URBAN AIR MOBILITY PERSPECTIVES OVER MID-TERM TIME HORIZON: MAIN ENABLING TECHNOLOGIES READINESS REVIEW

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Abstract

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 United Nations that share is projected to rise to 60% by 2030. 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 pushing towards innovative mobility options design, as ground infrastructure becomes increasingly congested. In this framework, a novel transportation concept has been proposed aimed to exploit the vertical dimension in urban transport environment: the Urban Air Mobility (UAM). This paper focuses on the description of the UAM perspectives over the mid-term time horizon, based on the consideration of the expected readiness level of the main enabling technologies for UAM implementation, while also considering aspects related to propulsion, information and communication technologies, infrastructures and U-Space, all of them necessary for the deployment of UAM. This work was carried out in the framework of the ASSURED UAM project (Acceptance Safety and Sustainability Recommendations for Efficient Deployment of UAM), funded by the European Commission through the Horizon 2020 work programme.

Introduction

What is UAM? Urban Air Mobility 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 it is seen as an option to provide a safe, sustainable and convenient transport solution that leverages the airspace above cities.

Traffic is congested in urban areas and the situation 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. However, existing technologies and regulations only allow the UAM concept be implemented with conventional helicopters. Nevertheless, 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 etc.).

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.

The UAM vehicles will have the best chances for full-scale implementation provided that they will be focused on safety, operated smartly, and connected under the supervision 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 equipped with high autonomy level, 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 this paper, the current technologies advancements about UAM are described and the technologies that have to be targeted within the next 5 years are indicated.

Main enabling technologies for UAM implementation

The rapid evolution of 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 [1]. 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. Another immediate focus of the vehicle developers is overcoming obstacles on the path to certification. Detailed certification requirements for UAM vehicles are still under development by the relevant 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.

UAM technologies have currently reached a good level of maturity, but not such as to allow their immediate insertion in the market. In the sections below, aspects relating to the type of enabling vehicles, infrastructure, propulsion, ICT and U-Space will be analyzed.

UAM vehicles

UAM vehicles can be classified according to take-off and landing requirements and their application, as follows:

- Short Take-Off and Landing (STOL) vehicles,
- Vertical Take-Off and Landing (VTOL) vehicles,
- Personal Air Transportation System (PATS) vehicles,
- Cargo Drones.

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. 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. Heavier planes will require more distance to take off. For the future, it is necessary to improve STOL performances in order to exploit such capabilities in the field of the Door 2 Door (D2D) transport. 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 aircraft [2]. A typical example of STOL capable aircraft is reported in Figure 1

Figure 1. PZL-104 Wilga (STOL Aircraft)

For the aforementioned reasons, STOL technology is useful for peri-urban mobility but not particularly indicated as candidate vertical technology for UAM application inside urban environment, in which VTOL technology is more appropriate.

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 2. As indicated by available market analysis reports, eVTOL (electrical Vertical Take-Off and Landing) 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 [3]. 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.

Figure 2. EHang 216 eVTOL

For example, the following aerial vehicles should be considered [2]:

- Convertiplanes,
- Gyrocopters,
- Quadcopters.

Although some eVTOLs may look similar to helicopters, 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. Over 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 one, whereas a vehicle designed for inter-city and regional connectivity air mobility is the Lilium one [2]. The Lilium Jet (represented in Figure 3) is designed as a five-seats aircraft and it is powered by 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.

Figure 3. Lilium Jet

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. 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.

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 (see Figure 4) roadable aircraft has been 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 [2].

Figure 4. Pal-V Liberty

Despite the fact that PAT aircraft were born to fully satisfy the D2D paradigm, there are still many barriers to be evaluated, such as 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.

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 [4]. 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 permit to fly 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.

Of particular interest here are the drones for cargo application with maximum take-off weight (MTOW) more than 25 kg. Pipistrel company is developing the hybrid-electric powered cargo drone Nuuva V300 VTOL (Figure 5), 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 [5].

Figure 5. Pipistrel Nuuva V300

Another enabling technology for the transport of goods, was created in collaboration by the two German companies Volocopter and Schenker (logistics company) with the VoloDrone [6], 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 [7]. Furthermore, Volodrone is equipped with a standardized attachment system for flexible goods, therefore adaptable for different goods solutions. A representation of this vehicle is reported in Figure 6.

Figure 6. VoloDrone

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 7) 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 [8][9].

Figure 7. EHang 216L

The Italian company Leonardo, in collaboration with D-Flight (a company of the Italian ENAV group), is also conducting a series of demonstration flights authorized by ENAC, to test a 130 kg drone (see Figure 8) with electric propulsion, capable of transporting payload up to 25 kg. The demonstration flights were conducted in Turin. The project, named SUMERI [10], 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 goods will be flown up to 50 km by operators using a Beyond Visual Line of Site (BVLOS) control system. The SUMERI 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,
- high level of automation,
- advanced capabilities for dealing with air traffic management.

Figure 8. Leonardo experimental cargo drone

The demonstration carried out 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.

Infrastructures

The greatest operational barrier for the success of Urban Air Mobility is the availability of the infrastructure to take off and land. Creating an adequate UAM infrastructure is a major challenge for any city. Due to UAM nature of picking up passengers or dropping them off in heavily congested urban districts, “vertiports" need to be integrated into existing city infrastructure architecture (Figure 9) but also new dedicated vertiport infrastructures (Figure 10) need to be built, ensuring safe and fast boarding and disembarkation.

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.

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 (represented in Figure 10) for electric vertical take-off and landing aircraft”. 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.

Figure 9. Example of vertiport integrated in already existing urban infrastructure

Figure 10. Example of new vertiport infrastructure in urban environment

Skyports has joined forces with Volocopter to launch commercial services in Singapore [11] and Paris [12], which puts Singapore and Paris in pole position to launch Urban Air Mobility in Asia and Europe.

The German company Lilium has been working on a lean, modular [13] design that will help make vertiports accessible to both large and small drones and suitable to be placed at an existing transport terminal (Figure 11), such shopping centers, car parks or alongside a suburban residential development.

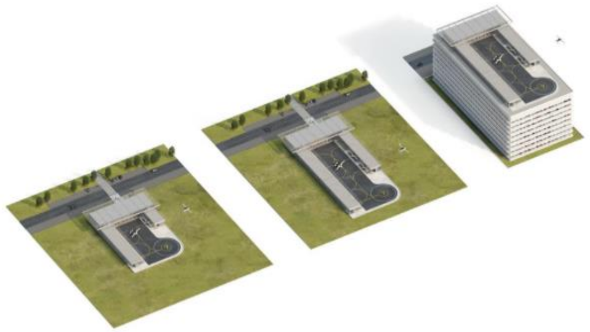

Figure 11. Lilium vertiport design near Airport terminal

Propulsion

VTOLs UAM technologies could be powered by different propulsion systems, ranging from hybrid to fully electric powered solutions, referring to the eVTOL vehicles, which are the most suitable for the UAM implementation.

Most UAM vehicles 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 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 higher noise as the propeller tips rotate with greater velocity. Thus, in order to maintain noise level as low as possible within urban areas, more suitable rotors are the ones with smaller diameter. Thereby, more rotors yet smaller are the goal many manufacturers try to accomplish with their aircraft design.

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: lower noise emission, lower energy/fuel consumption. This is achieved by reduction of aerodynamic drag around the wingspan and also behind it, by boundary layer ingestion and wakefilling. Furthermore, such configuration provides reduced weight of the vehicle and lower maintenance costs.

Ducted rotors (Figure 12), despite additional weight compared to the one without a duct, exhibit improved aerodynamics. This 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 12. Bell Nexus 6HX with ducted rotors

Further important considerations relate to the powertrain technologies. 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 the emergence of electrically powered aerial units, the need for efficient, high performance powertrain is growing rapidly. 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. Distributed electric propulsion systems deliver better 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 technology is therefore crucial field of research for UAM implementation.

There are many battery types available on the market today, including: Lead-acid, Ni-Cd, Ni-MH, Li-ion/Li-Po; the Table 1 below shows the main characteristics according to the type of battery [14].

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.

Table 1. Core properties of different types of batteries

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/m3]	25-60	25	70-100	80-200
Power density [MW/m3]	<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

Table 2. Lilium Jet mass and battery data

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

However, if the battery size is increased, then heavier the vehicle becomes. Therefore, this factor decreases the useful energy for cruising. Depending on the vehicle 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. An example of battery pack installed in modern passenger UAM vehicle is the one from Lilium Jet (reported in previous Table 2 [15]). The manufacturer claims a 245 km range and a total flight time of 55 min. 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.

Alternative UAM propulsion solution could be represented by combined use of electric power train with fuel cells. Fuel cells are electrochemical devices that convert the chemical energy directly to direct current (DC) electricity and generate also some by-products of the electrochemical reaction in the 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 systems (simultaneous use of heat and electricity) that usually boost the overall system efficiency [16].

Another propulsion system of UAM vehicles is represented by the hybrid (electric-petrol combination). In the past few years, a concept of hybrid electric aircraft has received a great deal of attention by aviation industry. Hybrid technology has become popular, well known and reliable especially due to hybrid electric ground vehicles which appeared on the global market more than 20 years ago. Hybrid vehicles appreciation is due to simple and reliable mechanics, fuel economy, low maintenance costs and reduced CO2 emission. The same is expected from hybrid technology to be implemented into aircraft, both manned and unmanned.

ICT

UAM 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 the 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, through aircraft-to-aircraft and aircraft-to-ground communications, especially in extreme weather conditions, and 5G’s low latency and high bandwidth will be a must for inflight passenger applications and smart-city MaaS (Mobility as a Service) applications [17].

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, 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 of fully integrated metropolitan transport system (i.e. to the System of Systems level), for both goods and passenger transport.

U-Space

U-Space provides Air Traffic Management (ATM) services for drones. These services consist of a set of agreements, protocols, communication means and standards that together enable an orderly growth 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 (ATC) of manned aviation. U-Space will be an enabler for UAM operations.

The conceptual specification of U-Space is currently set up in Europe by SESAR (Single European Sky ATM Research) and EUROCONTROL [18]-[19], while legislation is underway. SESAR is now setting up an extended concept for the use of U-Space in UAM. EASA (European Aviation Safety Agency) provides European regulation that will become mandatory for U-Space airspaces in all EU States by January 2023.

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 through 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 Unmanned Aircraft System (UAS). This is referred to as Very Low Level (VLL) airspace.

The U-Space services will be gradually introduced over four phases, from U1 to U4 (Figure 13), 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 [19].

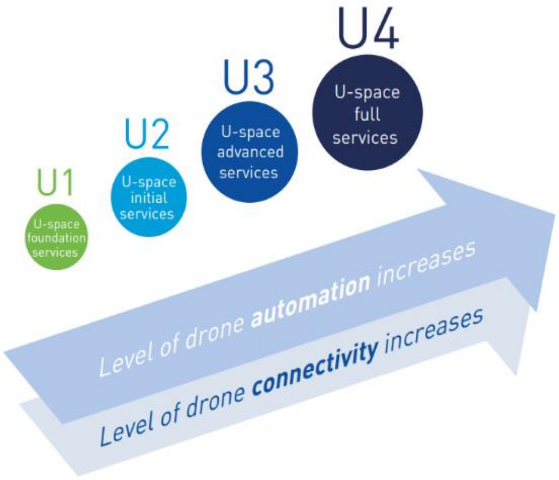

Figure 13. U-Space services levels

The services associate to each phase can be summarized as follows:

- U1: foundation services, covering e-registration, e-identification and geofencing;
- U2: initial services for drone operations management, including flight planning, flight approval, tracking, and interfacing with conventional air traffic control;
- U-3: advanced services supporting more complex operations in dense areas, such as assistance for conflict detection and automated detect and avoid functionalities;
- U4: full services, offering very high levels of automation, connectivity and digitalization, for both the drone and the U-Space system.

UAM technologies readiness level

This section analyzes the readiness level of the UAM enabling technologies discussed in the previous sections, based on the literature study carried out within ASSURED UAM project.

Table 3. UAM technology roadmap [2]

Technology	2022	2027
STOL	🟦	🟦
VTOL		🟦
PATS		

With reference to Table 3, the following considerations apply to each vertical technology candidate for UAM application:

- **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 UAM, 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, so that such technology cannot be considered over the mid-term time horizon (up to 2027) addressed in Table 3.

As regards the UAM application for goods transport, the roadmap relating to these technologies is shown in the following Table 4.

To ensure the operations of enabling technologies for cargo drones, in terms of urban, peri-urban and extra-urban air mobility, it is required, among other things, to have the necessary infrastructure for boarding, disembarking, take-off and landing, maintenance and battery charging operations, i.e. suitable vertiports are needed, as indicated in the previous section of this paper, integrated within the city, in the airports, and in the vicinity of motorways. Based on the literature studies carried out, in the following Table 5 a possible roadmap for vertiports implementation is indicated.

Table 4. Cargo drones roadmap

Technology for goods delivery >25 Kg MTOW	**2022**	**2027**
VTOL	Flight Tests still ongoing	On demand and in rural area

Table 5. Vertiport roadmap

Infrastructure	**2022**	**2027**
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

As indicated in the previous section, then, one of the key issues for UAM, and in general in the electrification of aviation, is represented by the electricity storage systems, i.e. the batteries and their weight. 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.

Another possibility for UAM is the usage of fuel cells for propulsion. Nevertheless, 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).

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 (Proton-Exchange Membrane) PEM FC (Fuel Cell) 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 from about 60 to 90 minutes.

Internet Communication Technologies are seen as rapidly developing. The Covid-crisis additionally driven the progress in this domain. 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 optimization;
- improving of access to the real-time transport data, because digitalised system equipped with sensors and appropriate in terms of efficiency communication infrastructure allows for gathering, processing and further sharing of real-time data about system operations;
- decreasing of the effort imposed on passenger with regard to multimodal travel arrangement/ management, because mobile applications gathering the available real-time traffic information from transport operators are able to generate optimised multimodal travel route;

- availability of more customer-oriented services, because more reliable and robust information about current condition of the transport process enable better optimization and efficiency increase;
- automation and autonomisation in transport, due to the clear trend towards autonomous car, bus, train, ferries and aircraft;
- algorithmic governance, because the increasing complexity of management systems covering more and more resources (e.g. more than one transport mode) leads to difficulties in controlling and adhering to changing regulations;
- use of privately generated data, because for instance private data are already used in application like "Google Maps", even if the real revolutionary potential is seen in private data not directly related with the transport needs.

About 5G technology in particular, currently it is not in its full services version, but this goal is not far off.

About U-Space services, as introduced in the previous section of this paper, 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/UAS. The U-Space blueprint [18] defines four levels of services and the related target implementation, i.e. the expected readiness level over the next years, is reported in the following Table 6. Currently there are twelve European ongoing projects [20] (BUBBLES, DACUS, ICARUS, METROPOLIS 2, USEPE, PJ34-W3 AURA, AMU-LED, CORUS-XUAM, GOF2.0, SAFIR-MED, TINDAIR, USPACE4UAM) devoted to USpace research and demonstration.

UAM perspectives over the mid-term time horizon

The five years from 2022 to 2027 will be characterized by a wide range of tests and experiments (first with cargo drones for safety reasons), in order 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 will 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.

The following Figure 14 indicates a possible roadmap, starting from today to 2027, 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 evolving towards people's transportation. Cargo drones will take flight in a niche market from 2022 to 2025. Privately owned passenger eVTOL for individual use and ownership could become a reality, at least as experimental trials, after the cargo drones operations, within a period of about five years after cargo applications.

Table 6. U-Space roadmap [18] [19]

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	2022-2025	Flight planning, Flight approval, Tracking, Airspace dynamic information, Procedural interfaces with air traffic control

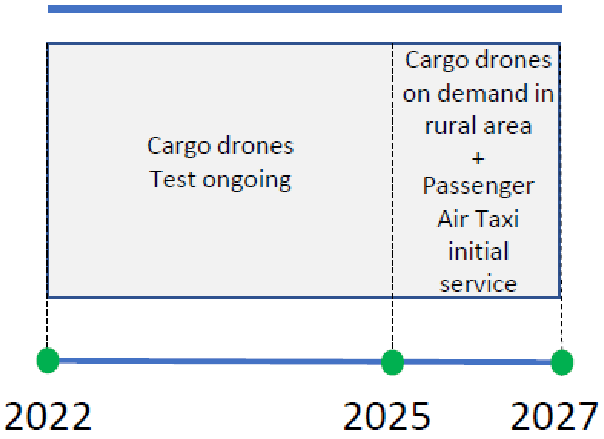

Figure 14. UAM technology roadmap in the mid-time term horizon

Conclusions

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 will become a reality are several and of different nature. The identified barriers are related to 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 started from 2018. Some applications target the end of 2022 for certification and competition around vertical mobility will heat up in the decade from 2025 to 2035. Also ATM needs to be enhanced to allow both ATM and UTM coexistence and integration, in order to in turn enable higher traffic density for passenger drones. It is likely that this will evolve from the best practices that will be developed in operating inspection and goods drones as first UAM application that will mature by 2025, towards passengers' transport by means of UAM vehicles starting as experimental operations from 2025 to 2030 and going on towards maturity in the following decade.

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