercial usage in the next 5-6 years. With these efforts, North America is also projected to embrace the urban air mobility concept faster than the other regions barring Europe. Figure 3 reports a view of the forecasted UAM market growth rate up to 2035 [8].

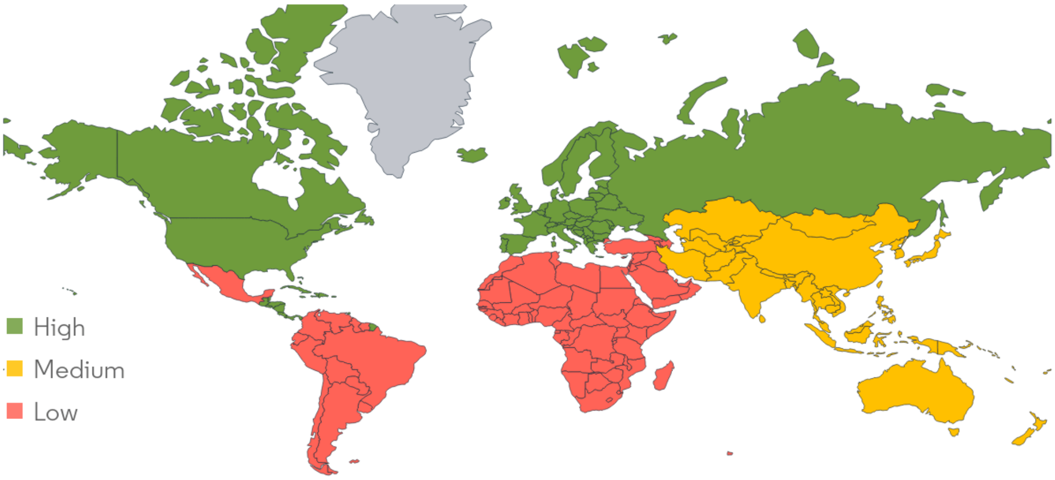

Figure 3: UAM Market Growth Rate by Region (2024-2035) [8]

Textron Inc., Uber Technologies Inc., Airbus SE, The Boeing Company, Lilium, Volocopter, EHang are some of the prominent players in the market. The market is still in its development phase, with many players that through collaborations and partnerships are trying to launch their UAM systems in the market in the next five years. However, at the same time, a lot of groundwork in terms of the necessary infrastructure and air traffic management still needs to be done, for which the players are partnering with several other companies/agencies offering the necessary technologies. For instance, Uber and NASA partnered in 2018 to develop technologies for UAM airspace management to make large-scale UAM operations possible. Likewise, in October 2019, Porsche and The Boeing Company signed a memorandum of understanding to explore the UAM market and its benefits. With the growing emphasis on environmentally friendly and economically sustainable technologies in mobility, players are mainly focusing on developing eVTOL (electric Vertical Take-Off and Landing) aircraft, whereas other players are looking beyond electricity to alternative energy sources, like the hydrogen fuel cells. Moreover, investments in autonomous aircraft in this industry are increasing as well [8].

3.3 COVID 19 pandemic market impact

The impact of the COVID-19 pandemic has been unprecedented on a global scale. The consequences have been wide, particularly for the aviation industry. Globally, the aviation industry is expected to lose more than USD 84 billion in 2020. Probably, the challenge for eVTOL companies is even harder. The industry is still in its formative stages. It will rely on a shared flight model to make the industry work and the value proposition partly depends on cutting travel time on otherwise congested routes [12].

In the pre-COVID-19 scenario, the UAM eVTOL industry had experienced an impressive growth trajectory. In the first few months of 2020 alone, over USD 1 billion was invested in the sector with Toyota leading a USD 590 million investment in Joby and EHang's USD 650 million IPO[3] valuation. UAM investment is expected to exceed USD 318 billion by 2040. Earlier this year, the Federal Aviation Administration (FAA) in the US announced that it is currently engaged with manufacturers of more than 15 eVTOL aircraft. Uber Air, EHang,

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[3] An Initial Public Offering (IPO) is the process through which a privately held company issues shares of stock to the public for the first time. Also known as "going public," an IPO transforms a business from a privately owned and operated entity into one that is owned by public stockholders.

Volocopter, Joby, and Lilium are among those who have signalled their intent to launch commercial passenger operations within the next three to five years. Labour and supply chain disruption were noted by EHang as hampering to overseas market development. The most notable casualty has been Voom, an Airbus backed app-based helicopter booking platform. Voom ceased operations in 29 March of the 2020 [13], citing the impact of COVID-19. Although Airbus has reasserted its commitment to its CityAirbus eVTOL program [12].

There are signals that suggest the impact could be temporary, with some organisations and certain jurisdictions forging ahead. Wisk [14] resumed testing in mid-June after a three-month delay and EHang received a special flight operations certificate from Transport Canada Civil Aviation in 29 July 2020 [15] that will allow for routine trial flights in Quebec province [12].

US aerospace manufacturer Bell [16] has also stated that it is on track for its Nexus eVTOL program and its timeline has not been impacted by the pandemic. Ultimately, however, the severity and duration of COVID-19 is near impossible to predict. As is the willingness of consumers to travel in confined spaces, and whether governments will allow them to do so. Outcomes are also likely to vary by region [12].

The COVID-19 pandemic will not impact all organisations equally. Companies' financial stability and access to capital will be key.

The movement of freight could become increasingly attractive for the eVTOL sector. During the pandemic, EHang's eVTOLs transported medical supplies [18] to a local hospital in the Guangxi province [12].

In conclusion, the pandemic on the one hand slowed the development of UAM technologies but on the other hand it made it clear its importance even in critical circumstances such as this of the COVID-19 pandemic. For this reason, the experimentation will continue and it is expected that between now and the next 5 years there will be the introduction of this technology for private use.

4. Main enabling technologies for UAM implementation

4.1 UAM technologies State of the Art

The rapid evolution Urban Air Mobility vehicles industry has generated a significant level of enthusiasm between aviation designers and manufacturers, resulting in numerous vehicle configurations. The majority of the prototype UAM vehicles have more than 4 rotors or propellers, have electric propulsion, carry 2 to 5 passengers, fly more like a helicopter (vertical takeoff and landing) than a fixed-wing aircraft and will fly relatively close to the ground and near buildings [19]. There are many technical challenges facing industry‘s development of safe, quiet, reliable, affordable, comfortable, and certifiable UAM vehicles and vehicle operations. Some of those challenges address safety and reliability of the electric power system and electric powertrain for these UAM /eVTOL vehicles.

The push to deploy electric vertical takeoff and landing (eVTOL) aircraft in a variety of roles from unmanned delivery drones to urban air taxis is governed by the limits of available onboard electric power as above mentioned. Because of their flight profiles, eVTOLs require substantial levels of power during peak performance phases of flight during takeoff, landing, and flying into headwinds. The challenge in the future is the development of new batteries more light and with huge capacity.

In theory, any power requirement can be met by carrying a sufficient number of rechargeable batteries; however, this solution can consume an eVTOL’s payload capacity by adding excessive weight to the airframe. Any realistic battery solution has to thus balance the provision of sufficient power against the weight and size of the batteries carried onboard.

There is no doubt that considerable progress has been made in developing efficient and powerful battery solutions for eVTOLs. What is open to debate is whether these solutions will be sufficient to power eVTOLs through all phases of flight, or whether limitations in the current state-of-the-art require a hybrid power generation solution, similarly to the gasoline/battery approach used in hybrid cars.

Another immediate focus of the vehicle developers is overcoming obstacles on the path to certification. The public has experience flying in large transport aircraft and regional fixed-wing aircraft and are calibrated to associated safety levels for commercial air transportation. Detailed certification requirements for UAM vehicles are still under development by the relevant certifying authorities. For UAM aircraft, research is needed that addresses safety and reliability expectations of the traveling public and certifying authorities.

In addition, UAM traffic will require new air traffic corridors in the sky, a different way for human beings to commute, to work, and transport goods using mainly eVTOLs. Similar to a helicopter, this new breed of aircraft is somewhere between commercial airplanes and remotely piloted small drones, configured to carry large payloads and people.

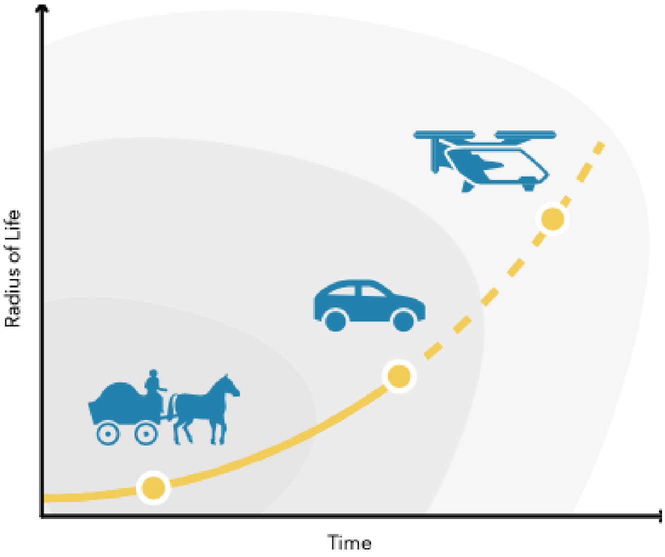

Figure 4: Potential impact of eVTOL on urban mobility

Figure 4 shows the potential which eVTOL represents: a dramatic and disruptive shift in the way we travel. As the automobile transformed the world of horse and carriage in the industrial age, eVTOLs have the potential to fundamentally change transportation in the digital age.

In conclusion, the enabling UAM technologies have currently reached a good level of maturity, but not such as to allow their immediate insertion in the market. However, Urban Air Mobility is expected to become a reality in the next 15 years, first with the introduction of the goods delivery and initial private mobility service (2025) and subsequently with incremental wider development of the commercial passengers' mobility service (2035).

4.2 Aeronautical/vertical technologies

In every public transport network there are critical issues, from both the spatial point of view (the connection with rural areas and suburbs of the cities) and the temporal point of view, for example considering the evening and the weekend. It is important to identify these gaps, expand the network with a modern transport on demand concept and integrate all existing offers for citizens, in order to obtain a wider coverage of public transport. A technology that can help bridging this kind of gap is by air and this led to the concept of UAM.

Concepts of operations for UAM airspace integration at different stages of operational maturity are listed below ([1], [20]):

- **Emergent UAM operations:** characterized by low-temporal, low-density flights along a small set of fixed routes between a few take-off and landing areas. At the moment, it is expected that the earliest UAM operations will be aimed to demonstrate their potential benefits to the general public and metropolitan areas. These initial UAM flights will be used to gather preliminary feedback from surrounding communities (for example, on noise) and gain support for initial commercial operations.

- **Expanded UAM operations:** characterized by higher-temporal, higher-density flights in a small network of vertiports feeding a common hub location, managed by UAM operators and third-party services. Currently there are three fundamental issues during clear weather operations: gates, runways, and ATC workload. While UAM is unlikely to use conventional gates and runways, ATC workload may limit UAM if not properly designed. As such, developing the concepts, technologies, and procedures (planned for the decade 2025-2035) that will enable UAM to be integrated into the airspace system and managed without tactical intervention from ATC represents a significant portion of the effort towards achieving higher-density, higher-temporal UAM operations.

- **Mature UAM operations:** characterized by high-temporal, high-density flights in a network with multiple hub locations, potentially with very big orders of magnitude of vehicles. Starting in 2035, UAM airspace integration effort will focus on exploring possibilities for the services, procedures and tools necessary to support high-tempo, high-density mature operations. Stakeholders will develop and refine the initial airspace integration concepts for both emergent and early expanded UAM operations just described.

Up to date, ANSPs provide ATM services for aircraft in all stages of flight from gate to gate. This includes services in the surface and terminal environment (i.e., the airport and its surrounding airspace), as well as the en-route environment (i.e., high-altitude airspace). ATM is designed to manage flights between cities. Communications are primarily via radio, and surveillance technologies track aircraft that are spaced miles apart. Ground-based navigational aids serve as a backup to Global Navigation Satellite System (GNSS) surveillance information, but these are not suitable for surveillance purposes in UAM traffic environment. Current CNS (Communication, Navigation and Surveillance) technologies, airspace structures and procedures over low-altitude urban areas are designed for helicopters and general aviation aircraft that self-separate using see-and-avoid procedures [20].

For the UAM operational environment, nevertheless, it is indeed necessary to consider that UAM flights have unique needs. They will take off and land from numerous skyports(or vertiports as also defined) across a city. They will require smaller separation standards than current practice to accommodate the anticipated high traffic volumes. They will carry passengers and goods, fly in closer proximity to buildings and other aircrafts, rely more on data link rather than voice communications, transition to autonomy and operate in airspace adjacent to fixed-wing commercial aircraft. UAM flights will spend most of the duration of flights over densely populated areas and they will share airspace with traditional urban traffic.

In the following Table 1, the potential hazards within and across the various UAM domains are listed. Although some of the hazards may have few downstream consequences, many others may have cascading effects that interact with other hazards [20].

Table 1: Examples of UAM Domains and Potential Hazards[20]

UAM Domains	*Potential Hazards*
Vehicle, equipage, systems	Loss of electrical power to control systems Failure of GPS/Receiver Autonomous Integrity Monitoring
Vehicle servicing and maintenance	Unavailability of necessary replacement parts
Communications (datalink, Command-and-Control link)	Command-and-Control link lost Degraded Quality of Service (QoS) for critical control commands
Aerial operations, flight procedures, flight management	Vehicle upset attitude Vehicle fly-away
Routing, airspace, air traffic management	UAM route conflicts with existing air traffic Loss of safety-critical functions on ground station

External environment (weather, obstacles, aerial traffic, birds)	Convective weather (hail, severe downdrafts) Buildings, power lines, airborne vehicles
Pilots (on-board and remote)	Inadequate pilot training for maintaining safety margins Loss of pilot situational awareness
Dispatch, control center, emergency pilots	Dispatch understaffed, flight planning delayed Loss or degradation of ground control station capability
Ground-based operations and infrastructure	Lack of vertiport availability (occupied, damaged, closed) Inadequate ground crew training for maintaining safety margins
Passengers	Passenger interference with pilot/vehicle operations Passenger illness during flight
Cybersecurity	Inadequate authentication of Command-and-Control link (undetected hijacking of link)

In addition, it is important to notice here that the vertical transport in urban and peri-urban environment needs to be integrated with the existing transportation networks for surface transport, in order to allow benefitting at the maximum possible extent of the new dimension (the vertical one) made available for transport of goods and passengers in the big cities and to allow seamless transportation. This led to the consideration of the Door-to-Door (D2D) transport paradigm, which requires the establishment of an integrated multimodal transport system, as envisaged in the SESAR ER funded project X-TEAM D2D [20]. In the following paragraphs, therefore, the most relevant vertical transport technologies that are candidate for the implementation in the UAM environment are examined not only in terms of their characteristics and performances as "standalone" means for vertical transport in urban environment but also from the point of view of their potential for integration in the framework of a D2D urban transport system including UAM. Under the perspective of integration of the considered UAM technologies in a D2D multimodal system, some relevant features will be taken into account and a related score will be assigned to each vertical transport technology by means of stars (to be interpreted as follows: one star is a weakness, two stars is an acceptable level, three stars is a strength). The features that will be evaluated under the integrability perspective are listed in the following:

- **Integrability:** feature linked to the predictability of the flight time and the availability of operational services and dedicated infrastructures.
- **Endurance:** maximum length of time that the vehicle can spend in cruising flight**.**
- **Weather resilience:** ability to adapt to weather changes, in order to preserve correct functioning.
- **Manoeuvrability:** ability to perform manoeuvres with certain characteristics, for example by making safe trajectory changes.
- **Runway length:** length of the rectangular area prepared for the landing and take-off of the vehicle on a land aerodrome.
- **Independency:** feature linked to the number of passengers on board the vehicle.

4.2.1 Short Take-Off and Landing (STOL) Aircraft

Many different definitions of STOL aircraft have been used by different authorities and nations and a common one indicates that STOL performance of an aircraft is the ability of aircraft to take off and clear a 50-foot obstruction in a distance of 1500 feet from beginning the take-off run. It must also be able to stop within 1500 feet after crossing a 50-foot obstacle on landing. Short take-off ability permits operations from micro airfields with runways of less than 1000 feet that could open up new opportunities for regional point-to-point transportation. There is great interest for this technology, in the next future, by 2025 the market will be enriched with aircraft of this category. The main development is also focusing on the environmental impact and, for this reason, hybrid STOL are planned. This trend will have an increasing weight over time, with the forecasts for the 2035 market that tends towards fully electrification: in this case, the aircraft are known as eSTOL. For a more long-term perspective, up to 2050, the scenario is twofold. On the one hand, the aim is to improve the technology itself, by improving the environmental impact with sustainable technologies, as well as the aspects of autonomous flight, in order to completely replace the pilot with technology, unlike the previous period in which technology supports the pilot or in any case intervenes only in an emergency. On the other hand, it is necessary to consider that major changes have been required airside to overcome a doubling of traffic air every 12-15 years. In a still-growing number of countries, the capacity to build additional runways continues to be the critical obstacle to accommodating this growth, although advances in technology have partially compensated by enabling smaller aircraft (150-250 passengers) to take off and land on shorter runways, approximately 5000 feet long. The following Table 2 shows several STOL aircraft and their corresponding take-off and landing distances [20].

Table 2: STOL performance comparison[20]

Aircraft	*Take-off to 50 ft (15 m)*	*Landing from 50 ft (15 m)*
Just Superstol	550 ft (168 m)	450 ft (137 m)
Zenith STOL CH 801	400 ft (122 m)	300 ft (91 m)
ShinMaywa US-2	920 ft (280 m)	1080 ft (329 m)
Quest Kodiak	760 ft (232 m)	915 ft (279 m)
Australian Aircraft Kits Hornet STOL	656 ft (200 m)	623 ft (190 m)
Sukhoi Su-80	2686 ft (819 m)	1715 ft (523 m)
PAC P-750 XSTOL	1196 ft (365 m)	950 ft (290 m)
Slepcev Storch	126 ft (38 m)	110 ft (34 m)
Bounsall Super Prospector	300 ft (91 m)	250 ft (76 m)
PZL-105M	1109 ft (338 m)	1070 ft (326 m)
Peterson 260SE/Wren 460	1000 ft (305 m)	1000 ft (305 m)
Zenith STOL CH 701	1257 ft (383 m)	1257 ft (383 m)
AAC Angel	1404 ft (428 m)	1046 ft (319 m)

Spectrum SA-550	675 ft (206 m)	675 ft (206 m)
Antonov An-72	1312 ft (400 m)	1148 ft (350 m)
De Havilland Canada Dash 7	1200 ft (366 m)	1050 ft (320 m)
Maule M-5	550 ft (168 m)	600 ft (183 m)
CASA C-212 Aviocar	2001 ft (610 m)	1516 ft (462 m)
IAI Arava	984 ft (300 m)	902 ft (275 m)
Britten-Norman Defender	1050 ft (320 m)	995 ft (303 m)
SIAI-Marchetti SM.1019	1185 ft (361 m)	922 ft (281 m)
Conroy Stolifter	450 ft (137 m)	400 ft (122 m)
De Havilland Canada DHC-6 Twin Otter	1200 ft (366 m)	1050 ft (320 m)
De Havilland Canada DHC-5 Buffalo	2100 ft (640 m)	2100 ft (640 m)
Britten-Norman Islander	1100 ft (335 m)	960 ft (293 m)
Evangel 4500	1125 ft (343 m)	1140 ft (347 m)
Short SC.7 Skyvan	1050 ft (320 m)	1485 ft (453 m)
PZL-104 Wilga	625 ft (191 m)	780 ft (238 m)

For all these aircraft, the take-off and landing distance will vary with their conditions and the payload. Heavier planes will require more distance to take off. For the future, it is necessary to improve their performances in order to exploit their capabilities in the field of the D2D. Moreover, it should be noted that the STOL class excludes vertical take-off and landing (VTOL) types, rotorcraft, aerostats and most of the so-called light aircrafts [20]. A typical example of STOL capable aircraft is reported in Figure 5.

Figure 5: PZL-104 Wilga (STOL Aircraft)

The following table shows an analysis of D2D performance for a generic STOL aircraft. The score should be interpreted as follows: *one star* is a weakness, *two stars* is an acceptable level, *three stars* is a strength.

Table 3: D2D performance for a generic STOL Aircraft [20]

Feature	*Score*		
Time horizon	2025	2035	2050
Integrability	★☆☆	★★☆	★★☆
Endurance	★★☆	★★☆	★★★
Weather resilience	★★☆	★★☆	★★★
Manoeuvrability	★★☆	★★☆	★★☆
Runway length	★☆☆	★★☆	★★☆
Independency	★★☆	★★☆	★★☆

Based on the analysis carried out above, it results that STOL technology is useful for peri-urban mobility but not particularly indicated as candidate vertical technology for UAM application inside urban environment, in which eVTOL technology is more appropriate, as examined in the following paragraph.

4.2.2 Vertical Take-Off and Landing (VTOL) Aircraft

The flying car market is set to revolutionize the mobility concept and one of the major contributions will be given by Vertical Take-Off and Landing (VTOL) aircraft, of which an exemplary realization is shown in Figure 6 [22], as confirmed by available market analysis reports showing in particular that eVTOL aircraft market is estimated to be around 524 million dollars in 2025 and is projected to reach 1.9 billion in 2035, in terms of value [23].

Figure 6: EHang 216 eVTOL [22]

The market is anticipated to witness a CAGR of 13.75% during the forecast period from 2025 to 2035. This growth is further aided by factors such as increasing road traffic congestion in urban areas and a growing need for faster and efficient transportation. A further proof of the push to the development of this technology is given by Lilium, a company that attracts investors such as Amazon, Tesla, Airbnb, Spotify, SpaceX. Thanks to these reversals, they even have the ambition to be on the regional air mobility market with their electric aircraft as early as 2025 [23].

A VTOL aircraft is one that can hover and land vertically. In addition to helicopter concept, many approaches have been tried to develop aircraft with vertical take-off and landing capabilities. For example, the following aerial vehicles should be considered [20]:

- **Convertiplane:** aircraft which uses rotor power for vertical take-off and landing, then converts to fixed-wing lift in normal flight (usually in tiltrotor configuration, that is the aircraft generates lift and propulsion by way of rotors mounted on rotating shafts at the ends of a fixed wing).
- **Gyrocopter:** type of rotorcraft that uses an unpowered rotor in free autorotation to develop lift. Forward thrust is provided independently by an engine-driven propeller.
- **Quadcopter:** main mechanical components are a fuselage or frame, the four rotors and motors. For best performance and simplest control algorithms, the motors and propellers are equidistant.

A new generation of VTOL aircraft, then, is now being developed and is defined as electric Vertical Take-Off and Landing (eVTOL). It will further improve the ability of VTOL technology to comply with the UAM needs [24]. With the advancements in multirotor distributed electric propulsion systems and the sophisticated controls to manage them, electric propulsion has finally become a viable alternative to hydrocarbon-based systems, so allowing fundamental benefits from the environmental point of view in urban areas.

Although some eVTOLs may look similar to a helicopter, they will be powered by batteries, hybrid engines or other new technologies that will make them much quieter than the helicopters of today. Advanced avionics will enable eVTOLs to navigate with high precision, exchange information digitally and respond to changes in flight conditions autonomously. At initial launch, many eVTOLs will have pilots on board. With time, however, these aircraft will mature to a stage where they will operate autonomously. Urban air taxi services will certainly be a challenge for these aircraft. For example, an aircraft designed with this mission in mind is definitely the Volocopter[4] one, whereas a vehicle designed for inter-city and regional connectivity air mobility is the Lilium[5] one [20]. The Lilium Jet (represented in Figure 7) is designed as a five-seats aircraft and it is powered by no. 36 electric motors: six on each front wing and twelve on each rear wing. The propellers and engines are installed in twelve tilt able wing parts, so as to allow the vertical take-off and landing.

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[4] The Volocopter website, www.volocopter.com/en

[5] The Lilium Gmbh website, www.lilium.com

Figure 7: Lilium Jet [25]

The following table shows an analysis of D2D performances for a generic VTOL aircraft. The score should be interpreted as follows: *one star* is a weakness, *two stars* is an acceptable level, *three stars* is a strength [20].

Table 4: D2D performance for a generic VTOL Aircraft[20]

Feature	Score		
Time horizon	**2025**	**2035**	**2050**
Integrability	★☆☆	★★☆	★★☆
Endurance	★☆☆	★☆☆	★★☆
Weather resilience	★☆☆	★★☆	★★☆
Manoeuvrability	★★☆	★★☆	★★★
Runway length	★★★	★★★	★★★
Independency	★★☆	★★☆	★★☆

EASA expects VTOL operations to make use of existing runways and heliports, on one hand, but on the other hand, the focus of these aircraft will be put on a vast number of future dedicated vertiports, although appropriate requirements do not yet exist. Furthermore, the current legal scope in European regulations usually refers to helicopters. Thus, from an airworthiness perspective, it was intentionally decided to classify the new entrants as a Special Class to provide them with an adequate set of regulations, considering their expected features and potential evolution. The characteristics of the landing locations for VTOL aircraft are being identified, irrespective of whether located within an aerodrome or at a remote location. Considering that, in some phases, VTOL aircraft might have similar characteristics with rotorcraft, current heliports could be used as long as VTOL performance meet the design characteristics of the heliport. A detailed assessment of the EASA aerodromes and heliports rules should ensure that specifications can accommodate VTOL aircraft and, if necessary, develop new elements, in particular when these vertiports or landing sites are located in an urban environment.

4.2.3 Personal Air Transportation System (PATS)

PAT systems involve the use of personal air vehicles, an emerging type of aircraft proposed to provide on demand aviation services. This alternative to traditional land transport methods has made possible by unmanned aircraft technologies and electric propulsion. Thus, this could be one of the solutions to avoid the typical problems associated with ground-based transportation, namely the creation of a personal air transport system capable of overcoming the environmental and financial costs associated with current methods of transport. Indeed, such a system could allow quick travel in the city and it can eliminate the time loss, even if it has to be connected with procedures such as check-in and security controls. Many prototypes have been built since the early 20th century, by using a variety of flight technologies, such as distributed propulsion, and some of them have demonstrated VTOL performance. The PAL-V Liberty roadable aircraft aims to become in 2021 the first flying car in full production. Nevertheless, the large-scale use of this technology is not yet mature. In fact, available infrastructure is not currently capable of handling the increase in aircraft traffic that would be generated by PAT systems. Currently FAA Next Generation Air Transportation System is planned for 2025 [20].

An example of personal air transport is provided by the use of quadcopter as passenger drone [42]. The following table shows a list of the most known PAT aircrafts. Their peculiar characteristics are: less than 5 passengers, cruising speed of 150/200 mph, quiet, comfortable, reliable, able to be flown also autonomously, as affordable as travel by car or airliner, near all-weather capability enabled by synthetic vision systems, highly efficient (able to use alternative fuels, fuel cells or electric batteries), range of 800 miles and D2D transportation solutions integrated [20].

Table 5: List of most famous PAT aircraft[20]

Model	Seats	Speed (km/h)	Range (km)
BLI Helodyne	4	230	1950
Lilium Jet	1	300	300
PAV-X	1	110	64
GEN H-4	1	200	60
Mosquito XE/XEL	1	130	240
Samson Switchblade	2	108	555
Terrafugia Transition	2	185	787
Samson Skybike	1	140	80
Parajet Skycar	2	160	320
VerdeGo Aero PAT200	2	240	32/64
PAL-V gyrocopter	2	180	350/500

Despite the fact that PAT aircrafts were born to fully satisfy the D2D paradigm, there are still many barriers to be evaluated, among them usability, airworthiness, aviation safety, airspace integration, operating costs, aircraft noise and emissions. Many efforts will be needed to allow the necessary adaptation of infrastructures and services to the new emerging paradigm but, as opportunities address both social and economic aspects, it will only be a matter of time: personal air transport system can become a reality that will irreversibly change both our cities and our way of life. An example of possible PAT vehicle is reported in the following Figure 8.

Figure 8: PAV-X [26]

The following table shows an analysis of D2D performance for a generic PAT aircraft. The score should be interpreted as follows: *one star* is a weakness, *two stars* is an acceptable level, *three stars* is a strength [20].

Table 6: D2D performance for a generic PAT Aircraft[20]

Feature	Score		
Horizon	**2025**	**2035**	**2050**
Integrability	N/A	★☆☆	★★☆
Endurance	N/A	★☆☆	★★☆
Weather resilience	N/A	★☆☆	★★☆
Manoeuvrability	N/A	★★★	★★★
Runway length	N/A	★★★	★★★
Independency	N/A	★★★	★★★

It will be crucial to investigate the technologies needed to provide the operational infrastructure required for a PAT system to be used on a large scale, as this system will provide wider use of small aircraft, served by small airports, to create access to more communities in less time. An important factor to consider are the main natural determinants of personal transportation system efficiency, i.e.:

- traveling time as effect of speed, infrastructure, traffic management system and accessibility;
- energy used (fuel) on the realization of one passenger-kilometre at given speed;
- resources used for the transport and infrastructure production on one passenger-kilometre;
- environmental impact.

The global determinant including all factors expressed in monetary form is the generalized cost of transport of one passenger-kilometre. One disadvantage of the system could be the time loss connected with procedures such as check-in and security controls, which can reduce the potential advantage of higher travel speed. It will therefore be very important to also look at these pre and after trip procedures.

In conclusion, with reference to the technologies mentioned above, it can be said that the most accredited ones for Urban Air Mobility in terms of passengers transport are certainly eVTOL and PATs vehicles.

4.2.4 Cargo Drones

Drones for goods transport are becoming an important part of the rapidly expanding modern logistics industry. The transport of goods is shifting from traditional methods (e.g. by road) to a new generation transport [27]. Today, through the use of cargo drones for goods transport, cargo drones applications are leading the way for the already operational use cases of UAM. This is linked to the fact that a large number of national authorities have issued permits that allow logistics companies to try commercial cargo drones. The most important feature of cargo drones is short delivery times. Moreover, delivery drones have the potential to decongest urban streets through the use of parcel delivery.

One of the big advantages in using drones for the transport of goods, in addition to extremely short delivery times, is also the ability to reduce traffic jams related to the transport of goods by road, which translates into a reduction of C02 emissions into the atmosphere, with well knows environmental benefits.

In this section the cargo drones enabling technologies with MTOW more than 25 kg will be analysed. Such MTOW threshold excludes popular applications as e.g Amazon drones, Wingcopter drones etc., because they involve typically MTOW lower than 25 kg. For dronw with MTOW greater than 25 kg it is needed the authorization to operate from the national aviation authorities and, in addition, operating organizations must meet the following requirements:

- holding an appropriate technical and operational instrumental of the assets for the intended flight operations and characteristics for the drone fleet;
- appointing a technical director for the management of operations, airworthiness and training;
- having the availability of duly certified drones;
- employ pilots certified by the relevant body (e.g. ENAC for Italy);
- preparing the applicable flight operations manual and distributing it to all the staff involved in the operations.

Pipistrel is developing the hybrid-electric powered cargo drone Nuuva V300 VTOL (Figure 9), a long-range, large-capacity, autonomous UAV. It will take off and land vertically with battery power, meaning it does not require a runway and has significantly lower operating costs than helicopters. It can carry loads up to 300 kilograms for more than 300 km (186 miles), making it an ideal solution for deliveries to areas traditionally accessible only by helicopter. At lower take-off altitudes and with shorter mission requirements, the payload can be increased to up to 460 kg [29].

Figure 9: Pipistrel Nuuva V300 ibrid-electric cargo drone [28]

The Nuuva V300 takes-off and lands using eight independent battery-powered Pipistrel E-811 electric engines, already Type Certified. This revolutionary zero-emission powertrain is entirely liquid-cooled, including the batteries, and has demonstrated the ability to withstand faults, battery thermal runaway events, and crash loads as part of the EASA certification process. The whole system is safeguarded by the integrated health self-monitoring system that alerts of potential malfunctions even before they occur, increasing the reliability and safety [29].

Another enabling technology for the transport of goods, was created in collaboration by the two German company Volocopter and Schenker (logistics company) with its VoloDrone [30], which is able to transport goods weighing from 150 kg to 200 kg. Volodrone is a fully electric drone, capable of carrying a payload of up to 200 kg for an autonomy of approximately 40 km [31]. Furthermore, Volodrone is equipped with a standardized attachment system for flexible goods, therefore adaptable for different goods solutions. A representation of this vehiche is reported in Figure 10, whereas its main performances are reported in the following table.

Table 7: Volocopter "Volodrone" characteristics [31]

Volodrone	Range [km]	Cruise Speed [km/h]	Payload [kg]	Safety
	35-65	80	150-200	10^{-9}

Figure 10: VoloDrone – Volocopter [30]

The Chinese company Ehang made available a cargo version of its Ehang 216 drone in October 2020, for short and medium-range air logistics in urban and rural areas. The cargo drone EHang 216L eVTOL (represented in Figure 11) is powered by 16 electric motors arranged in a coaxial manner for redundancy and safety issues in the event of an engine failure, it has a maximum cruising speed of 130 Km / h, a flight time of 21 minutes at full payload, distance covered at maximum speed of about 35 km and a maximum payload of 200 kg [32]-[33].

Figure 11: EHang 216L cargo drones [32]

The Italian company Leonardo, in collaboration with D-Flight (a company of the ENAV group), is also conducting a series of demonstration flights authorized by ENAC, to test a 130 kg drone (see Figure 12) with electric propulsion, capable of transporting goods up to 25 kg. The demonstration flights were conducted in Turin (Italian city). The project, named SUMERI [34], is the first in Italy, and among the first ones in the world, in which a freight drone flew in an urban context. This project is part of a series of experiments that will lead to a future where drones carrying hundreds of kilos of cargo will be flown up to 50 km by operators using a Beyond Visual Line of Site (BVLOS) control system.

Figure 12: Leonardo experimental cargo drone [34]

The trial incorporated three factors that will be essential in the development of innovative logistics services for urban environments: the high load capacity of the drone, a high level of automation and advanced capabilities for dealing with air traffic management. The benefits to citizens of such services will include faster deliveries, lower costs and, most importantly, reduced pollution due to the drones' electric

propulsion systems. The demonstration conducted in the SUMERI project was benefited by a software platform for air traffic management developed by D-Flight, which also provides registration services and drone identification code (QR-Code) for the flight test.

On February 26, 2020, Drone Delivery Canada company announced that it will begin commercial operations testing of its long-range heavy-lift Condor [35] cargo delivery unmanned aerial vehicle (see Figure 13). This phase of testing, which will involve BVLOS flights, will take place at the Foremost UAS Test Range in Alberta.

Figure 13: Condor cargo drone [35]

The Condor has a lifting capability of 180 kgs (400lbs) of payload, a travel range of 200 km and an operating speed of 120 kph. The multi-package payload compartment is designed to carry approximately 20 cubic feet of cargo. Measuring 22 feet long, 5 feet wide and 7 feet tall, and with a rotor diameter of approximately 20 feet, it is capable of vertical take-off and landing (VTOL).

Another company engaged in the design, construction and testing of cargo drones is UK-based Malloy Aeronautics [36]-[38]. Figure 14 shows one of their cargo drones and in particular the T-150, with a payload capacity of 68 kg, covers a maximum distance of 70 km and 36 minutes of flight at full load.

Figure 14: T-150 cargo drone of the Malloy Aeronautics company [38]

4.3 Infrastructures

The greatest operational barrier for the success of vertical mobility is the infrastructure to take off and land. Setting up a suitable UAM infrastructure is a major challenge for any city. Due to its nature of picking up passengers or dropping them off in closely congested city districts, "vertiports" (see Figure 15) must be integrated into an existing city infrastructure and architecture, ensuring a fast but also secure boarding and deboarding.

Figure 15: Example of vertiport integrated in an existing city [39]

The German company Lilium, one of the main leaders together with Volocopter in the development of enabling technologies for Urban Air Mobility, has proposed a scalable vertical model and therefore adaptable to every need (see Figure 16) [40]. Lilium has been working on a lean, modular design that will help make vertiports accessible to developers large and small and suitable to be placed at an existing transport terminal (see Figure 17), next to a shopping center, on top of a busy car park or alongside a suburban residential development.

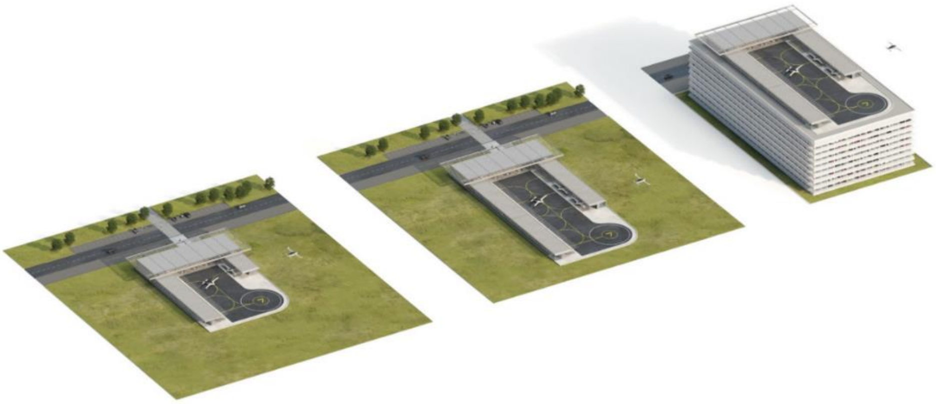


Figure 16: Lilium scalable vertiport design [40]

Each module consists of a set of functional components that are optimized for regulatory compliance and reliable operations. Lilium have followed existing regulations where applicable, for example in the design of the safety areas, in the guidance relating to obstacle clearance, and in the design of the Landing and Take-off Area, which has a diameter of 1.5x the ‘critical dimension’, which in their case is the wingspan of the Lilium Jet.

Figure 17: Lilium vertiport design near Airport terminal [40]

Other problems are the recharging of a drone and its repair as well as parking it waiting for passengers. The UK ground infrastructure developer Skyports, specialized in landing infrastructure in cooperation with Volocopter, opened what it describes as “the world’s first vertiport (see) for electric vertical take-off and landing aircraft” in Singapore in the 2019 and has made the first live flight trials with Volocopter’s 2X prototype in the same year.

Figure 18: Urban Air Mobility new Vertiport Infrastructure [41]

Skyports has joined forces with the Volocopter to launch commercial services in Singapore [42] and Paris [43] starting from 2022, which puts Singapore and Paris in pole position to launch Urban Air Mobility in Asia and Europe. In October 2019, Volocopter completed the air taxi demonstration flight in Singapore, giving observers the opportunity to have a sense of what UAM will look like. Before launching the services in Singapore, Volocopter will obtain the necessary regulatory approvals, including those from CAAS and the European Union Aviation Safety Agency. To achieve this, Volocopter will be conducting comprehensive tests, flight trials, evaluations, and certification before approval to commence commercial air taxi operations can be granted [42][44]. The first route is expected to be a touristic route. Follow-on connections may include cross-border flights, which may enhance regional connectivity.

Volocopter will start testing its electric Air Taxi VoloCity in Paris in 2021, with the perspective to put Paris in a significant strategic advantage as a major European hub generally and providing a good opportunity for fither UAM initial applications in view of the upcoming 2024 Olympics and Paralympics set to take place in the city. The first half of 2021 will see Volocopter setting up the necessary infrastructure, first in the air and then in the boarding areas within the nearby buildings. With the cooperation of the DGAC (the local Civil Aviation Authority), parking, take-off and landing operations, as well as operations around the vehicle, whether maintenance or electrical recharging, will be tested beginning in June 2021 [45].

Vertiports and ground based support infrastructures are fundamental to UAM implementation, because electric VTOL aircraft will only become a useful component of tomorrow's mobility if they are well and thoughtfully integrated into the overall transport network of a city, so eVTOL landing sites, or vertiports, are a determining factor for the ecosystem. A city needs to have sufficient sites for take-off and landing as well as charging, in addition to the necessary resources to operationalize air traffic control. Finally, urban eVTOL infrastructure has to strike an acceptable balance between benefits and disturbances, such as defining and zoning the proper use of rooftops. Of course, existing aviation infrastructures such airports, heliports can also be used as primary candidates to host vertiports.

Some main infrastructural elements of a vertiport can be inspired from ICAO Annex 14 Volume 2, Heliports. This includes, in terms of conceptual design: markings, lightings, Touchdown and Lift-Off (TLOF) area as well as Final Approach and Take-Off (FATO) area. Infrastructure growth will be driven by the initial build-out phase and the ensuing stages of expansion and elaboration, when an increasing number of vertiports service a growing base of passenger drones. Other components that need to be built are standardized and efficient fast-charging stations and systems for air traffic control communications.

4.4 Propulsion

VTOLs UAM technologies could be powered by different propulsion systems, ranging from hybrid (conventional combustion engine or gas turbine combined with e-motor) to fully electric powered solutions, referring to the eVTOL vehicles, which are the most suitable technologies for the UAM implementation.

Take-off and landing aircraft face the same challenge as the automotive industry: the battery. To date, the eVTOLs on which the focus is mostly on offer systems with lithium-ion (Li-ion) batteries which still represent the only real reliable alternative on a commercial level despite having important limits in terms of weight, capacity and safety (they are highly flammable).

In the future, it will be necessary to find solutions that guarantee greater autonomy and power, recharging times and lower weight, so it is assumed that the leap could take place with the advent of solid-state batteries. Other options, such as that represented by hybrid engines, appear inadequate in terms of noise and pollution.

4.4.1 Thrust and lift design configurations

UAS design plays significant role in the way the aircraft flies, the infrastructure it requires for operation and the noise it generates. These are the factors the passengers and authorities pay the most attention to, because they affect the living in the closest vicinity to the UAS operations.

On the other hand, UAS design is crucial when it comes to its performance and flight parameters. Thus, UAM services operators seek the most efficient, versatile and cost-effective UAS. One of the most important aspects in every aircraft design is the propulsion system that has enormous impact on nearly most of the UAS parameters.

Aircraft system designs of most UAM nowadays utilize the thrust generated by rotors to propel the vehicle. Amongst the most important features that affect the performance of rotor systems are:

- Number and size of rotors
- Rotors distribution
- Presence of duct around the rotor

Number and size of rotors

Number and size of rotors are mutually dependent. This stems from the fact that in order to lift the aircraft into the air, sufficient amount of thrust must be generated. As the thrust per one rotor increases with the rotor size, the less the rotors the bigger they must be. However, bigger rotors generate more noise as the propeller tips rotate with greater velocity. Thus, with an aim to maintain noise level as low as possible within urban areas, more favorable rotors are with smaller diameter. Thereby, more rotors yet smaller, are the goal many manufacturers try to accomplish with their aircraft design.

Figure 19. Volocopter – VoloCity with 18 rotors

Rotors distribution

Rotors distribution has become more popular with the emergence of electric engines that require less mechanical, heavy components. Distributed propulsion has many benefits and some of them are: less noise emission, less energy/fuel consumption. It is achieved by reduction of aerodynamic resistance around the wingspan and also behind it by boundary layer ingestion and wake-filling. Furthermore, such configuration provides: reduced weight of the vehicle and maintenance costs.

Figure 20. Lilium Jet with distributed electric propulsion

Presence of duct around the rotor

Ducted rotors, despite additional weight compared to the one without a duct, exhibit improved aerodynamics. It is achieved by decreasing the propeller tip vortices that deteriorate the ideal airflow through the rotor and thus reduce the thrust at the same power. Eliminating or reducing those tip vortices increases the thrust to power ratio and thereby reduces the energy/fuel consumption.

Figure 21. Bell Nexus 6HX with ducted rotors

4.4.2 Powertrain technologies

Depending on the powertrain system, the aircraft may have different operational characteristics which is strongly correlated to the available power, energy capacity and resulting weight of the aircraft. The perfect solution would be the maximum available power with abundancy of energy and the weight of the aircraft as low as possible. Unfortunately, when some parameters enhance, another must deteriorate. With an emergence of electrically powered aerial units, the need for efficient, high performance powertrain is growing rapidly. Below are presented the types of powertrains developed intensively nowadays.

4.4.2.1 Electric with battery/capacitors energy source

The use of electric motors provides many advantages over the combustion engines. The most prominent advantages are: over twice the efficiency, less complicated design and thus less weight. This is why more sophisticated design of UAS appear on the market, featuring distributed propulsion system. Such solution delivers more aerodynamic optimization and thus less energy consumption and lift/cruise flight modes. On the other hand, conventionally used batteries exhibit low capacity to weight ratio, which leads to reduced cruise ranges of aerial vehicles.

Batteries specification

There are many battery types available on the market today, including: Lead-acid, Ni-Cd, Ni-MH, Li-ion/Li-Po.

Among above-given examples, the most power density and discharge rate have li-ion batteries. Thereby, they are used in most of electric aircrafts nowadays. To give more explanation why the li-ion batteries are commonly used in electric vehicles, below is the table that presents the core properties of batteries:

Table 8: Core properties of different types of batteries [46]

Property	*Lead-acid*	*Ni-Cd*	*Ni-MH*	*Li-ion*
Specific energy [Wh/kg]	1-60	20-55	1-80	**3-100**
Specific power [W/kg]	<300	150-300	<200	**100-1000**
Energy density [kWh/m^3]	25-60	25	70-100	**80-200**
Power density [MW/m^3]	<0,6	0,125	1,5-4	**0,4-2**
Maximum cycles	200-700	500-1000	600-1000	**3000**
Efficiency [%]	75-90	75	81	**99**

Bearing in mind that electric motors exhibit great efficiencies, reaching up to 96% [47], worth remembering is that auxiliary systems are needed to power them, for example: controllers, cables, battery, BMS (battery monitoring system), cooling system, etc.

Considering the electric powertrain with battery as the heaviest component, the range of the aerial vehicle is dependent on the energy consumption during the flight and on the battery capacity. The higher the battery capacity, the more energy is available for consumption during the flight. However, when the battery size is increased, the heavier the vehicle becomes. Therefore, this factor decreases the useful energy for cruising. Depending on the vehicle aimed size and passenger/cargo capacity, the manufacturer must optimize the total battery size and the resulting range to provide optimum room and satisfactory flight distance.

The example of battery pack installed in modern passenger UAM vehicle is the one from Lilium Jet (presented below). The manufacturer claims the 245 km range and the total flight time of 55 min.

Table 9: Lilium Jet mass and battery data [48]

Property	*Value*	*Method of estimation*
Total mass [kg]	490	Assumed
Battery mass [kg]	240	Computed
Battery mass to total mass ratio	49%	Computed
Total battery energy [kWh]	38	Computed
Specific energy [Wh/kg]	157	Assumed
Specific power [W/kg]	735	Assumed

While the passenger UAVs are being developed substantially for air taxi purposes, the other major sector where drones can be employed is logistics. It is assumed that big cargo drones can be used for heavy items shipping. One of such aircrafts is fully electric multicopter – VoloDrone that can fly for up to 40km with a payload of 200kg [49].

Figure 22. . VoloDrone, Volovopter and DB Schenker

On the other hand, small up to 25kg cargo UAVs may serve the last mile delivery purposes. There are many examples of such services being tested. One of them is DHL cargo drone with the maximum payload up to 5kg. The manufacturer claims the operational range of 8km and the delivery time for that range as 8 minutes [50].

Figure 23. Cargo delivery drone, DHL

Capacitors specification

Capacitors are mainly used as a complementary to li-ion batteries onboard the electric vehicles. This stems from the relatively low specific energy of capacitors. On the other hand, their high charge/discharge rates make them perfect for emergency maneuvers that may occur during the UAS flight. Worth noticing is that there are super-capacitors or ultra-capacitors that exhibit greater specific energy values compared to classic capacitors and therefore they are mounted in electric vehicles.

The table beneath presents the differences between the li-ion batteries and super-capacitors that indicate the factors that affect their use in electric vehicles.

Table 10: Comparison of super-capacitors and Li-ion battery [51]

Property	*Super-capacitor*	*Li-ion battery*
Specific energy [Wh/kg]	5-15	120-240
Specific power [W/kg]	Up to 40k	1000-3000
Maximum cycles	500k-1000k	500-5000
Charge time	1-10 sec.	10-60 min.

As it can be noticed in the table above, super-capacitors cannot be used separately in electric vehicle as a main energy source as their specific energy is much lower than for li-ion batteries. However, by combining capacitors with batteries, the electric vehicle is able to perform fast and quick maneuvers requiring sudden outburst of thrust and thus electric energy. Another fact about li-ion batteries is that they are not intended to high discharge rates. Super-capacitors are then a great solution.

Impact on environment, infrastructure, society

As electric motors do not emit harmful compounds just as combustion engines do, electric vehicles including electric UAS are perceived as environmentally friendly. This is true but only partially. Whether the UAS has low or high carbon footprint, even though it is electric, the most important factor is the source of electric energy. If the energy comes from the renewables, the carbon footprint is very low. On the other hand, when the electricity comes from fossil fuels, carbon footprint may increase substantially.

When it comes to infrastructure, the most crucial factor relates to recharging/swapping facilities to provide seamless UAM services. The so-called superchargers should be installed on vertiports and other UAM infrastructure to ensure fast charging capabilities. However, when battery swapping is allowed in UAS by its manufacturer, the batteries storage facilities must be established. The concept of fast battery swap has been presented by Volocopter.

Figure 24. Battery pack swap concept by Volocopter [52]

From the sociological point of view, electric powertrains exhibit more advantages rather than disadvantages. That is mainly correlated to carbon and nitrogen emissions coming from combustion engines. However, electric powertrains are a relatively young technologies installed in aerial vehicles. This raises the issues with social acceptance of UAM services. Thereby, the more test campaigns with use of UAM vehicles, the more trust people will give to new mode of urban transport.

4.4.2.2 Electric with fuel cell energy source

Fuel cells are electrochemical devices that convert the chemical energy directly to DC electricity and generate also some by-products of the electrochemical reaction in fuel cell such as water, heat and low-oxygen containing exhaust air. In high temperatures fuel cells heat as a by-product can be used in cogeneration system (simultaneous use of heat and electricity) that usually boost the overall system efficiency [53].

Fuel cells used in aviation, compared to stationary, automobile and portable applications, need to meet special, higher requirements and safety issues, with the need for dynamic changes and adjustment to various environmental conditions concerning: altitude, temperature, pressure, humidity, vibrations, shock and radiation [54].

The development of fuel cell technology reduces the weight per unit volume at the same time increasing power and energy density as a response to one of the biggest challenges in aviation technology – mass. This results in an advantage of fuel cell systems over advanced batteries in current UAVs. Compared to combustion engines fuel cells generation of noise and emission of heat and exhaust gasses, except small amounts of water vapour, is relatively small, thus leaving no noise and heat signature.

Fuel Cells specification

Generally, fuel cells can be classified according to two parameters: the type of electrolyte and temperature. Regarding electrolyte:

- DMFC - Direct Methanol Fuel Cell
- PEMFC – Electrolyte Membrane Fuel Cell or Proton Exchange Membrane Fuel Cell
- AFC – Alkaline Fuel Cell
- PAFC – Phosphoric Acid Fuel Cell
- MCFC – Molten Carbonate Fuel Cell
- SOFC– Solid Oxide Fuel Cell

Currently the most promising type of fuel cell for alternative power source for the use in aviation is Polymer Electrolyte Membrane Fuel Cell/Proton Exchange Membrane Fuel Cell (PEM). PEM fuel cell can be beneficial for powering UAVs, providing low temperature operations that fuel cells can operate efficient with short start-up and shut down times in ambient temperature conditions. PEM fuel cells are characterized with a high efficiency, fast response to the load, a reliable power output for vehicular and mobile applications that make them technically visible to power UAVs [54].

Table 11: Properties of different types of fuel cells [55]

Fuel Cell Type	*Applications*	*Advantages*	*Challenges*
Polymer Electrolyte Membrane (PEM) ***Operating temperature:*** < 120°C ***Electrical Efficiency (LHV)****:* 60% direct H2; 40% reformed fuel	Backup power Portable power Distributed generation Transportation Specialty vehicles	Solid electrolyte reduces corrosion and electrolyte management problems Low temperature Quick start-up and load following	Expensive catalysts Sensitive to fuel impurities

Alkaline (AFC) ***Operating temperature:*** < 100°C ***Electrical Efficiency (LHV)****: 60%*	Military Space Backup power Transportation	Wider range of stable materials allows lower cost components Low temperature Quick start-up	Sensitive to CO_2 in fuel and air Electrolyte management (aqueous) Electrolyte conductivity (polymer)
Phosphoric acid (PAFC) ***Operating temperature:*** 150°C – 200°C ***Electrical Efficiency (LHV)****: 40%*	Distributed generation	Suitable for CHP Increased tolerance to fuel impurities	Expensive catalysts Long start-up time Sulfur sensitivity
Molten carbonate (MCFC) ***Operating temperature:*** 600°C – 700°C ***Electrical Efficiency (LHV)****: 50%*	Electric utility Distributed generation	High efficiency Fuel flexibility Suitable for CHP Hybrid/gas turbine cycle	High temperature corrosion and breakdown of cell components Long start-up time Low power density
Solid oxide (SOFC) ***Operating temperature:*** 500°C – 1000°C ***Electrical Efficiency (LHV)****: 60%*	Auxiliary power Electric utility Distributed generation	High efficiency Fuel flexibility Solid electrolyte Suitable for CHP Hybrid/gas turbine cycle	High temperature corrosion and breakdown of cell components Long start-up time Limited number of shutdowns

UAS fuel cell development

Research on the use of fuel cells in small unmanned aircraft has already been underway for a number of years and there have been several fuel-cell-powered unmanned aerial vehicles.

Recently it has been proved that fuel cell energy systems can also be implemented in air taxis and cargo UAV significantly increasing their possibilities. Fuel cells have a higher energy density than lithium batteries, increasing operational range and flight time. It also takes less time to refuel hydrogen tank than to fully charge a battery, increasing the utilization rate.

One of the operable prototype of hydrogen fuel cell system has been built by HyPoint company which focusses on the eVTOL providing turbo air-cooled fuel cell system. With the entire system taken into account, the HyPoint system can deliver delivers 2 kW/kg of power per kilogram of mass. The energy density of the full system is estimated at around 960 Wh/kg. The working temperature is in the range of -50 to +50 °C. Additionally it is predicted that this fuel cells will last some 20,000 hours without maintenance [56].

One of the Hypoint's partners is Piasecki Aircraft Corporation, developer of the PA-890 eVTOL aircraft and a range of other urban air mobility-related technologies. The PA-890 eVTOL aircraft is an all-electric-powered Slowed-Rotor Winged Compound helicopter. It is intended for use in a variety of missions including Emergency Medical Services (EMS), delivery of high-value On-Demand Logistics (ODL), On-Demand Mobility (ODM) personnel air transport; and many other commercial applications. Piasecki Aircraft Corporation is one of HyPoint's airframe partners [57].

Figure 12 PA-890 eVTOL – HyPoint and **Piasecki Aircraft Corporation [58]**

HyPoint cooperates also with Urban Aeronautics to incorporate hydrogen power into the company's CityHawk eVTOL and with Britani to incorporate fuel cells into Bartini's eVTOL. There aircrafts are intended for passenger transportation.

Israel-based aircraft developer Urban Aeronautics has announced an agreement with HyPoint to incorporate zero carbon emissions hydrogen power in its CityHawk eVTOL with Coaxial 4-rotor "Fancraft" with 6 seats, 168 mph top speed, 93-mile range [59].

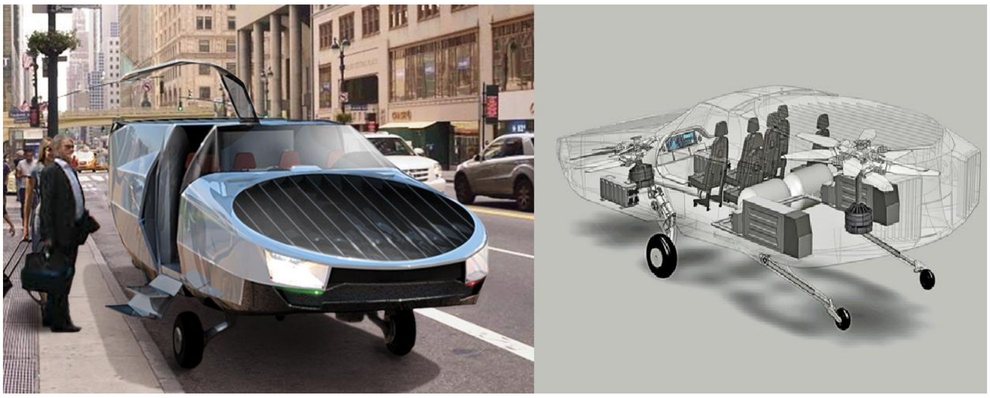


Figure 13 CityHawk eVTOL – HyPoint [60]

Bartini's eVTOL design with eight tilting, coaxial ducted rotors, promises 550-km (342-mi) ranges and 300-km/h (186-mph) speeds.

Figure 14 Bartini's eVTOL design [61]

A new electric vertical take-off and landing (VTOL) air taxi company came out of UAV using a hydrogen fuel cell powertrain that generate electricity, powering all onboard systems and 6 quiet electric out-runner motors. Alaka'i Technologies' Skai UAV has a range of up to 4 hours and 400 mi (640 km) and a five-passenger capacity [62]. There is liquid hydrogen tank onboard that needs less than 10 minutes for full refuelling [63].

Skai specification include [64]:

- Co-designed by Designworks with inherent quality craftsmanship;
- Powered by clean hydrogen fuel cells, with zero emissions;
- Range: up to 4 Hours, ~ 640 kilometres;
- Six reliable, quiet, efficient electrimotors with designed-in redundancy;
- Seats up to five passengers;
- Reliable, fault-tolerant architecture for safety and security;
- Piloted version launched first, with autonomous versions to follow;
- Designed for the ultimate in safety, with an Airframe Parachute.

Figure 15 Skai design concepts [65]

Impact of hybrid electric propulsion systems on infrastructure, environment and society:

There is a potential of fuel cell application in UAVs during various missions and applications. For small UAVs fuel cells have definitely better efficiencies and optimal energy density parameters compared to combustion engines.

The main challenges and current research on fuel cell in aviation focuses mainly on the following topics:

- Power and energy management for hybrid energy sources

Due to the fact that none of the available energy sources can easily fulfil alone all the demands that of electric UAV to enable them to compete with conventionally powered UAVs, hybridization of battery, fuel cell, supercapacitors allows for an optimized energy balance, better response to the flight requirements and operation fulfilling the expected flight range and maintaining UAVs performance.

- Fuel storage and onboard electricity generation

Fuel cells exhibit no moving parts, which makes UAVs energy system more reliable. It simplifies maintenance as well as decrease vibration without compromising the efficiency [66].

Compared to the combustion engines, fuel cells with air cooling system generate relatively small amount of noise and emission of heat and exhaust gasses with small amount of water vapour, thus, leaving no noise and heat signature easy to detect [67]. Fuel cells do not emit pollutants directly, and the emission related to this technology is linked mainly with hydrogen production.

Nevertheless, there is still a need for improvement in weight, volume, cost reduction, sensitivity of the electrode catalyst to poisons and the poor hydrogen generation infrastructure in order to deliver fuel for fuel cells, which are already in use.

4.4.2.3 Hybrid electric with petrol as energy source

In the past few years a concept of hybrid electric aircrafts has received a great deal of attention by aviation industry. Hybrid technology has become popular, well known and reliable especially due to hybrid electric vehicles which has appeared on the global market more than 20 years ago. Hybrid vehicles owes their appreciation due to simple and reliable mechanics, fuel economy, low maintenance costs and reduced CO_2 emission. The same is expected from hybrid technology to be implemented into aircrafts both manned and unmanned. Electric motors are the most desirable for propulsion. They can produce sufficient power and torque in the whole operational range, with very high efficiency which is up to 95% and low noise level. The only issue is to deliver sufficient electric power for their operation as battery energy storage is still a big challenge. Compared to the high specific energy of conventional jet fuel which is approximately 13 000

Wh/kg, specific energy of batteries is very low – approximately 100-200 Wh/kg [68]. This is why the use of batteries as energy source is at the moment only feasible for small aircrafts which have a low weight and limited range.

Figure 12. Hybrid electric platform "Silent Air Taxi"

The first approach for hybrid electric propulsion is to provide additional power in specific mission phases such as take-off and climb. Such conception can allow for conventional engine to be optimized for a single flight condition while during any other phase propulsion can be supported by electric powertrain. This kind of technology can save approximately 7,5% [69] of fuel consumption in short range missions and this effect is demonstrated due to lower weight and optimization of operational mode of conventional piston or gas turbine engine.

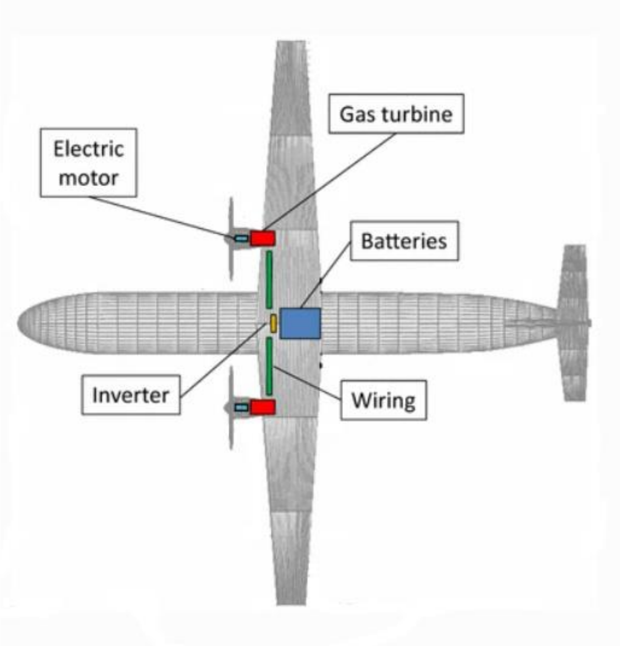


Figure 13. Aircraft hybrid electric propulsion integration

The second conception is a fully electric powertrain with a conventional petrol engine used as a range extender. This combination allows for any configuration of electric motors and allows for limited weight of batteries which no longer have to exhibit great capacity. In such system petrol engine drives only the electric generator which deliver all electric power needed for propulsion and other aircraft systems. Many profits can be demonstrated from such approach. First of all conventional piston or gas turbine engines can be optimized for specific operational range which would be constant in all flight phases. This can provide better efficiency, less fuel consumption, extended maintenance intervals and lower noise level. This kind of solution also provides specific improvement in technology design such as aircrafts with distributed propulsion which might especially find use for UAM. Distributed propulsion can be used to enhance efficiency by wake-filling and boundary layer ingestion. In addition a higher integration of the propulsion system and airframe can lead to a lower structural weight and what is especially desirable in VTOL aircrafts electric motors can be easily placed on movable components of an aircraft.

As reliance to UAM technology still needs better recognition and society acceptance it is expected the first to be deployed to the city traffic are cargo UAM. There are ongoing projects for such solution just like Pipistrel Nuuva V30012 [70] which is a cargo drone capable to lift a payload of 460 kg. This UAM is a great example of VTOL hybrid electric aircraft which combine all advantages of its distributed propulsion system and take-off and landing capabilities. The aircraft takes off and lands using electric motors, powered by batteries then turns the VTOL propellers and uses an internal combustion engine for the pusher propeller for forward flight. The Nuuva V300 can be optimized to fly a lighter load with a longer range or fly a heavy load with a shorter range. For example, the manufacturer claims the range of 300km with a 300kg of payload. The aircraft also has anti-ice capabilities that allow it to fly in cold environments.

Figure 25. Pipistrel Nuuva V300 - Hybrid Electric VTOL

Hybrid electric propulsion systems should be considered as a transitional solution. As long as modern technology is not yet developed to provide high efficiency batteries as electric source, hybrid systems are the best solution for improving performance, economy and CO_2 emission reduction. It is especially important in order to deal with challenges related to global programs for climate change protection.

Hybrid electric propulsion systems should be considered as a transitional solution. As long as modern technology is not yet developed to provide high efficiency batteries as electric source, hybrid systems are the best solution for improving performance, economy and CO_2 emission reduction. It is especially important in order to deal with challenges related to global programs for climate change protection.

Impact of hybrid electric propulsion systems on infrastructure, environment and society:

New technologies, regardless of its accurateness often meet with a lack of acceptance in society or even among some part of industry experts. New solutions usually might be considered as controversial or not obvious. Hybrid electric systems have a big advantage over other new technologies and gained a huge acceptance over past years and this stems from its high reliability, improved economy and better identification thanks to hybrid vehicles which are already well known and recognized. Hybrid systems need only minor changes in infrastructure – recharging stations localized on airports and in any locations where especially UAM are likely to occur in further time horizons and fuel stations where not available. This kind of infrastructure is not significantly demanding and allows for renewable energy source implementation as well. However the battery manufacturing and disposal process is the biggest challenge. The CO_2 footprint during production and sourcing valuable raw materials is relatively high and needs improvement to deal with significantly growing demand for this kind of products which are more and more likely to find use in any industry branch. On the other hand, fuel burning by combustion engines during the operation of UAS is a source of major air pollution. Having this in mind, hybrid electric technology is an intermediate solution that combines many advantages and drawbacks at the same time.

4.5 ICT

Cities around the globe are growing at a rate that no one could have ever predicted in the past. With many opportunities available, people are now incentivized to relocate to urban areas in the search to improve their quality of life. However, with increasing urbanization, cities will start to face significant challenges in the future, including the need for more infrastructure, the improvement of health services and the management of energy resources. This poses the question: How will the cities of the future solve these types of difficulties using new technologies, in particular in the mobility field? The development of Information and Communication Technologies (ICT's) has allowed traditional cities to promote new initiatives in order to solve many of these issues. This is how the concept of "Smart City" was born. The Smart Cities initiative aims to mitigate problems by implementing new technologies to deal with fields like optimizing living spaces, reducing pollution and managing energy consumption. In addition, more factors involved in the immersion of Smart Cities are the emerging trends of automation, machine learning, and Internet of Things devices, which have increased to 50 billion devices since its inception in 2009.

One of the key areas in the development of Smart Cities is transportation, which many refer to as "Smart Mobility." The most common problem for commuters is the large traffic congestion during their morning commute. The U.S. loses USD 120 billion dollars every year due to these congestions, according to INRIX. With new solutions, transportation will start becoming more efficient in urban areas, allowing its citizens and governments to save more resources and decrease environmental impact. Public entities, large corporations and smart cities startups, all of them are suggesting their own solutions to improve mobility in smart cities.

The technology that could be very useful to solve the traffic congestion of the commuters during their morning commute is the UAM, as indicated in the previous sections of this document. Nevertheless, it needs a suitable ICT infrastructure, because many vehicles need to be connected all together with huge data sharing and, furthermore, also the autonomous flight needs to manage big quantity of data with lower latency time. The solution at this problem could be deployment of the 5G communications. The rollout of 5G communications will be important for eVTOLs, as near real time communications will be essential for keeping city skies safe as the volume of eVTOLs traffic grows. 5G will be crucial for situational awareness, and aircraft-to-aircraft, and aircraft-to-ground communication, especially in extreme weather conditions. Just as important, 5G's low latency and high bandwidth will be a must for inflight passenger applications and smart-city MaaS (Mobility as a Service) applications [71].

Air-to-ground communications is a primary focus for 5G as indicated by the 3rd Generation Partnership Project (3GPP) efforts to change the specifications for aircraft. Applications include sharing weather and traffic data at altitude between aircraft and ground control, providing more accurate forecasts of cloud formation and turbulence, real-time monitoring of aircraft for preventive maintenance, and passenger Wi-Fi and entertainment services. Another possible solution is service from constellations of small satellites that will use unlicensed spectrum for 5G communication service, including air-to-ground service. Small satellites will be part of the broader 5G umbrella and will be able to track aircraft all over the globe, including in remote areas not well covered by terrestrial antennas. However, it is not clear if small satellites can overcome the challenges of traditional satellites regarding high-latency and low speed. Presently, direct air-to-ground communication is superior to satellite service due to its lower latency and per-bit cost compared to satellites, which means air-to-ground has the potential to enable a much larger set of applications [71].

While terrestrial applications are the focus of early 5G rollouts, several telecommunications companies are working to address the aviation 5G market to ensure secure communication and data exchange. One is AT&T, which recently announced a partnership with Uber. The relationship includes AT&T assessing and enabling LTE (Long-term Evolution) and 5G connectivity for low-altitude autonomous cargo drones and piloted aircraft. Volocopter recently announced plans for a new 5G-enabled eVTOL called the VoloCity, an urban air taxi that will carry two people a distance of 35 km at a speed of 110 km/h. The 5G capability will allow the aircraft to "see" around corners, avoid obstacles, and download flight data quickly to enhance performance and safety. Volocopter has reportedly demonstrated these capabilities at trials in Dubai and Singapore. In addition, in Benidorm, Spain, a consortium of Vodafone, the Advanced Center for Aerospace Technologies and the Polytechnic University of Valencia recently tested the first drone controlled by 5G in an urban area beyond the pilot's line of sight. The demonstration included air traffic control of flights in restricted areas and the resolution of real-time flight conflicts. All of these early efforts are relevant for 5G for eVTOL aircraft and their connection with other smart-city MaaS services and infrastructure [71].

Based on the above reported considerations, it is clear that ICT should be seen as a main mean to integrate the transport both on the level of single mode as UAM as well as multimodal metropolitan transport system. Algorithms optimizing processes, connecting all components of the transport system with users (e.g. passengers), infrastructure and regulatory body in future, supported by progressing digitalization in numerous areas of the city, not limited to transport allow for thinking about shifting the level of management far above the single mode of transport, to the level fully integrated metropolitan transport system (i.e. to the System of Systems level), for both goods and passenger transport.

The ICT domain related applications that can be used to support UAM and multimodal transport include not only the 5G, as detailed above, but also other relevant technologies of interest for UAM. Therefore, a wider outlook is provided below to the full spectrum of ICT relevant in the UAM framework:

- Internet of Things (IoT) – It refers to the concept of enabling direct or indirect communication and data transfer and processing between different components (things) of the system. It requires equipment with appropriate hardware and software (interfaces). When applied to the transport, it creates possibility to directly communicate with all transport system components (vehicles, infrastructure, etc.). Information collected can be used for monitoring and diagnosing the condition of the system as well for as for managing it by making dispositions.

- Communication technologies - 5G and beyond. Wireless communication enabling transfer of big amount of data between large numbers of users/devices is seen as main enabler for Internet of Things among other. Currently deployed in Europe and predicted to be replaced by 6G network in future will determine the efficiency of transport management systems (and not only).

- Big Data processing - If data, big amount of data comes from different sources they are often of big Volume, Variety (in terms of type and nature), coming with different Velocity, they are of varied Veracity (truthfulness or reliability), Value and degree of Variability (5Vs). Taking advantage of such information requires dedicated multilevel solutions. With regard to transport it can concern the building of models describing expected demand for transport on base of e.g. various everyday life data, not directly related with transport activity.

- Smart cities concept - A smart city is a city management concept taking advantages from different types of ICT technologies e.g. sensors to collect data. Insights gained in this way (expressed as datasets) are employed to increase the efficiency of management of various assets, resources and services. In general, the data is used to improve the operations across the city. The data are collected from citizens, devices, buildings and assets that is then processed and analysed to monitor and manage traffic and transportation systems, power plants, utilities, water supply networks, waste, crime detection, information systems, schools, libraries, hospitals, and other community services.

Such as transport management system, employing IoT, 5G communication technologies, Big Data dedicated tools and interwoven into the concept of smart city is compliant, however independent on e.g. U-Space or ATM and oriented solely on optimisation of available resources – increase the efficiency of transport. Besides hardware part of the transport ecosystem ICT technologies should be seen as equally crucial as expected to be main driver of the way we use future mobility. Both related to goods and passenger transportation. Section 5 will provide indications about particular solutions and technologies expected to be available/ present in future metropolitan transport systems.

4.6 USpace

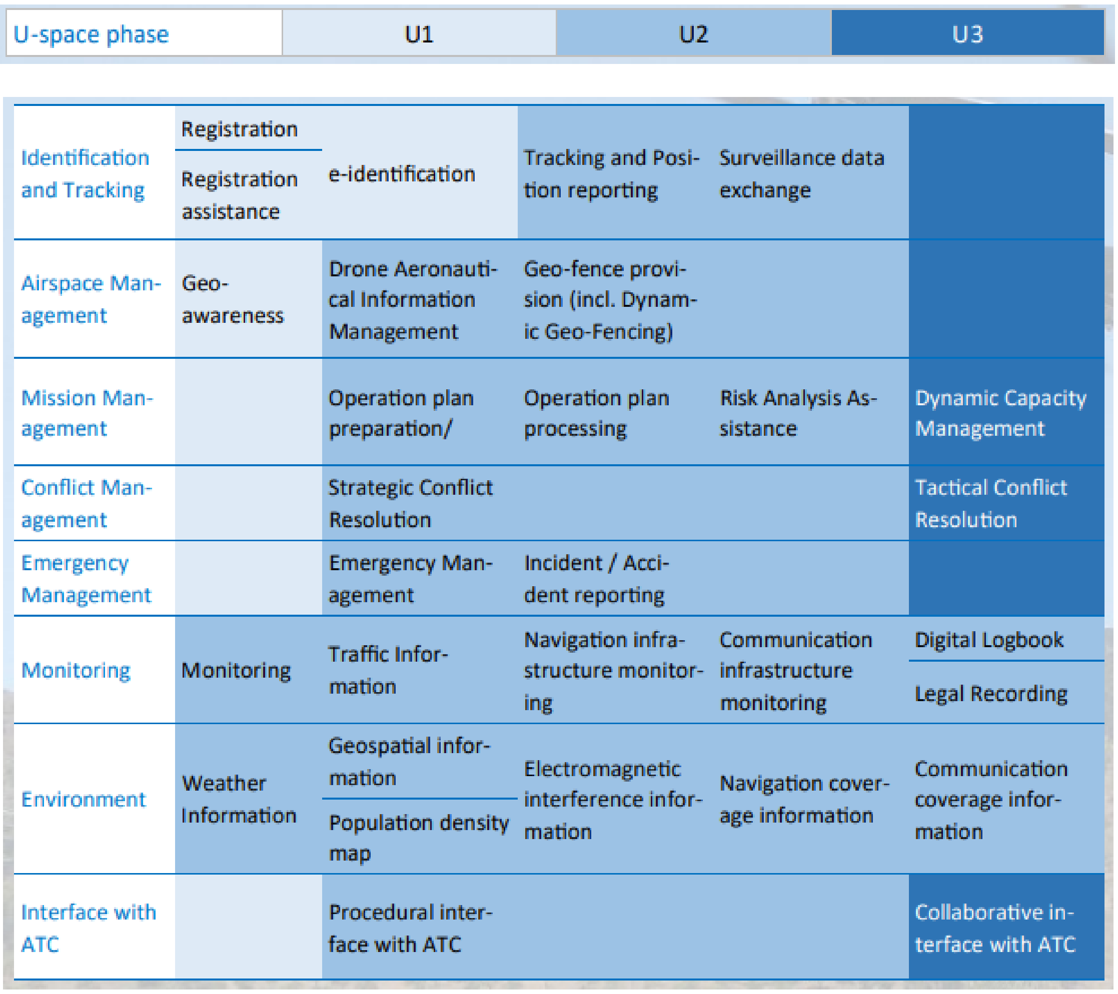
U-space provides air traffic management services for drones. These services consist of a set of agreements, protocols, communication means and standards that together enable an orderly grow of unmanned traffic in the future. The full extent of U-space is larger than just those of air traffic services: U-space is considered a full ecosystem to support safe and efficient drone flights and includes legislation, airspace management, information services and traffic services, including a link to air traffic control of manned aviation. U-space will be the enabler for new concepts and operations, like urban air mobility.

The conceptual specification of U-space is currently set up by SESAR and EUROCONTROL [72]-[73], while legislation is underway. SESAR is now setting up an extended concept for the use of U-space in UAM. EASA provides European regulation that will become mandatory for U-space airspaces in all EU-states by January 2023.

The philosophy of U-space is to provide a number of distributed services that can be offered by different providers and together form the full set. The services will be offered by U-space Service Providers (USSP), also called Drone Service Providers (DSP), in an open and competitive market, where end users can use the USSP of their choice. Interoperability will be guaranteed through EC-wide or world-wide standards that are currently prepared by e.g. the Global UTM Association (GUTMA) and EUROCAE (e.g. WG105 on Unmanned Aircraft Systems and WG112 on Vertical Take-off and Landing). The concept of USSPs will allow dedicated services to be developed by specialized companies, e.g. weather services can be provided by dedicated meteorological organizations.

At the moment, the first implementations of U-space become available, mostly driven by ANSPs that are concerned about drone movements around airports. They implement specific sets of services dedicated to the specific environment, through selected USSPs. Services that are provided first are geo-awareness, identification and flight authorization, representing U1 level services. U2 services will follow soon, while U3 services are expected to be ready in 2027 and U4 in 2035. The following table shows the specific services per U-space phase; U4 is not included as no specific services are specified in that phase yet.

Table 12: Specific services per U-space phase



U-space phase	U1	U2	U3

Identification and Tracking	Registration Registration assistance	e-identification	Tracking and Position reporting	Surveillance data exchange	
Airspace Management	Geo-awareness	Drone Aeronautical Information Management	Geo-fence provision (incl. Dynamic Geo-Fencing)		
Mission Management		Operation plan preparation/	Operation plan processing	Risk Analysis Assistance	Dynamic Capacity Management
Conflict Management		Strategic Conflict Resolution			Tactical Conflict Resolution
Emergency Management		Emergency Management	Incident / Accident reporting		
Monitoring	Monitoring	Traffic Information	Navigation infrastructure monitoring	Communication infrastructure monitoring	Digital Logbook Legal Recording
Environment	Weather Information	Geospatial information Population density map	Electromagnetic interference information	Navigation coverage information	Communication coverage information
Interface with ATC		Procedural interface with ATC			Collaborative interface with ATC

U-space has the potential to stimulate flight planning, guidance and monitoring in complex environments, such as cities, where it can be linked to UAM, including mobility of passengers per drones and Beyond Visual Line of Sight (B-VLOS) operations. It is foreseen that the low-level airspace, i.e. the airspace up to 500 ft. (about 150 meters) where manned aviation is not present in normal operating conditions, will be made available to UAS. This is referred to as Very Low Level (VLL) airspace.

The U-space services rely on a high level of digitalization and automation of functions and specific procedures designed to support safe, efficient and secure access to airspace for large numbers of drones. As such, U-space is an enabling framework designed to facilitate any kind of routine mission, in all classes of airspace and all types of environment, even the most congested, while addressing an appropriate interface with manned aviation and air traffic control. In support of this initiative, in 2017 the SESAR Joint Undertaking drafted the U-space blueprint [72]-[73], a vision of how to make U-space operationally possible. As depicted in the Figure 26 and outlined in the previous table, the blueprint proposes the implementation of four sets of services to support the EU aviation strategy and regulatory framework on drones. The U-space services will be gradually introduced over four phases, from U1 to U4, depending on the increasing availability of blocks of services and enabling technologies, the increasing level of drone automation, and advanced forms of interaction with the environment, mainly enabled through digital information and data exchange [73].

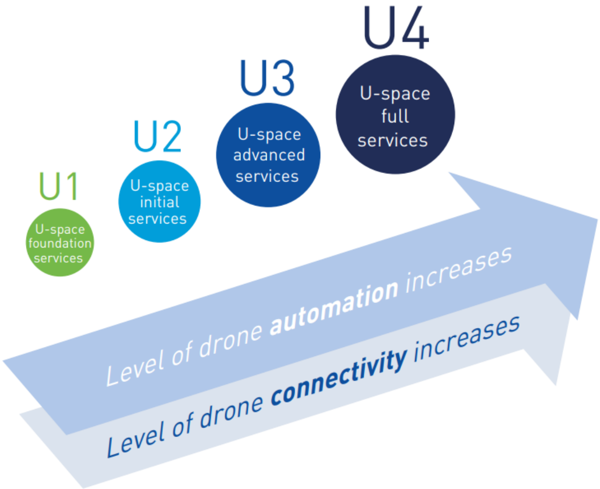


Figure 26: U-space levels[73]

The services associate at each phase are [74]-[75]:

- U1 → U-space foundation services covering e-registration, e-identification and geofencing.
- U2 → U-space initial services for drone operations management, including flight planning, flight approval, tracking, and interfacing with conventional air traffic control.
- U3 → U-space advanced services supporting more complex operations in dense areas such as assistance for conflict detection and automated detect and avoid functionalities.
- U4 → U-space full services, offering very high levels of automation, connectivity and digitalisation for both the drone and the U-space system.

According to applicable EU regulations about rules and procedures for the operation of unmanned aircraft, operations with drones are divided into three categories:

- Open;
- Specific;
- Certified.

Operations with drones in the ***"Open"*** category are not subject to prior operational authorization or an operational declaration by the drone operator before the operation takes place.

Operations with drones in the ***"Specific"*** category require an operational authorization issued by the competent authority.

Operations with drones in the ***"Certified"*** category require drone certification in accordance with applicable regulations, operator certification and, if applicable, the remote pilot license.

The Open category is further sub-divided into three subcategories as follow:

- **A1**: flights over people (but not over open-air assemblies of people) intended for hobby users flying drones under 911g (or 81J) class C1 or C0 (see the table below);
- **A2**: flights close to people, but a safe distance from them for heavier UAs class C2, and require passing a recognised theory test;

- **A3**: flights far from people, generally intended for model aircraft clubs class C0 and C4.

The main characteristics of the drone classes are indicated in the following Table 13.

Table 13: General characteristics of drone classes [73]

Class	MTOW [g]	Max speed [m/s]	Max height [m]
C0	250	19	120
C1	900	19	120
C2	4000	-	120
C3	25000	-	120
C4	25000	-	-

In addition, the Very Low Level (VLL) airspace where drones are expected to operate is divided into different parts according to the services provided. Three basic configuration types are:

- **X:** no conflict resolution is offered;
- **Y:** only pre-flight conflict resolution is offered;
- **Z:** pre-flight conflict resolution and in-flight separation are offered.

Type Y airspace will be available from the set of services offered by U-space phase U2, and will facilitate VLOS, EVLOS and BVLOS flight.

Type Z airspace is divided into Zu and Za, controlled by UTM and ATM respectively. Za is the usual controlled airspace and is therefore already available, while Zu space will be available from U3 phase of U-space.

Because U-space provides more risk mitigations for Z type, it will allow higher density operations than Y airspace, while allowing VLOS and EVLOS and facilitating BVLOS and automatic drone flight [73].

To enter in the abovementioned airspaces some requirements must be met, as listed in the following table.

Table 14: Airspaces access requirements [73]

VLL Airspace Type	Access Requirements
X	• There are few basic requirements on the operator, the pilot or the drone. • The pilot remains responsible for collision avoidance. • VLOS and EVLOS flight are easily possible. • Other flight modes in X require (significant) risk mitigation.
Y	• An approved operation plan. • A pilot trained for Y operation.

	• A remote piloting station connected to U-space. • A drone and remote piloting station capable of position reporting when available. ***Y airspaces may also have specific technical requirements attached to them***
Z	• An approved operation plan. • A pilot trained for Y operation. • A remote piloting station connected to U-space. • A drone and remote piloting station capable of position reporting when available. ***Z airspaces may also have specific technical requirements attached to them, most probably that the drone be fitted with collaborative detect and avoid system for collision avoidance.***

Open X Airspace category will host flights with low demand for U-Space services due to the low risks associated with such flights. Furthermore, in this category the pilot maintains visual contact (VLOS) with the drone for the duration of the operation, and remains responsible for any event that may occur [74]. A typical scenario of the airspace X is represented in the following figure.

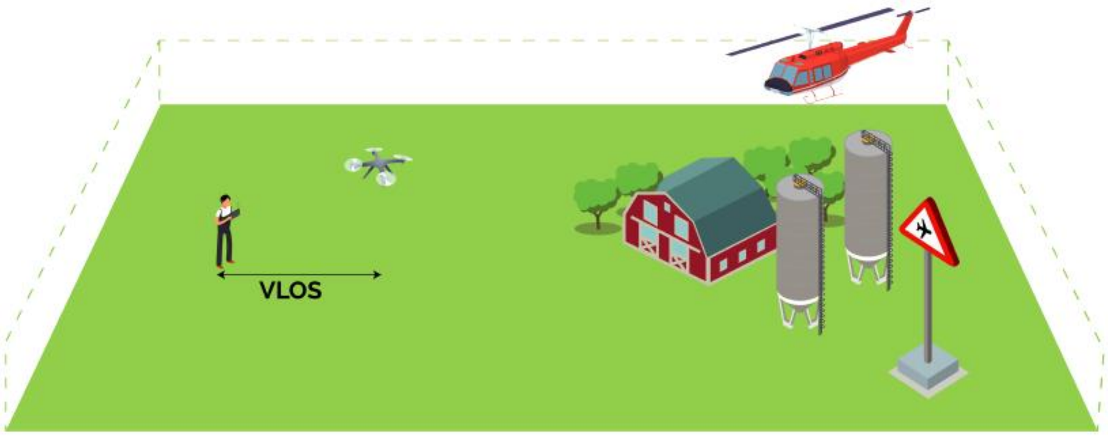


Figure 27: Example of a X volume operations [74]

For access to airspace Y, different requirements are needed. There is a need for an approved operational plan. A training course is required from the pilot. A remote pilot station connected to U-space environment and a UAS capable of propagating its position are required. Y volumes facilitate VLOS and BVLOS flight. In volumes Y there are means of risk mitigation provided by U-space which are not available in X. In airspace Y, conflicts between flights are resolved before take-off. As there is no tactical in-flight separation service offered in this airspace, pre-flight resolves these conflicts while minimizing risk. During the operations there will be traffic information available, the provision of which requires all aircraft to be tracked [74]. A typical scenario of the airspace Y is represented in the following figure.

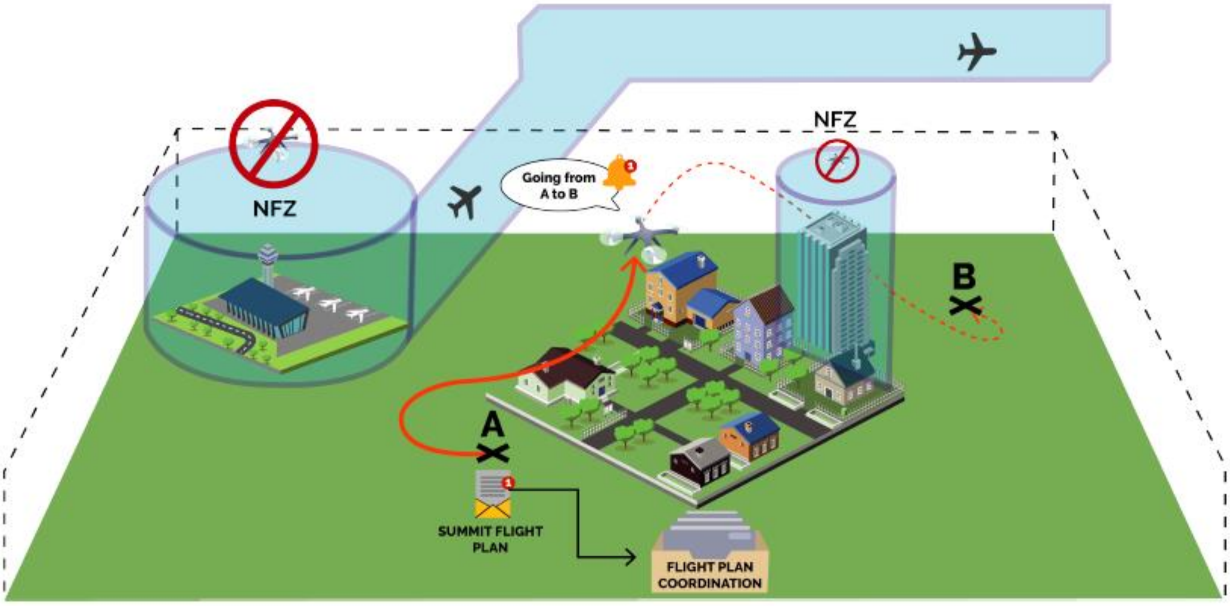


Figure 28: Example of a Y volume operations [74]

Airspace Z allows operations with higher density than airspace Y, and therefore are expected where traffic demand exceeds the capacity of airspace Y, or where there it is a high risk due for example to the presence of urban areas. As for access to the airspace Y, also to access the airspace Z it is necessary to have an operational plan, and in addition to have the continuous connection of the pilot to the U-Space and the provision of aircraft position reports for continuous tracking. Z volumes facilitate BVLOS and automatic drone flight, and also allow VLOS. In Z there are more risk mitigation means provided than in Y or X. In Y volumes, the lack of tactical conflict resolution requires that strategic conflict resolution takes account of the residual risk due to wind, or other sources of perturbation to the flight. Hence, the traffic in Y is kept far apart. Residual risks remaining after strategic (pre-flight) separation can be reduced by tactical (in-flight) conflict resolution. Z volumes, therefore, have a tactical conflict resolution service, whose provision is unique for a given volume where only one entity is responsible for aircraft separation. When the separation is provisioned by U-space, the Z volume is named Zu. On the other hand, if air traffic controllers are in charge of providing the separation, then the volume is named as Za. Thus, a Za volume is controlled airspace and use of U-space services will be limited to a subset of services, for instance to enable communication and surveillance, but not for conflict resolution [74]. A typical scenario of the airspace Z is represented in the following figure.

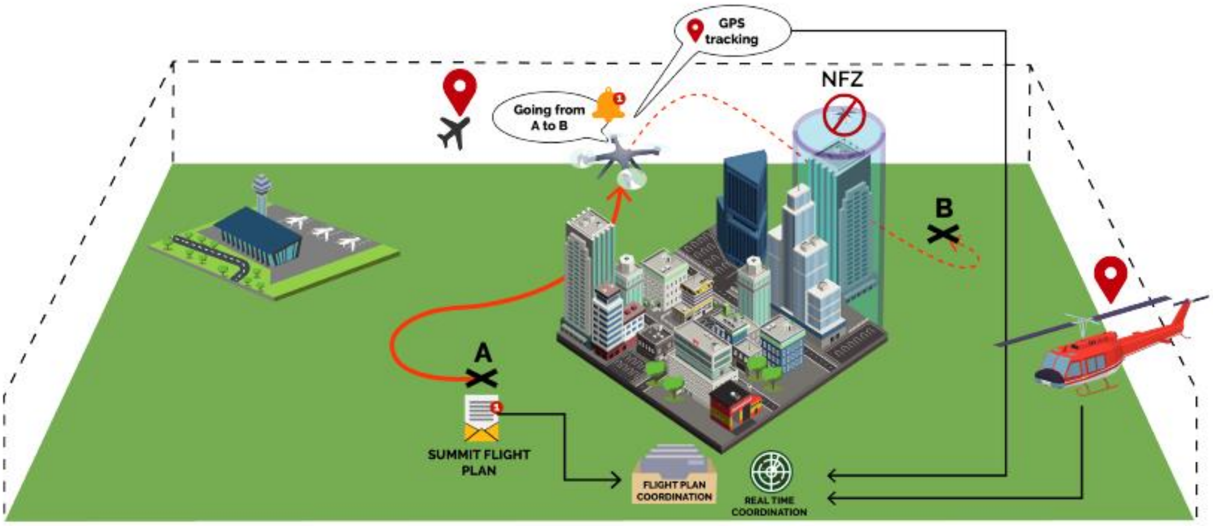


Figure 29: Example of a Z volume [74]

In conclusion, phase U3 of the set of services provided by U-Space is fundamental for the safe development of UAM and phase U4 will be fundamental for the integration of UAM in civil air traffic.

5. Expected technologies readiness levels in 5, 10 and 15 years

5.1 Aircraft systems

5.1.1 Passengers Drones

Much of the eVTOL investment to date has been focused on design what the aircraft looks like, how it is powered, and how it performs, as well as how to make it as safe or safer than commercial aircraft aviation and how to create an amazing customer experience.

The design criteria include:

- **Payload.** The range for air taxis is from a single-person (100 kgs) to a nine-person-plus-baggage (960 kg) payload. Companies like Lilium and Joby Aviation are focused on a five-passenger eVTOL, while Volocopter and EHang are opting for a more compact solution. EASA and FAA are recommending setting the maximum take-off weight for eVTOLs at 3,175 kg [75].

- **Safety.** To fly above cities, eVTOLs will be required to be at least as safe as general aviation aircraft. However, with rapid growth expected in the number of eVTOLs operating in city skies, regulators may impose more stringent safety standards than those that apply to general aviation [75].

- **Noise.** Sound pollution, both frequency and decibel level, is a big issue for operating eVTOLs in urban environments. Uber has a set of requirements that specify eVTOLs must be 15 decibels (dB) less noisy than existing light helicopters, which is about 70 dB at 500 feet versus 85 dB for a typical helicopter [76]. In comparison, the noise from a commercial jet at 25 meters is 150 dB, while a quiet rural area is 30 dB [77].

- **Cost.** As part of the mobility-as-a-service revolution, eVTOLs will be managed by service provider and will likely not be sold to private customers. The service providers will purchase fleets of eVTOLs that will be part of an on-demand business service. This model will allow them to minimize per-vehicle production costs, and drive down the passenger cost-per-mile, which will help drive the success of the commercial eVTOL ventures.

Today many companies are experimenting the three following main concepts design, much of them already have done the first flight tests (e.g. EHang, Volocopter, Boeing, Airbus, Lilium etc.).

Main concepts are:

- **Multirotor Systems;**

- **Decoupled Propulsion;**

- **Tilt-rotor.**

The Multirotor concept are like drones (Figure 30), or aircraft by the German startup Volocopter (Figure 31) or EHang 216 by Chinese company EHang (Figure 6 in the section 4).

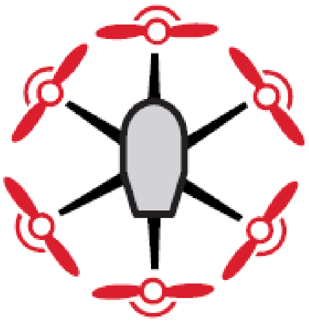


Figure 30: Multirotor concept [78]

Figure 31: VOLOCITY by Volocopter [79]

As the name suggests, multirotor means having a series of motors arranged in a ring around the cabin. In these flying technologies, flight control is achieved by varying the speed of the individual rotors. Multirotor concepts have the twin advantage of being fairly simple and offering safety. On the other hand, these systems are hindered by a reduction in travel speed, as well as weight and range limitations due to significantly lower efficiency. Initial multirotor systems, however, have a low risk profile and will help define future standards in a step-by-step process.

The decoupled propulsion concepts (Figure 32), such as the Aurora Compamy eVTOL (Figure 33), combine rotors for lift and fixed wings for forward flight.

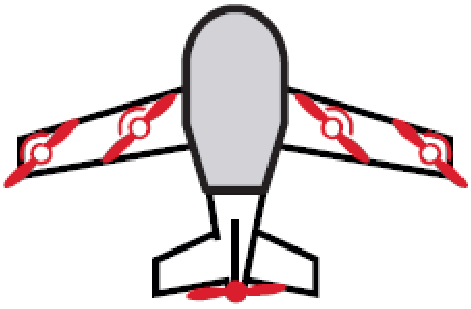


Figure 32: Lift and cruise concept [78]

Figure 33: PAV eVTOL Passenger Air Vehicle "Aurora Flight Sciences" [80]

This type of aircraft system is comprised of various hybrid models, all with separate drive trains for the lift and cruise flight phases. The hybrid model enables them to take advantage of the respective properties of fixed wing and rotor aircraft. Wings give them longer range, while rotors enable them to vertically take off and land more efficiently and maintain a higher airspeed.

The basic technologies of both elements are already available, and the overall complexity of hybrid models is in the middle range, depending on a particular system's design. Next-generation hybrid drones can be considered the second phase in eVTOL aircraft development as they offer increased speed and efficiency. They provide more time savings and lower operational costs, two key drivers for commercial success in comparison to other modes of transportation.

Furthermore there is the Tilt-rotor concept (Figure 34), like Lilium Jet (Figure 7 in section 4) eVTOL concept, which is a rotorcraft with two or more motors, often arranged in a ring around or a top the cabin.

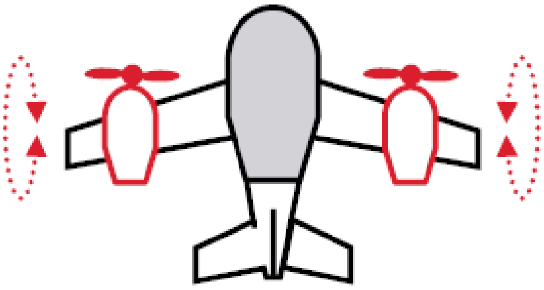


Figure 34: Tilt-rotor concept [78]

The tilt-rotor concept includes wings and rotors or ducts, all of which can be tilted. Since they have rotating components that need to reliably and safely handle the transition from the lift to the cruise phase, the complexity of tilt-rotor systems is significantly higher.

The following table shows the characteristics of the three different types of aircraft that could be used for Urban Air Mobility.

Table 15: Aircraft systems characteristics [78]

Characteristics	Multirotor	Decoupled Propulsion	Tilt-rotor
Time to market	Fastest certification	Slower certification	Slower certification
Cruise speed	~50-100 Km/h	~100-200 Km/h	~200-300 Km/h
Routes	Selected	All	All
Use	~70% of intracity	100% of intracity and city to city	100% of intracity and city to city

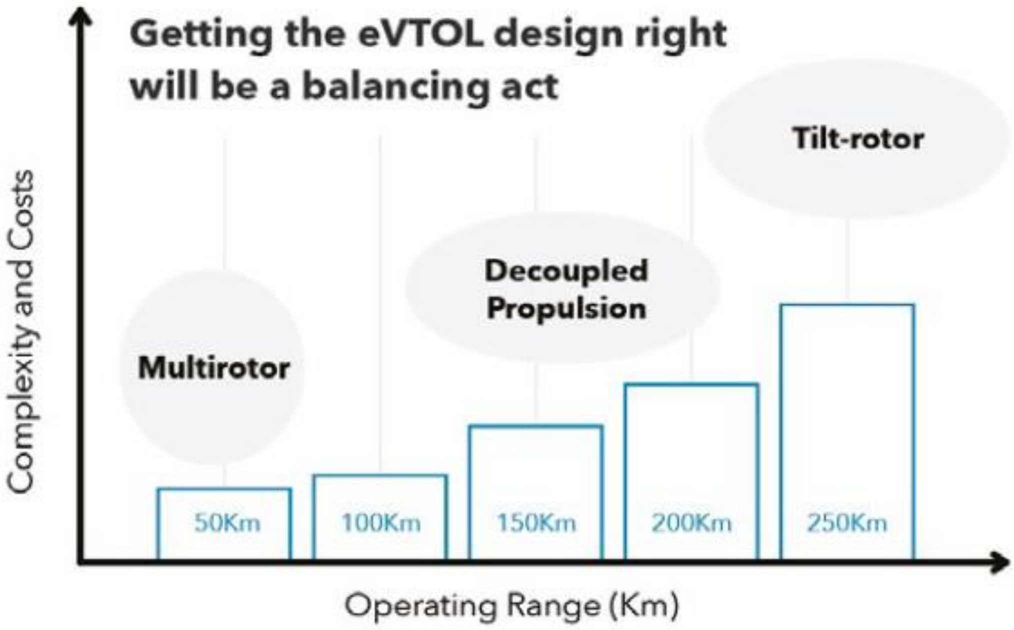


Figure 35:Each eVTOL is optimized for one or more uses case based on a variety of factors including range, cost, and complexity [71]

As depicted in Figure 35, the right compromise must always be found between design, costs and operating range for which UAM technology is intended (Multirotor, Decupled Propulsion and Tilt Rotor). Therefore, for each operating range one technology is indicated rather than another, and it is fundamental to notice that, given that these flying technologies are all electric for a matter of sustainability and also to reduce CO2 emissions in atmosphere, a great challenge for the future will be precisely to improve the capacity of the batteries and contain the weight.

Considering the time horizons addressed in the ASSURED UAM project (5, 10 and 15 years) and the analysed technologies for UAM deployment indicated in the section 4, in terms of technology readiness expected over such time horizons the technology roadmap indicated in the following table is considered as appropriate, as assumed also in the framework of the SESAR ER ongoing project X-TEAM D2D [20].

Table 16: UAM technology roadmap [20]

Technology	2021	2025	2030	2035
STOL	🟦	🟦		
VTOL		🟦	🟦	🟦
PATS				🟦

In particular, the considerations indicated in the following apply to each candidate vertical technology for UAM application [20]:

- **STOL** technology is partially available, since while aircraft development is now mature, short runways are still not very widespread in urban areas. Consequently, its potential cannot be fully exploited yet but it will be shortly possible.
- **VTOL** technology, perhaps the most important element for Urban Air Mobility, is less available, since there are few ready vehicles, and the biggest challenge will be building and managing the dedicated infrastructure.
- **PATS** technology presents the same problems mentioned in the previous item, but very more stringent regulatory aspects will have to be addressed.

For what concern flying technologies, experimentations and improvements will continue in the coming years, making these technologies ready for the market, but for the operational phase of UAM other barriers must be overcome. An example are both newly built infrastructures and those to be built in existing structures in the city (e.g. vertiport on the roofs of buildings).

5.1.2 Cargo Drones

As indicated in section 4.2.4, many companies all around the globe are engaged in the construction and tests of cargo drones with MTOW higher than 25 Kg, so summing up from the point of view of enabling technologies we are at a very high level of technological readiness. However, for the inclusion of these technologies in civil air traffic for the delivery of goods there is still a lot to do, especially as regards the infrastructures for their inclusion in urban contexts. In this case it is necessary that the cities provide dedicated areas where these cargo drones can land, take off, recharge battery etc (e.g. Skyport see following section about infrastructures).

For shipping companies, the last mile is the most expensive and such a system could save shipping companies a lot of money and the time of goods delivery is very short.

Another fundamental aspect concerns the regulation of these technologies for their safe insertion in the ATM. In this regard, before these technologies come into service it will be necessary to wait for the U2 / U3 and later for the U4 phase of the U-Space, for safety reasons, to include them in the ATM.

Based on the ongoing projects (Volocopter, Ehang, Pipistrel etc.) regarding abovementioned technologies, and how fast the cities will accept those and build all necessary infrastructures (e.g. vertiport) in the following Table 17 a possible roadmap is reported for cargo drones implementation.

Table 17: Cargo drones roadmap

Technology for goods delivery >25 Kg MTOW	2021	2025	2030	2035
VTOL	Flight Tests still ongoing	On demand and in rural area	Test phase in urban area	Probable technology on the market

5.2 Infrastructures

To ensure the operation of enabling technologies for urban, peri-urban and extra-urban air mobility, it is necessary, among other things, to have the necessary infrastructure for boarding, disembarking, take-off and landing, maintenance and battery charging operations. A sort of miniature airport integrated within the city, in the airports, and in the vicinity of motorways to have a different nodes where you can fly.

Today one of the emerging companies in the construction of vertiports is Skyport (English company) mentioned in the previous section of this document. It provides for the acquisition of the site, the design and construction of the vertiport and finally its commissioning.

Figure 36: Example of first prototype of vertiport called ”Voloport” by Skyport in cooperation with Volocopter [90]

The figure shows the first prototype of a vertiport called "VoloPort" built in October 2019 in Singapore by the Skyport company in collaboration with the German company Volocopter, a pioneer in the research and development of enabling technologies for the development of urban air mobility.

It was announced that the world's first airport for flying machines and cargo drones will be built in England this year, as represented in Figure 37. It represents the project of the Vertiport so called “zero-emission airport”, designed by Urban Air Port, which is supported by Hyundai Motor Group which plans to have commercialised its own flying vehicles by 2028. It is approximately 60% smaller than a heliport and will be the first of more than 200 vertical take-off and landing sites that Urban Air Port intends to install around the world over the next 5 years in response to growing demand of UAM. Initially the airport will be used to help citizens understand the technology and accept it and for this reason the British company Malloy Aeronautics will demonstrate here the use of large cargo drones [36].

Figure 37:The zero-emission airport, designed by Urban Air Port [36]

Infrastructures are getting more and more attention in recent years, this precisely due to the fact that flying technologies have now carried out the first flight tests with excellent results and the construction is needed of vertiports to allow these technologies to operate. Obviously, this alone is not enough for a widespread insertion of UAM-enabled flying technologies but it is also necessary to adapt cities from an urban point of view so that these technologies are welcomed and can operate safely. Given the growing interest in UAM, some companies have realized that the time has come to invest precisely in infrastructures, in order to allow the experimentation of the first aero taxi services and even before the delivery of goods. Based on the literature studies carried out, in the following table a possible roadmap for vertiports implementation is indicated.

Table 18: Vertiport roadmap

Infrastructure	2021	2025	2030	2035
Vertiport	Started the build of some vertiport to trial flights (Skyport with Volocopter).	Increase of the construction of vertiports. Initially used by cargo drones and some private air taxis.	The vertiports will be tested and are ready to be in service.	Vertiport will be in service.

5.3 Propulsion

The electrification in the aerospace field is a well-established trend in recent years. The introduction of electric and hybrid-electric technology has drastically opened the design space thanks to the synergy with Distributed propulsion and Boundary Layer Ingestion. In the following the most relevant considerations about the propulsion technologies possibilities for the next years are reported.

Thrust and lift design configurations

For eVTOL aircraft ready to market, much of the focus today is on three propulsion system alternatives, which are: multirotor eVTOL (wingless aircrafts); tiltrotor or vectored-thrust eVTOL (multiple propellers or fans); decoupled-propulsive (multiple fixed vertical propellers and a pusher to transition from vertical to horizontal flight). These different configurations are represented in the following Figure 38.

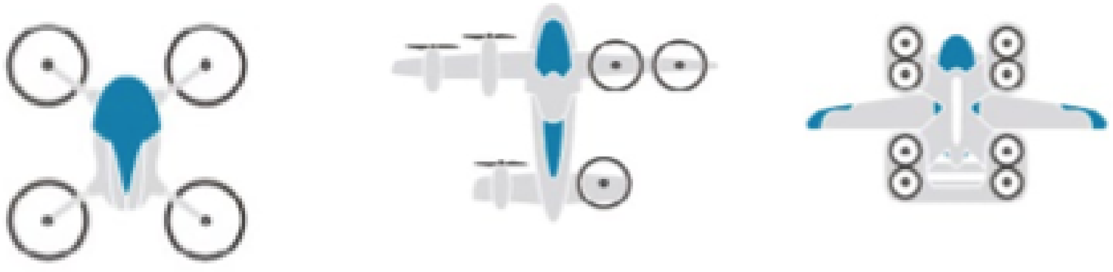


Figure 38: eVTOL propulsion systems alternatives

Electric with battery/capacitors energy source

One of the main key issues in the electrification of aviation is represented by the electricity storage systems, i.e., the batteries. In designing an electric or a hybrid electric aircraft, encumbrance is a constraint because there is little room for battery packs, electric motor(s) and power control electronics. For this reason, the volumetric energy density of the battery, i.e., the amount of stored energy per unit volume, is important. At the moment, lithium-based batteries, particularly Lithium-polymer (Li-po), are widely used to power Unmanned Aerial Vehicles (UAVs) because they have a much higher specific power and can be more shaped. An accurate determination of battery performance, health, and life prediction is necessary not only during battery usage but also in the design process. In fact, the misunderstanding of battery characteristics and performance causes substantial issues for battery management and impacts the actual range and the fuel economy of electrified power systems.

Electric with fuel cell energy source

The advantages of using the Fuel Cells need to be weighed against the increased weight and complexity of the resulting power system. In particular, the power and energy required for different missions and emergency landings should be estimated in order to size and compare the proposed hybridization schemes against Internal Combustion Engine (ICE) advanced hybrid power trains relying on ultra-light downsized technology.

Hybrid electric with petrol as energy source

It is also interesting continuing to investigate the performance of hybrid electric power systems to exploit the advantages of hybridization through energy management, integration, multi- functionalization, distributed propulsion comparing PEM FC with ultra-light downsized ICE. Hybrid thermal-electric power trains can be used to extend the range of small unmanned aircraft because electric power systems only based on batteries are characterized by low energy density and offer endurance that varies within the interval from about 60 to 90 minutes.

As today, hybrid power systems may compete against fully thermal engines both in terms of payload and SFC, if and only if a double major technological leap on the storage capacity will rapidly occur. While this looks within the reach of the existing expertise in the R&D community, the available technology is frustrating the expectations of the smart urban and city-to-city mobility aero community.

For the future, several technologies (Distributed Electric Propulsion (DEP), composite materials, new materials, advanced battery technologies, hybrid powerplants, aerodynamics, noise control technologies, among others) are now available, and will improve over the years to come, permitting to realize innovative air-vehicles configurations that will be capable of sustain Urban Air Mobility in metropolitan areas as well as to enable new air transportation possibilities in remote, unstructured areas and in critical conditions like emergencies and others.

Aircraft systems

Concerning the aircraft systems, flexible transmission systems, advanced control strategies will need to be ad-hoc developed and integrated in an innovative propulsion platform capable to meet the ambitious requirements of the new generation VTOL aircrafts for UAM.

Propulsion

Distributed Electric Propulsion (DEP), and the development of new advanced batteries technologies to be implemented in innovative hybrid thermal-electric power systems, will at the same time permit the shift toward more clean and sustainable energy source. For being a viable commercial transportation option, especially for longer flights, the electric power source, in the future, must be safer, last longer, be smaller, weigth less, and recharge faster than the current generation of lithium-ion batteries.

Indeed, the logical next generation is solid-state technology, which is expected to disrupt the battery storage industry by mid-decade [91]. Combined, the solid-state and lithium battery market is expected to reach USD 1 trillion in 2026, according to Markets and Research [92]. There is a significant investment in solid-state batteries that will use solid electrolytes, which has the potential to deliver a 2X performance improvement over lithium-ion batteries. Also, solid-state batteries can be safer because they are non-flammable.

It is also worth mentioning that a few pioneers have developed hydrogen-powered VTOLs. One is Alaka'i Technology's Skai VTOL that runs on hydrogen and serves the emergency- response and freight-distribution markets [93].

Given the space and weight constraints for an eVTOL, special attention will be done to the problem of storage for the hydrogen fuel on the aircraft. Volume efficiency and conformability will bring to innovative design for these containers. Carbon fibres and multi-chamber tanks will be explored in order to connect individual chambers in a suitable manner to realize the tank.

5.3.1 5 years horizon

Based on the expertise in the aviation sector as well as on the scientific and industrial publications, the year 2025 may not bring any breakthroughs in the field of powertrain technologies. Energy density of batteries, capacitors and efficiency of fuel cells will stay at the similar level as today. This will force the UAS manufacturers to seek the flight efficiency increase opportunities in the aircraft design optimization, battery fast recharging or swapping stations and utilization of hybrid technologies that can extend the flight range.

As for the fuel cell technology, many companies develop the powertrains for aviation industry. Part of them have already undergone the tests and first implementation into small UAVs. By 2025 minor technical improvements are to be expected, however, these years might bring increased reliability and acceptance for their implementation into bigger units.

5.3.2 10 years horizon

The most desirable energy source will deliver higher energy density, discharge and charge rates as well reliability over long periods of operation. As majority of UAVs nowadays use li-ion batteries and this number may grow significantly by 2030, a shift to more efficient, safe and accessible technologies is deeply awaited. Among many, post-lithium batteries may appear as proofs of concept (sodium-ion, multivalent metal-ion, metal-air, redox flow) as well as new generations of lithium batteries, such as: lithium-air and lithium-sulphur [94]. According to sources, the theoretical energy density of lithium-air cells might reach 11,680 Wh/kg (close to petrol energy density which is around 13000kWh/kg) [95], while the lithium-sulfur nearly 2600 Wh/kg [96]. Currently developed hydrogen fuel cells will be supported by the increasing number of hydrogen refueling stations, which is estimated to reach 3700 in Europe by 2030 and 1000 in USA [97]. PEM and other hydrogen fuel types will be developed for various applications, considering their operational parameters. Still, the operating temperature may be limited to positive values as the product of their operation is water.

5.3.3 15 years horizon

The pollution constraints may limit the use of hybrid electric aircraft, especially over urban areas. Long distance cruises utilizing petrol as a range extender may be however a common view over the skies. Battery technologies may shift to more efficient and reliable cells with more energy density. With the development of battery chemistry, auxiliary systems may be implemented into the powertrain. These may include: sensing and self-healing which may increase battery durability, enhance lifetime, lower the cost per kWh stored and significantly reduce the environmental footprint [98]. As for the fuel cells, after years of testing and certification processes, this type of powertrain may be installed in larger aircrafts intended for people transportation just like in Airbus foresights [99].

5.4 ICT

Internet Communication Technologies beside IT are seen as rapidly developing. The Covid-crisis additionally driven the progress in numerous their domains. Therefore, it is expected that future organization of transport systems will be fully powered by digital technologies. It will allow for significantly increase of efficiency of transportation processes, better and real-time interaction with all stakeholders as well as reduction of impact on natural environment.

The trends indicated in the following can be identified in ICT in relation to transport:

- Development of 5G/6G communication network. Enabling fast data transfer for big number of users.
- Progressing digitalisation in multimodal/intermodal transport and wider information about the status of particular system components enabling further optimisation.
- Improving of access to the real-time transport data. Digitalised system equipped with sensors and appropriate in terms of efficiency communication infrastructure allows for gathering, processing and further sharing of real-time data concerning operation of the system.
- Decreasing the effort imposed on passenger with regard to multimodal travel arrangement/ management. Mobile applications gathering the available real-time traffic information from transport operators are able to generate optimised multimodal travel route. Increasing their functionality is based on more data shared by operators.
- More customer-oriented services. More reliable and robust information about current condition of the transport process enable better optimisation and efficiency increase. The benefits coming from

it enable reduction of the cost and the price of the ticket or goods delivery and/or allow for service quality improvement.

- Automation and autonomisation in transport. Autonomous car, bus, train, ferries and aircraft etc. All the trends identified above allows for considering automatic and autonomous transport as being a future of both passenger and goods transportation. In addition, driven by progressing management capacities and flexibility constraints related to human operators' involvement.

- Algorithmic governance. The increasing complexity of management systems covering more and more resources (e.g. more than one transport mode) lead to the difficulties in controlling and adherence to changing regulations. Regulations understandable for machines and management on the regulatory level are seen as enabler for future integrated transport systems.

- Use of privately generated data. Private data are already used in application like "Google Maps" however the real, revolutionary potential is seen in private data not directly related with the transport needs. Access, ability to gather, sharing and processing of private information which suggest strong need for transport is seen as enabler for more accurate (near) real-time demand modelling and introduction of flexible, dynamic timetables for transport services.

In SESAR JU funded X-TEAM D2D project [20], the scenarios covering development of ICT were defined for three time-horizons: 2025, 2035 and 2050. 2025 and 2035 perspectives are considered as progressing implementation of 2050 vision defined as follow:

- Completed digitalisation and automation in all most loaded modes of transport (cargo transport, public means of transport). Personal means of transport dominated by autonomous cars. Supported by adequate performance of IT systems and communication infrastructure (6G and beyond).

- Regulated rules of access, collecting, processing and sharing of private data which are potentially useful for transport demand modelling. Together with aggregated operators data the ability to build near-real transport demand (within about one hour).

- Completed digital integration of transport system in metropolitan area – managed from the level of System of Systems.

- Efficient disruption management, ability to quickly adapt to dynamically changing demand.

For the Urban Air Mobility applications and with reference to the three time horizon considered in the ASSURED UAM project, this allows deriving the considerations indicated in the following.

5.4.1 5 years horizon

Goods delivery:

- Automated drone deliveries expected to be in testing phase. Therefore, strongly limited ability to take full advantage of available ICT solutions.

Passenger transport:

- Unmanned passenger UAM expected to be not available in Europe.

- Manned passenger operation over densely populated areas not covered by available ICT solutions due to relatively marginal scale of operation.

5.4.2 10 years horizon

Goods delivery:

- Cargo drone operations integrated into supply chain management. All functionalities available (e.g. shipment tracking – indicating the real drone position).
- Increased cargo operators' capacities in terms of sustainability optimisation (carbon footprint reduction).

Passenger transport:

- Unmanned passenger UAM expected to be not available in Europe.
- Manned public passenger operations over densely populated areas if available partially integrated locally – with limited modes on limited area (e.g. single ticket).

5.4.3 15 years horizon

Goods delivery:

- Fully autonomous, paperless goods supply chain for most loaded routes, automated warehousing, goods loading/unloading. Expected degree of integration and digitalisation of transport in densely populated metropolitan area require cargo drones to operate solely between nodes – dedicated secured ground infrastructure.

Passenger transport:

- Autonomous passenger air transport expected to be in testing phase in Europe. Therefore, not fully integrated.
- Manned public passenger operations over densely populated areas if available fully integrated locally – with limited modes on limited area (covering single, integrated management system, dynamic timetable based on demand modelling with use of private data – in a day-scale).

5.5 USpace

With the increase in drones operating in the 500 feet and below airspace, in the coming years, early engagement with all airspace users is paramount. As indicated in the previous section 4.6, U-space was defined in the 2017 as a set of services and procedures relying on a high level of digitalisation and automation of functions to support safe, efficient and secure access to airspace for large numbers of drones/Unmanned Aircraft Systems (UAS). The U-space blueprint [72] defines four levels of services, as shown below. Each level is a package of related services. ASSURE UAM will make use of this terminology. A U-space Concept of Operations (ConOps) is required, especially for VLL drone operations.

For example, in Italy there is the service provider U-Space named D-flight [87] (an ENAV company) which provides the accredited user with a set of products aimed at the safe use of UAS vehicles and fleets within the various operational scenarios. The set of services is designed to guarantee the user levels of automation and ease of use that comply with the typical characteristics of the UAS sector.

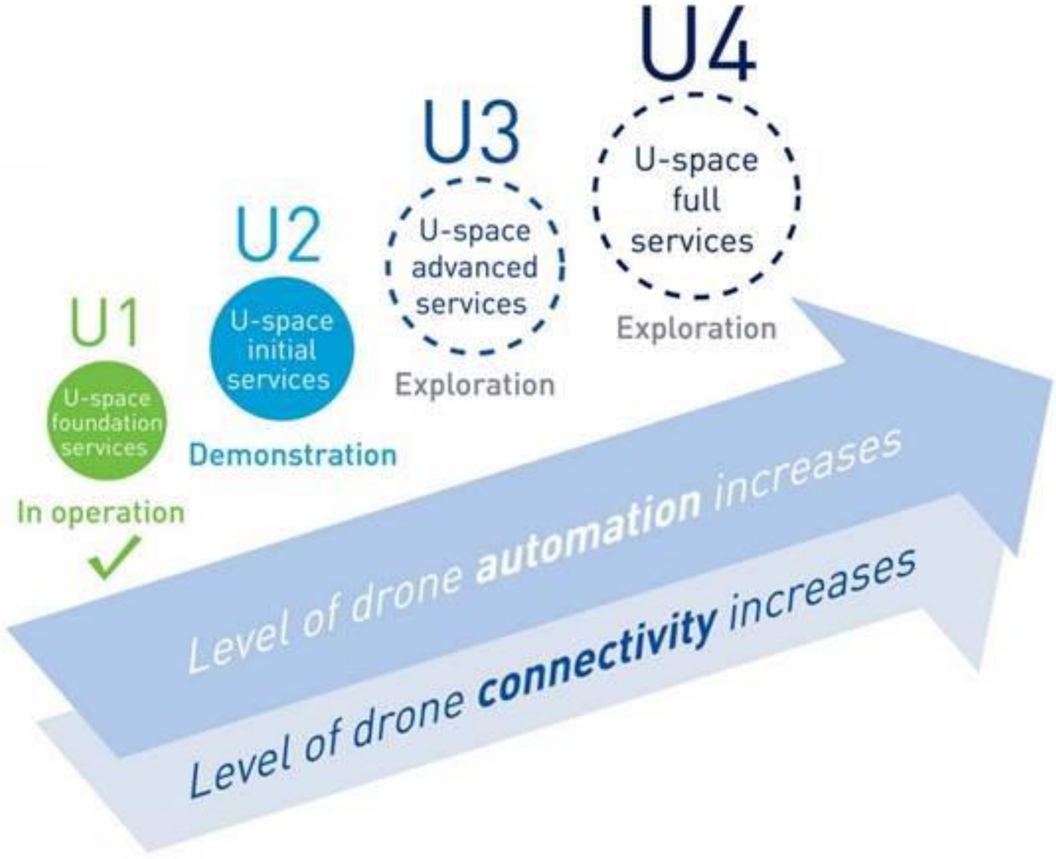


Figure 39: Current implementation U-SPace levels

As depicted in Figure 39, the level U1 is operating by 2019, while currently the U2 level is under demonstration mode. Currently there are twelve (BUBBLES, DACUS, ICARUS, METROPOLIS 2, USEPE, PJ34-W3 AURA, AMU-LED, CORUS-XUAM, GOF2.0, SAFIR-MED, TINDAIR, USPACE4UAM) European ongoing projects devoted to USpace research and demonstration [89]. The table below outlines the expected advancements during the next years.

Table 19: U-space roadmap [72][73]

Level	Name	Target	Example services
U1	U-space foundation services	2019	Electronic registration (e-registration) Electronic identification (e-identification) Geofencing
U2	U-space initial services	2022..25	Flight planning Flight approval Tracking Airspace dynamic information

			Procedural interfaces with air traffic control
U3	U-space advanced services	2025..30	Capacity management Assistance for conflict detection …
U4	U-space full services	2030..50	Integrated interfaces with manned aviation High level of automation, connectivity and digitalisation

5.5.1 5 years horizon (U-space phase U1 and partly U2)

In the following years, U-space will be deployed through the efforts of ANSPs who are obliged to regulate traffic around airports. The Very Low Level (VLL) airspace around airports will thus be made available for drones who need to make use of U-space services there. A limited number of other specific areas, like harbors and industry areas, will follow and provide VLL U-space services.

Through the EC-regulation [91], governments are obliged to assign dedicated U-space areas, where, depending on the ground and air risks, rules are specified that need to be adopted by drone pilots. The rules will specify what equipment is necessary and what procedures need to be followed to file a flight and during flight.

Several technological developments will contribute to the establishment of safe and efficient U-space services, such as automation (towards autonomy) and full connectivity (5G and others). The safety of manned aviation is guaranteed through well-defined protocols that offer interoperability between manned and unmanned traffic.

5.5.2 10 years horizon (U-space U2 and U3)

In the 10-year time frame, U-space services up to phase U3 will be available, meaning that anywhere, including in complex environments, drone operations can take place and that conflict detection and resolution is available to all airspace users. Conflict detection and conflict avoidance can take place through on-board systems or through on-ground U-space services that, through guaranteed connectivity, will provide certified services.

The link with air traffic control is fully operational, through a collaborative interface, where drone operators are in direct contact with ATC when needed. The normal interface, however, is a silent interface, where drones in U-space and manned traffic in controlled airspace are aligned with each other through a well-defined link between ATC and U-space.

Unmanned traffic, operating in an area that is designated for manned traffic will follow the rules of the air for manned aviation; manned traffic in a U-space designated airspace will use U-space.

The market for U-space service providers will become an open market, where the drone operator and drone pilot have their choice for the system they use, depending on their personal preferences for the concept they use or the details of the user interface.

5.5.3 15 years horizon (U-space U4)

U-space will be fully operational in all airspace, including urban areas. Local governments will organize the airspace above their cities, so that they can establish the concept for operation and they can set the rules concerning where to fly and where not.

U-space can also be set up according to temporary local requirements, such as a dedicated U-space area for an industry area, during a weekly market or for a local festival. The airspace can be commercially exploited, were a number of USSPs offer their services on contract basis, e.g. for the specific case of festivities.

Eventually, though timing for this is difficult to set, some derivative of U-space will become the new standard for air traffic control. All lessons learned from U-space can be fed back to the organization of services for manned traffic, including that for uncontrolled airspace. The level of automation and the concept of services will demonstrate improved safety of aviation and manned aviation will confirm to the use of the U-space and its corresponding rules.

5.6 Market and readiness levels

The use of electric drones for passenger transport will go through various stages, until they become real flying taxis, a real offer of commercial mobility.

The barriers to overcome before Urban Air Mobility becomes a reality are different. The first is the realization of the infrastructures necessary for the operations, the certifications of the enabling technologies, the increase of the battery capacity, the social acceptance and so on. Nevertheless, many companies started developing the technologies as early as 2015 and the first demonstration flights were made in 2018.

Targeting the end of 2022 for certification of its two-seat VoloCity multicopter, Volocopter intends to be one of, if not the first, to launch commercial eVTOL air taxi operations worldwide. Beginning with Singapore and Paris, Volocopter has laid some of the groundwork for its entry into numerous global markets through partnerships announced over the past few years and public demonstrations of its aircraft.

Figure 40 indicates a possible roadmap starting from today to 2035, based on the study of literature currently available. Passenger drones have yielded various proofs of concept, the first step now is to use the cargo drones before an than pass to people’s transportation. They will take flight in a niche market from 2022 to 2025. Privately owned passenger eVTOL for individual use and ownership could become a reality within the next four years. The market will expand from 2025 to 2035 when also commercial use is expected of those technologies.

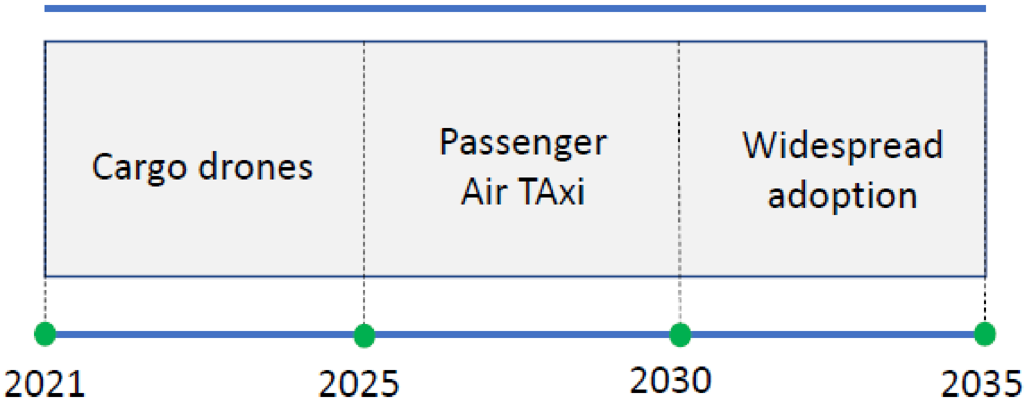


Figure 40 UAM technology roadmap in the three time horizon considered

The four years from 2021 to 2025 will be characterized by a wide range of tests and experiments (first with with cargo drones for safety reasons) to evaluate the various technical and business aspects. New concepts such as Lilium, Volocopter, or Uber Elevate will have to substantiate their claims and ambitions for private mobility in competition with existing mobility concepts. The lowered safety standard for novel and unproven eVTOL aircraft carries the risk that players in the field act in a too risk-prone or careless manner. Any resulting setback would endanger social acceptance.

Once first movers have begun to introduce their concepts to the market, the focus will shift more toward technology development and increased speed to roll out innovations faster. It will be a dynamic ecosystem marked by an expanding group of players, a growing number of varying concepts, and updates to already existent systems. In short, competition around vertical mobility will heat up in the decade from 2025 to 2035.

Finally, ATM needs to be enhanced to allow both ATM and UTM, to in turn enable higher traffic density for passenger drones. It is likely that this will evolve from the best practices developed in operating inspection and goods drones.