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TREBALL FINAL DE GRAU

TÍTOL DEL TFG: UAM Airspace Design

TITULACIÓ: Grau en Enginyeria de Sistemes Aeroespacials

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Resum

Aquest projecte té com a objectiu justificar la necessitat de la creació d'un espai aeri exclusiu per a dur a terme operacions amb drons, més en concret en l'àmbit de la Mobilitat Aèria Urbana (o UAM del anglès "Urban Air Mobility"), i raonar quins seran els aspectes que més limitin el disseny d'aquest espai aeri per a aeronaus no tripulades.

Per a justificar que una implementació efectiva de la UAM requereix la creació d'un espai aeri propi, així com una harmonització de la legislació en l'àmbit internacional, s'exposa el cas de l'aviació comercial: el mitjà de transport aeri que duu a terme milers de vols diaris d'una manera efectiva i garantint en tot moment uns estàndards de qualitat molt alts gràcies a les normatives definides i a l'estructura del seu espai aeri. Es raonen també els diferents motius pels quals l'adaptació de l'espai aeri comercial a l'àmbit de l'UAM no és viable.

Un cop demostrada la necessitat del sector UAM de tenir un espai aeri propi amb el dron al centre del disseny, es procedeix a destacar quines són les principals barreres i les possibles solucions a aquestes que els experts i les autoritats competents que treballen en el sector hi estan identificant. Aquests reptes pertanyen a camps tan diversos com la seguretat operacional, la protecció d'infraestructures i zones terrestres, adversitats meteorològiques, limitacions en l'àmbit tecnològic i dels mateixos vehicles així com un punt poc destacat en els estudis, però de gran importància, com és l'acceptació social.

La creació d'un espai aeri també implicarà el disseny d'una infraestructura terrestre que garanteixi que els vehicles podran enlairar i aterrar d'una manera segura en cada operació; s'expliquen les principals línies de disseny de vertiports en l'àmbit Europeu.

Finalment, amb tot el coneixement obtingut, es proposa un cas d'ús en el sector de la UAM que se centra en el transport de persones VIP, mitjançant tecnologia dron, des de diferents aeroports de Catalunya fins al Circuit de Montmeló de manera puntual en esdeveniments de rellevància mundial.

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Overview

The aim of this project is to justify the necessity of a specific airspace dedicated to drone operations, in particular in the Urban Air Mobility (UAM) field, and to expose which aspects are going to be the most limiting in the design of this airspace for autonomous aircrafts.

The commercial aviation case is presented to demonstrate that an effective implementation of the UAM requires the creation of a dedicated airspace as well as international legal harmonisation: a mode of air transportation that carries out thousands of flights every day while ensuring high levels of safety at all times thanks to its defined rules and airspace structure. The different reasons why the aviation airspace cannot be escalated to the UAM are also exposed.

Once the necessity for the UAM sector to have its own drone-designed airspace has been justified, the main barriers and potential solutions that the experts and corresponding authorities working on the sector have identified are exposed. These challenges come from fields as diverse as operational security, infrastructure and ground area protection, adverse weather conditions, technological and vehicle limitations, and a factor that is often overlooked but is crucial: social acceptance.

The establishment of the UAM airspace will require the development and design of a ground infrastructure capable of ensuring that aircraft can takeoff and land safely in each operation. The main European vertiport guidelines are explained.

To conclude the project and use the knowledge acquired in its elaboration, a use case in the UAM sector is briefly designed: the transport of VIPs by drone from different Catalan airports to the “Circuit de Montmeló” in punctual cases, such as when a Grand Prix is held.

A la Cristina Barrado, tutora del TFG, per haver-me ajudat a donar-li forma a aquest treball aportant el seu coneixement i dedicació en tot moment.

Al Roger Blas i al Jordi Moreso, qui han fet de la universitat una etapa inoblidable. Aquest treball és, en part, gràcies a vosaltres.

A la Marina per ensenyar-me a gaudir dels petits plaers de la vida i a veure la part positiva de les coses. Amb optimisme tot acaba sortint.

I especialment als meus pares, en Josep i la Isabel, per haver-me permès estudiar allò que més m'agradava, per haver aguantat el que quatre anys i mig de carrera comporten, i per ser absolutament sempre al meu costat. Aquest projecte va per vosaltres.

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LIST OF ACRONYMS AND ABBREVIATIONS

- AAM: Advanced Air Mobility
- ADS-B: Automatic Dependent Surveillance-Broadcast
- AI: Artificial Intelligence
- AIP: Aeronautical Information Publication
- ATC: Air Traffic Control
- ATM: Air Traffic Management
- ATS: Air Traffic Service
- ATZ: Aerodrome Traffic Zone
- CNS: Communication, Navigation and Surveillance
- CTR: Control Zone
- E: East
- EASA: European Union Aviation Safety Agency
- eVTOL: Electric Vertical Take-Off and Landing
- FAA: Federal Aviation Administration
- FATO: Final Approach and Take-Off Area
- GNSS: Global Navigation Satellite System
- ICAO: International Civil Aviation Organization
- IFR: Instrumental Flight Rules
- IMC: Instrumental Meteorological Conditions
- LEBL: Josep Tarradelles Barcelona-El Prat Airport
- LEGE: Girona Airport
- LELL: Sabadell Airport
- LETA: Circuit de Catalunya Heliport
- METAR: Meteorological Terminal Air Report
- NM: Nautical Mile
- OFV: Obstacle Free Volume
- SA: Safety Area
- SARP: Standards and Recommended Practices
- SESAR: Single European Sky ATM Research
- TAF: Terminal Aerodrome Forecast
- TLOF: Touchdown and Lift-Off Area
- UAM: Urban Air Mobility
- UAS: Unmanned Air System
- UAV: Unmanned Air Vehicle
- UTM: UAM Traffic Management
- VFR: Visual Flight Rules
- VMC: Visual Meteorological Conditions
- W: West

INTRODUCTION

Of all the papers and surveys dedicated to the Urban Air Mobility (UAM) sector, this project seeks to set itself apart from the others by defending the idea that a specific airspace is required to correctly introduce UAM operations in the near future. The main objective is to make the reader understand the necessity of developing a drone-designed airspace, as well as the several challenges that national authorities will have to face and some possible solutions to those problems. To achieve it and to show a possible use case of the UAM, the project has been structured into six different chapters.

The first chapter is a brief introduction to the UAM concept, including its origins, current level of development, what it is expected to provide to society, its main expected benefits, and the main challenges to its implementation.

Chapter 2 explains the flight rules and airspace structure of the commercial aviation sector as the key factors for the well-functioning of this mode of air transportation. The idea of the necessity of a UAM-dedicated airspace that can be derived from Chapter 2 is reinforced on Chapter 3, in which different justifications are given to show that a UAM-airspace is really necessary to implement urban air transport of people and cargo.

The fourth and fifth Chapters presents all the different difficulties that will be encountered when designing an urban airspace: safety factors to ensure to avoid dangerous situations for the aircraft and for ground structures and citizens, technological limitations in the field of traffic management and communication, navigation, and surveillance, the limitations of the vehicles that will be used, and finally, the need to gain the population’s favor. In addition to those challenges, some possible solutions and implementations are also briefly introduced.

Chapter six explains that not only must the airspace in which drones will operate be designed, but also the associated ground infrastructure. At European level, some drafts have been published; the main ideas about vertiport designs are given.

Finally, in order to put everything learned into practice, Chapter seven introduces a possible use case design for UAM operation. It is proposed that to reduce noise and emissions, VIPs attending the Grand Prixes at the “Circuit de Catalunya” can be transported by drone from the different Catalan airports instead of doing so by helicopter as has been traditionally done.

CHAPTER 1. URBAN AIR MOBILITY CONCEPT

Unmanned Air Vehicle (UAV) technology, also known as Unmanned Air Systems (UAS) or simply "drones", has piqued the interest of legal, governmental, law enforcement, commercial aviation stakeholders, and the technology industry since the early 2000s, but especially in the last decade.

One of the reasons for the recent increase in popularity of UAVs is the use of drones in applications that were previously done with manned aircraft such as helicopters of small propeller planes, lowering operational costs and preventing pilots from taking risks in certain delicate operations [1].

Taking into consideration the United Nations forecast of a hulking increase in world population in the following decades [2], several challenges for the future of Urban Mobility are concerning experts in the sector. How to deal with the incoming population density in big cities, the new infrastructures that will be needed, the best way to maintain safety standards while the demand is growing unstoppably, and how to improve air quality while increasing the capacity of given infrastructures are some of the main issues to be addressed [3].

The need to increase the capacity of urban mobility infrastructure, along with the recent successful flight tests with larger UAVs able to carry passengers and cargo [4], coupled with the last technological developments and improvements on electricity storage [5], have made the Urban Air Mobility (UAM) concept shine as never before.

Fig. 1.1 Volocopter UAM aircraft [7]

The European Union Aviation Safety Agency (EASA) defines UAM as the "new safe, secure, and more sustainable air transportation system for passengers and cargo in urban environments, enabled by new technologies and integrated into multimodal transportation systems" [6]. As also detailed by EASA, although the beginning contemplates the presence of a pilot onboard the aircraft, the future of UAM is expected to use autonomous UAVs.

For its part, the Federal Aviation Administration (FAA) of the United States has defined the concept of UAM inside a major concept, which is the Advanced Air

Mobility (AAM) [5]. While AAM focuses on goods and people operations between local, regional, intraregional, and urban environments, UAM focuses on the urban and suburban environment.

Both EASA and FAA definitions agree that the UAM concept comprises the rules, procedures, and technologies that enable air traffic operations for cargo and people in urban and suburban environments.

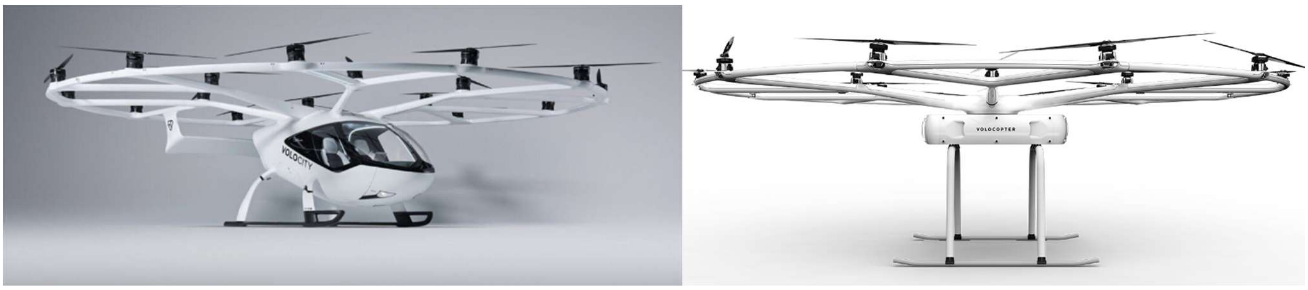


Fig. 1.2 From left to right, Volocity and Volodrone, Volocopter aircraft for people and goods transport [7]

Every new relevant technological advancement has an economic impact on society, and UAM is expected to have one: 90.000 jobs and a global market size of 4.3 billion euros by 2030 [6]. Non-economic benefits to note include time savings, which are expected to save between 15 and 40 minutes on average for standard city travel, faster activation of emergency equipment, and medical delivery, as well as safety benefits, as EASA expects UAM operations to have a lower probability of being involved in a fatal accident when compared to conventional road transport vehicles. Finally, urban flights are planned to be completed entirely with electric vehicles that will not emit CO2, lowering the pollution levels in cities; this is the reason why EASA talks about UAM as a green way of improving urban transportation.

Despite the technological improvements in the UAM sector, the legal part is probably the major barrier to its implementation, as commercial operations for larger UAV vehicles are still very restricted and unclear [8]. In recent years, some large corporations like Amazon, Google, and Uber have recognized the potential that UAM could provide to their value chains, so several tests and concepts have been carried out, putting pressure on competent authorities, like EASA, to create a legal mark that regulates this new way of transportation. This will not be an easy task as there is not a clear consensus on how it should be done, and it also has to take into account several factors such as different aircraft performances, social acceptance, restricted and dangerous zones, level of noise, technological limitations, and safety measures, among others.

The rapid growth of the UAV market in the last decade has shown that these types of vehicles will be a relevant part of the aviation sector in the near future, but while small UAV operations are being held concurrently with commercial aviation operations, the UAM concept is expected to be a major hazard to actual commercial aircraft operations [5].

CHAPTER 2. AVIATION FLIGHT RULES AND AIRSPACE STRUCTURE

2.1. Contextualization of Aviation sector

Nowadays, when organizing a trip that requires moving to another country or even a nearby city, whether for leisure or professional purposes, one will probably think of flying before driving or taking a train. This is because of the great expansion of the aviation industry in the last few years. In 2018, before the pandemics hardly hit the aviation industry, over 31.717 aircraft, serving 3.759 airports with the necessary help of the 170 air navigation service providers, were scheduled on average each day, which resulted in 12 million passengers and 120.000 flights per day [9]. The impact aviation had on the global transportation system in 2018 (both for goods, freight, and people) expressed in data is as follows [9]:

- 4.3 billion[1] passengers carried by airlines
- 58 million tons of freight
- 38 million scheduled commercial flights
- >48.500 routes worldwide
- 54 billion kilometers flown
- 85 million hours flown by airlines

The huge amounts of freight and people transported imply a global economic impact. According to the Air Transport Action Group (ATAG), the total economic impact (direct, indirect, induced, and tourism connected) of the global aviation industry reached USD 2.7 trillion (10 to the twelfth power), approximately a good 3.6% of the world's domestic gross product (GDP) [10], which can be translated into 65.5 million jobs supported by aviation worldwide.

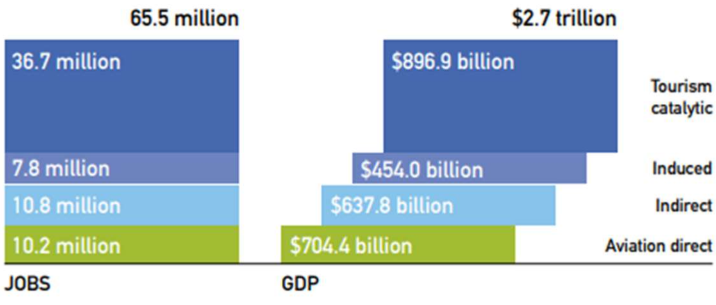


Fig. 2.1 Aviation Impact on jobs and GDP worldwide [10]

[1] Expressed in American "billions", which is equivalent to "a thousand millions" in the used European nomenclature.

The main objective of this paper is not to analyze the economic impact of aviation, or to focus on a certain aspect of the aviation sector, but this contextualization of the aviation economic impact and its exponential growth was needed to highlight the importance of a globally harmonized regulatory framework. Beyond this harmonization hides the International Civil Aviation Organization (ICAO).

2.2. International Civil Aviation Organization (ICAO)

On December 7th, 1944, was celebrated the Convention on International Civil Aviation, also known as the Chicago Convention, where, with the approval of 52 states, the ICAO was founded. It is also considered that, at that convention, the concept of “Modern Aviation” was created. According to the Chicago Convention, the ICAO’s mission is to support diplomacy and cooperation in air transport between the national governments that are members, as well as to promote the safe and orderly development of international civil aviation throughout the world, setting standards and regulations necessaries for aviation safety, security, efficiency, and regularity, as well as for aviation environmental protection [11].

Fig. 2.2 Actual ICAO logo, black and white format [12]

ICAO, currently formed by 191 Member States, works in cooperation with other members of the United Nations, such as the World Meteorological Organization (WMO), and other non-governmental organizations such as the International Air Transport Association (IATA) [12]. The main responsibilities of the ICAO are safety, registration, airworthiness, prevention of economic waste, fair competition, standardization, and aviation law [12].

2.2.1. ICAO Annexes

ICAO has defined several documents for each area of ICAO responsibilities; these documents, known as Standards and Recommended Practices (SARP), are contained in 19 different annexes.
Member states are not obliged to adopt SARPs as they are published, instead, each state can develop its own regulations, which may be stricter in certain aspects. From all the 19 annexes, the ones of vital importance are “Annex 2 – Rules of the Air” and “Annex 11 - Air Traffic Services”.

2.3. Rules of the Air (Annex 2)

One objective determined by ICAO is that air travel must be both safe and efficient. To achieve this, a set of internationally agreed rules of the air are required, among other necessary aspects. That is the reason of being of Annex 2, which rules apply without exception over the high seas, and over national territories. The person responsible for ensuring compliance with the rules of the air is the pilot-in-command of the aircraft [13, 14].

Every aircraft must fly following the general rules defined in Annex 2, which are the Visual Flight Rules (VFR) or the Instrumental Flight Rules (IFR). Also, any flight flying under IFR rules or a VFR flight to be provided with air traffic control services must fill a Flight Plan [14].

2.3.1. Visual Flight Rules (VFR)

Flying in accordance with VFR is permitted if the aircraft is flown in Visual Meteorological Conditions (VMC). The VMC determines the horizontal and vertical distance from the aircraft to the clouds well as the horizontal visibility the pilot should have from the cockpit. These distances and flight visibility are specified within ICAO's Annex 2, and have been collected in the following table [14]:

Altitude band	Airspace class	Flight visibility	Distance from cloud
At and above 3.050 m (10.000 ft) AMSL	A B C D E F G	8 km	1.500 m horizontally and 300 m (1.000 ft) vertically
Below 3.050 m (10.000 ft) AMSL and above 900 m (3.000 ft) AMSL, or above 300 m (1.000 ft) above terrain, whichever is the higher	A B C D E F G	5 km	1.500 m horizontally and 300 m (1.000 ft) vertically
At and below 900 m (3.000 ft) AMSL, or 300 m (1.000 ft) above terrain, whichever is the higher.	A B C D E	5 km	1.500 m horizontally and 300 m (1.000 ft) vertically
	FG	5 km	Clear of cloud and with the surface in sight

Table 2.1 VMC conditions for VFR flights [14]

As it will be seen in section "2.4 Air Traffic Services (Annex 11)", the airspace is divided into different types of classes.

2.3.2. Instrumental Flight Rules (IFR)

An aircraft will be obligated to fly under IFR conditions when VMC (shown in Table 2.1) are not met, this is, when Instrumental Meteorological Conditions (IMC) are given or whenever the flight crew requests it depending on the type of flight or the airspace classes they will get through, even if the weather is good [13].

In practice, most airliners fly under IFR regardless of the meteorological conditions given that day, primarily due to the fact that commercial aircraft will surely get higher than FL 200 [13]. Depending on the airspace class they are going through, aircraft will be provided with air traffic control service, air traffic advisory service, or flight information service.

The aircraft flying under IFR must be equipped with the appropriate instruments and navigation equipment to follow the flight plan and route determined, as well as be able to establish communication with the ATS at every moment of the flight [14]. In IFR flights, it is very important to maintain the selected, or assigned, heading and altitude in all flight stages to keep air traffic control (ATC) correctly informed about their given position, so they can properly do their job.

Finally, while in VFR it is the pilot who has the responsibility to maintain visual separation with other aircraft (remember the condition of flying at a speed that allows visual interception and enough maneuver time), in IFR the aircraft are separated between them by the air traffic controllers [13].

2.3.3. Flight Plan

Flight Plans are the form in which the main characteristics of both the airplane and the flight are provided to the Air Traffic Service Units.

It must be submitted prior to flying any flight in which at least a portion of the flight will be provided with air traffic control services, in any IFR flight within advisory airspace, in any flight crossing international borders, in any flight within or into designated areas or flight routes where so required by the ATS authority to provide information to search and rescue services or to facilitate coordination with military units and adjacent states ATS units [14].

The flight crew have to submit the Flight Plan before departure to the ATS office, or during flight to the appropriate ATS unit. Also, if the flight is to be provided with air traffic control service, it must be submitted not less than 60 minutes prior to departure [14].

The information contained in the flight plans is the one considered relevant by ATS units. Some of the data provided are the Aircraft Identification (ID), type of flights rules followed (VFR or IFR), type of aircraft, equipment onboard, cruising speed(s) and level(s), route to be followed, origin and destination aerodromes, fuel endurance, and people onboard, among others.

Apart from the elements mentioned above, the Flight Plan shall contain information considered relevant by the person filling and submitting the flight plan, or other information requested by the local ATS authority [14].

2.4. Air Traffic Services (Annex 11)

Air Traffic Services, or ATS, were not a widely implemented service before the Chicago Convention in 1944 [13]. At that convention the ATS were defined in order to ensure safety and efficiency in air traffic operations worldwide. The SARPs applicable to providing these services are collected in Annex 11 of the ICAO.

ATS, as it is known nowadays, is composed of Air Traffic Control (ATC), Flight Information, and Alerting Services. As defined in Annex 11, the objective of ATS is [13]:

- to prevent collisions between aircraft both on the ground and in the air,
- to expedite and maintain an orderly flow of air traffic,
- to provide advice and useful information to airplanes with the objective of performing a safe and efficient flight,
- and notifying appropriate organizations about aircraft in need of help or assistance.

Of the objectives mentioned above, the first two correspond to the ATC part, the third one is responsibility of the flight information services, and the last one is the goal of the alerting service [13].

As the purpose of this project is to study different possible designs of airspace for Unmanned Air Vehicles (UAV), more detail will only be given to one of the ATS parts, the air traffic control one, as it has been considered to be the most relevant part for the aim of the present paper.

2.4.1. Airspace classification

ATS airspaces have been divided into 7 by ICAO [18], so they shall be classified and referred to as follows:

- Class A: only IFR flights are permitted; all of them provided with air traffic control service and separated from each other.
- Class B: IFR and VFR flights are permitted; all of them provided with air traffic control service and separated from each other.
- Class C: IFR and VFR flights are permitted; all the flights are provided with air traffic control services, IFR flights are separated from all the flights (both IFR and VFR), but VFR only are separated from IFR flights and receive traffic information from VFR ones.
- Class D: IFR and VFR flights are permitted; all the flights receive air traffic control service, while IFR flights are separated from other IFR and receive traffic information from VFR, VFR flights only receive traffic information from the rest of the aircraft.
- Class E: IFR and VFR flights are permitted; IFR flights are provided with air traffic control service and are separated from other IFR flights. All flights will receive traffic information as far as is practical. Class E should not be used for control zones.

- Class F: IFR and VFR flights are permitted; all IFR flights receive air traffic advisory service, and all flights receive information service if requested.
- Class G: IFR and VFR flights are permitted and receive flight information service only if requested.

In the following section a summary table of the different airspace classes is provided.

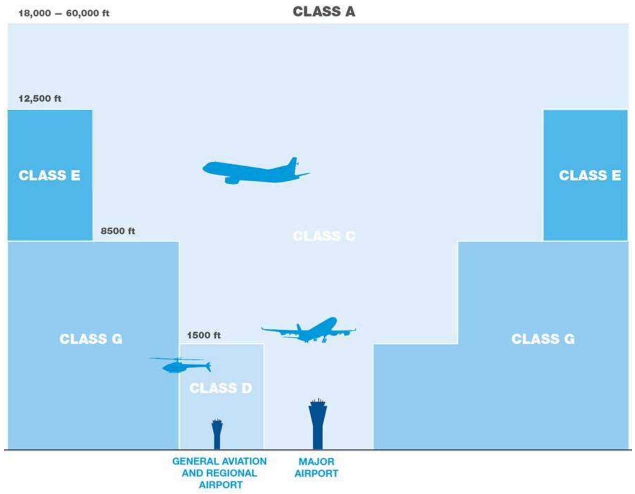


Fig. 2.3 Australian airspace architecture [19]

2.4.2. Air Traffic Control (ATC) services

To effectively perform its objectives [18], the air traffic control service, ATC, is divided into three distinct parts, each with the goal of providing service to a specific stage of the flight:

- Area control service: provision of air traffic control service in cruise phase. This ATC service will be provided by an area control center or a specific unit providing control service in a control zone.
- Approach control service: provision of air traffic control service on those parts of the flight associated to arrival or departure. Approach control will be offered by an aerodrome control tower, an area control center, or, in cases where traffic density is high, by a specific unit named approach control unit.
- Aerodrome control service: provision of air traffic control service for aerodrome traffic. This control service will be provided by the control tower of each aerodrome.

As mentioned previously, the main aim of the ATC unit is to prevent collisions between aircraft in ground operations and in mid-flight, as well as to expedite and maintain an orderly flow of air traffic. To do it properly, ATC units will have to be equipped with those systems which will enable them to obtain all the necessary information from the aircraft in, at least, the airspace zone they are controlling [18]. The following table shows which flights are allowed in each different airspace class and also whether ATC service and separation clearances are provided:

Class	Type of flight allowed	Separation Provided	Service Provided	ATC clearence needed?
A	IFR only	All aircraft	Air Traffic Control (ATC) service	Yes
B	IFR	All aircraft	Air Traffic Control (ATC) service	Yes
	VFR	All aircraft	Air Traffic Control (ATC) service	Yes
C	IFR	IFR from IFR IFR from VFR	Air Traffic Control (ATC) service	Yes
	VFR	VFR from IFR	Air Traffic Control (ATC) for IFR separation; VFR/VFR traffic information and avoidance under request	Yes
D	IFR	IFR from IFR	Air Traffic Control (ATC) Service, traffic separation about VFR, avoidance advice under request	Yes
	VFR	None	IFR/VFR and VFR/VFR traffic information, avoidance advice under request	Yes
E	IFR	IFR from IFR	Air Traffic Control (ATC) Service and traffic information about VFR as far as practical	Yes
	VFR	None	Traffic information as far as practical	No
F	IFR	IFR from IFR as far as practical	Air Traffic advisory service and flight information service	No
	VFR	None	Flight information service	No
G	IFR	None	Flight information service	No
	VFR	None	Flight information service	No

Table 2.2 Summary of airspace classes and ATC services [18]

As shown in the table above, ATC units shall provide separation in this four cases:

1) Between all flights in airspace class A and B,
2) Between IFR flights in airspace class C, D and E,
3) Between IFR flights and VFR flights in class C airspace,
4) When possible, between IFR flights in class F airspace.

2.5. Importance of harmonized regulatory framework to UAV sector

Despite the aim of this current project being to analyze where we are in terms of airspace structuration and design related to the UAV sector, it has been thought that the analysis of the actual commercial aviation regulatory framework will be essential to see how necessary it is to globally, or at European level, harmonize airspace structuration, service provision and operation definition to make possible people and freight transportation with drones.

Clearly, ICAO annexes and SARPs were defined having in mind the type of operations performed in the aviation sector, the size and performance of the different aircraft, and the infrastructure availability, but not the characteristics of drones, among other reasons, because at that moment the UAV sector was not as developed as it is now and it was not the aim of the Chicago convention. That is why the applicability of SARPs defined by ICAO to the drone sector is unlikely to happen.

In the following sections, the reasons why commercial aviation structure is not applicable in the UAV sector will be explained, and we will also get through the main aspects that will have to be taken into account when developing airspace aimed at drone use, different studies that have already been made, an European proposal to unify it, and different implementations and uses that could be viable.

CHAPTER 3. IS UAM AIRSPACE NECESSARY?

3.1. Introduction to a specific UAM airspace

Urban Air Mobility (UAM) implementation in cities, as well as UAV commercial operations in urban environments, seems closer than ever before, as governments, local authorities, and other companies in the urban mobility and technological fields see the potential in its use with the ultimate goal of increasing the life quality of residents: quicker assistance from first responders, inspection of critical structures, sustainable transport, among others [20].

However, these new aerial operations that will take place in and over cities appear to be of concern to the aviation sector because aircraft are currently overflying cities at relatively low altitudes during certain procedures [20]. Some airport related associations, such as Airport Regions Council (ARC), claim the need for a low-level airspace over populated areas and the creation of a common legal framework where UAM and commercial UAV operations are expected to be implemented. Furthermore, ARC also ask the national and regional competent civil aviation authorities to be involved in the legal implementation and approval of the UAM airspace.

The development of the “U-Space” regulation at the European level, driven by the Single European Sky ATM Research, or SESAR, is clear evidence of the need for an urbanely designed airspace as well as a legal framework. The U-space is a set of new services relying on a high level of digitalization and automation of functions and specific procedures designed to support safe, efficient, and secure access to airspace for a large number of drones [23]. As a result, the scope of the U-space includes not only defining the infrastructure of the airspace, but also achieving automated UAS management for a large number of operations taking place simultaneously while coexisting with the current Air Traffic Management System (ATM). In U-space regulation, the new ATM defined for drone operations is called UTM.

Fig. 3.1 U-space logo [22]

In the course of this chapter the lecturer will be shown some of the principal ideas that reinforces the idea and the need of a airspace specifically for UAM and UAV operations, especially in urban areas, like cities, or zones with a dangerous proximity to aviation activities. To do so an explanation about the UAM vehicles, difficulties in adapting the ATC to UAM and potential risks derives from this type of operations has been done.

3.2. Electric Vertical Takeoff and Landing (eVTOL)

At this point in the paper, the terms UAV and drone have been mentioned several times as recent technologies that have a big potential in both cargo and people transportations in cities. But as it goes into further detail, specifically in urban aerial mobility, the term “eVTOL” is going to be introduced because it is a key piece in the concept of UAM, hence its design. A lot of companies and organizations such as EASA [6] or NASA [5] expect that UAM operations will be performed by electric vehicles that will vertically takeoff and land. That is where eVTOL came from: electric Vertical Takeoff and Landing, which at the same time is a new concept originated by mixing “electric” with the particle VTOL itself, which is an already existing concept widely used in aviation, especially for military purposes.

EASA has been working in specially designed safety and regulation features regarding the VTOL as it is expected to be the vehicle performing the UAM operations [24]. Throughout this section EASA approach of VTOL will be addressed.

3.2.1. Difference between VTOL and Helicopter

A flying vehicle taking-off and landing vertically is not new, so anyone could say that, following the criteria exposed above, a helicopter could be considered a VTOL, but it is not because of the small letter in the VTOL definition.

VTOLs are defined as air vehicles taking-off and landing vertically by using more than two propulsion units, that is, engines. This redundancy in engines can increase aircraft safety as critical function will be shared by more than one component. [24] Also, VTOLs are expected to be able to reduce aviation’s carbon footprint by combining it with non-conventional sources of energy like using batteries instead of fuel (eVTOL).

3.2.2. VTOL specifications

Despite the fact that more documents are on the way, and more detailed documents about the technical requirements have already been published on the EASA website, the following are the main VTOL specifications [25]:

- Redundancy in propulsion and systems to increase reliability
- Capability of taking-off and landing vertically enabling new types of operations in narrow urban zones or other environments that have limited space.

- Fail-safe systems and structures: systems that are activated automatically in the event of a failure on main systems, lowering the risk of accidents and increasing the safety of passengers, citizens and surrounding aircrafts.
- Manned VTOLs will initially be able to collect data and gain experience in UAM operations, paving the way for years later, full automatization of VTOLs with a safety record acting as a backup.

3.2.3. Generalities in the design and safety features

There will surely be different-looking VTOLs on the market in the near future because every manufacturer will have their own shape and aspect design. But they will have a lot of common properties and features, as happens with commercial airplanes designed by different companies. With the purpose of just explaining and showing possible materializations of what will be their common features, EASA has created its own virtual eVTOL, which, as said, only has divulgative purposes [25]. In the following sub-sections some of the features which are expected to be common in the majority of VTOLs are listed and briefly explained.

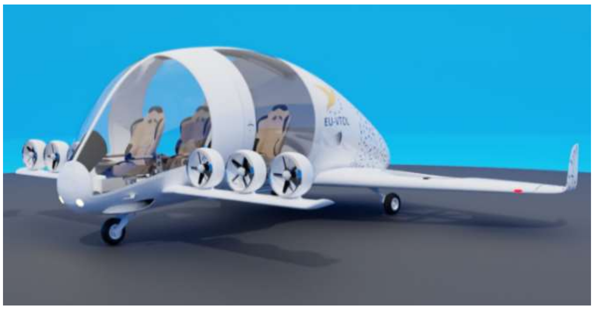


Fig. 3.2 The EU-VTOL, EASA designed VTOL [25]

3.2.3.1. Motors

As it has been defined above, the minimum number of motors and rotors of a vertically taking-off and landing vehicle to be considered a VTOL is three. This is the principal feature that distinguishes them from helicopters.

The expected high number of motors and rotors will optimize performance and provide redundancy for safety purposes, as more motors will remain available to perform an emergency landing if one (or more) fails [25]. Also, having a larger number of engines enable the rotors to operate at lower speeds, providing the desired lift with less energy consumption.

Finally, having several motors and rotors distributed around the VTOL causes the forces which could create the rotation of the fuselage to cancel out, avoiding the need of for a tail rotor as it happens in helicopters.

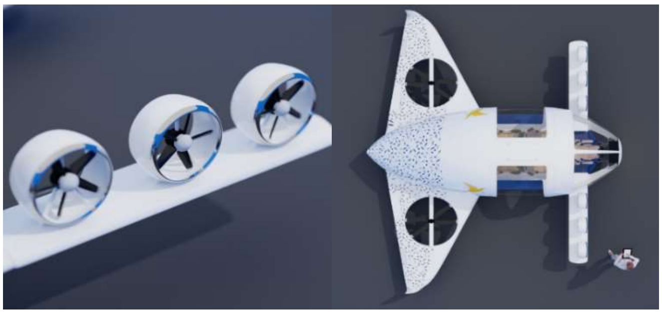


Fig. 3.3 EU-VTOL, detail of motors and rotors [25]

3.2.3.2. Pilot presence

As it has been mentioned throughout this section, at the begging there is expected to be a pilot onboard controlling the eVTOL which will lead to fully autonomous vehicles once safety records for this type of flight are available and ready to be analyzed. In the first stages, pilot and passengers will share the cabin of the eVTOL without any type of separator [25].

3.2.3.3. Batteries

EASA sees the concept of UAM as “green mobility of the future” [23], meaning that the vehicles will not emit carbon dioxide or other contaminants into the atmosphere. This is the reason why the VTOL concept has been named eVTOL after the intention of using batteries instead of fuel. Using batteries as the main power source is a complex task in which EASA has not imposed any major requirements yet, but for the need for the batteries to supply energy even in case of failure.

3.2.3.4. Other considerations

The characteristics explained in the previous sub-sections are the ones on which AESA has focused more in its articles about main features of VTOLs, but more technical documents have been published on the website aimed at manufacturers [24].

Other factors that will be important in VTOL certification include [25]:

- Materials: intended to be light, hard to break, and to resist environmental and operational conditions in the urban region.
- Windows: big windows allowing the passengers and, more importantly, the pilots, to have good situational awareness and good visibility to avoid other aircraft and obstacles.

- Flight controls: prior to fully automated VTOLs, pilots will have on-board controls to control the vehicle. The high number of motors and rotors will require advanced high-level controls.

3.3. Air Traffic Control scalability to UAM operations

The design of an exclusive UTM system coupled with the design of an urban airspace structure exclusively thought for UAM and UAV operations faces a lot of different challenges and constraints. One of them is studying the possibility of escalating or adapting the actual aviation Air Traffic Control (ATC) system to support these new types of operations [26]. Different ATC scalability studies done in the past have shown that it is a constraint more related to the operational environment than it is to vehicle performance. Factors such as the demand pattern or the airspace location influence in such a great manner the adaptation of ATC to other air-type operations [26].

The differences between vehicles that will perform UAM operations and the actual commercial aviation aircraft, as well as the difference in operations (VTOLs will fly considerably lower than commercial aircraft, in closer proximity to one another, and closer both to people and residential zones), have to be considered when thinking of the idea of a possible escalation of the ATC system [26].

Different organizations such as NASA, FAA, SESAR, and companies like Google, Amazon, or General Electrics, have being announcing their own programs in this field of UAM implementations in cities since 2015. This effort coming from different parts of the world to find an effective way to handle UAM operations indicates that the actual ATC system may not correctly support UAM and UAV operations.

3.3.1. Challenges of ATC scalability

The idea of escalating the actual ATC systems to control and organize the UAM and UAS flights will cause ATC systems and professionals to face several challenges. This is because of the unique characteristics of these vehicles and sector [26]. A study performed using an American data base identified four major challenges, which will be addressed in the following subsections:

1. Major fleet and total operations
2. Greater density of operations
3. Low altitude of operations in urban zones
4. Variety of aircraft performance, aim, and pilot training.

3.3.1.1. Major fleet and total operations

Since 2015, the FAA has tracked over 900.000 UAS in the USA, and it has been expected that there will be over 3.5 million hobbyist UAVs and 400.000 commercial drones in operation by 2022 [26]. The total amount of UAVs out there represents a potential flying fleet that is nineteen times larger than the commercial aviation and general aviation (not commercial aircraft) combined [26]. Despite the fact the utilization of recreational and professional drones is unlikely to overcome the number of airplane flying at a given time, the concentration of drone operations in certain places, like crowded cities, may be larger than the scale of current operations at a city airport.

On the other hand, even though UAM is a more recent concept than UAV commercial operations, taking into account the number of operations planned by private companies, such as UBER, for example, roughly 27.000 flights could be taken into account per day per city. When compared to the nearly 44.000 flights that occur every day in the United States, it is clear that even if the forecast falls short, the UAM and UAV expected demand will exceed the current ATC capacity [26].

3.3.1.2. Greater density of operations

The forecasted prediction of both UAM and UAV operations specified above can seem like an optimistic expectation [26], but if only half of it was to be available, the number of aircraft in relatively small portions of space (above a city or metropolitan area) would still cause a large density of operations that would probably collapse the actual ATC system.

To begin with, the existing technologies of surveillance and navigation may not be enough. Hundreds of UAVs flying over a few hundred square kilometers (Barcelona has 101 square kilometers [27]) would cause surveillance radars to be unable to detect them all [26]. Hence they would not provide effective surveillance. Some studies, such as [28], propose various methods for covering surveillance in UAM conditions, as discussed in section “5.1.1.3 Surveillance”.

Then, the actual ATC system is based on voice communications via radio, if in the case of UAM and commercial UAV operations this was to be implemented, the number of air traffic controllers needed to verbally be in contact with all the vehicles would not be feasible without any automatization or machine help [26].

Finally, ICAO Document 4444 and National Aviation authorities establish separations between aircraft in the different phases of flight [29]. These defined separations cannot be applied to UAV operations within a city or metropolitan area because only a few UAVs can fly at the same time to maintain separations. In Spain, ENAIRE (the air navigation manager) has defined the en-route separation to those areas where surveillance is provided by a Secondary Surveillance Radar (SSR) to at least 5 nautical miles [30], which is the same as 9.26 kilometers. The image below depicts the separation that UAVs should maintain over Barcelona if the current commercial aviation is used, which would only allow a few UAVs flying at the same time.

Fig. 3.4 Distance of 5 Nautical Miles above Barcelona [own source, Google Earth]

3.3.1.3. Low altitude of operations in urban zones

The effectiveness of surveillance systems, such as radars, will also be negatively affected because of the low altitude at which UAM and UAS commercial operations will take place. Flying at low altitudes in an urban environment will cause radars to not have enough coverage due to line-of-sight limitations [26]. The UAM airspace then will not be fully covered; meaning that not all the flying vehicles will be detected by the surveillance equipment.

On the other hand, traditional navigation aids (VOR & DME) may not also provide reliable coverage for the same reason mentioned above. The same happens when using Global Navigation Satellite Systems (GNSS) technologies like GPS: in cities and metropolitan areas, its reliability is not good enough due to different phenomena that will be seen in Chapter 5.

3.3.1.4. Variety of aircraft performance, aim, and pilot training

Commercial UAM and UAV operations will not only differ from traditional commercial aircraft operations, but will also differ between them. So the ATC will have to take into account not only vehicles that are different in terms of maneuverability, performance, configuration, and capabilities from the commercial aircraft, but also vehicles that will be different between them. This disparity in terms of vehicle types will difficult the ATC scalability for UAS operations.

It must be highlighted that while EASA states that despite the intention is to have fully autonomous vehicles performing UAM operations, there will be on-board or remote pilots flying the vehicle in the initial stages [6], some other companies have started doing tests with autonomous vehicles from the beginning [26]. Moreover, the training of the pilots aboard the UAV is not defined at the moment [23], as is the effectivity of the aircraft itself in the case of autonomous flights, which can be translated into a less predictable resolution maneuver when instructed.

The fact of mixing manned with autonomous vehicles coupled with the undefined training of the pilots [23], would lead to air traffic controllers having to handle aircraft with pilots onboard, remote pilots, and automated vehicles, which will cause an extra workload for them as there might be different types of communications to be taken into account simultaneously, complicating the task.

3.4. Specific hazards of UAM operations

The use of eVTOLs will introduce a new set of operational features, which will also mean new hazards that could put at risk the safe development of the operation [31]. Taking into account that safety is at the top of the list of priorities when conducting commercial aviation operations, it will not be otherwise in the UAM and UAV sector.

A hazard does not necessarily have to be understood as an event putting the flight in extreme danger, it can also be a condition that will, in some way, affect the planned operation. The consequences can be very different and can affect only the flight itself and its passengers, or also the surrounding flights and their corresponding passengers, which will have a considerable impact on the system [31].

Some of the UAM potential hazards may be quite similar to aviation ones, but others will be different in some aspects or completely new. This will be caused by the differences between vehicles and their systems. For example, hazards related to batteries as the only source of energy may not be encountered in commercial aviation nowadays [31]. Despite the fact that in Chapters 4 and 5 more detail will be given on what elements should be considered in UAM airspace design, the following table introduces the lecturer to some of the UAM-exclusive hazards in function of different aspects:

UAM aspect	Hazards
Power source	Failure of batteries and power supply to motors and other systems
Systems	Not enough reliability in navigations systems
Vehicles	Lack of spare parts in case of malfunction Malfunction in autonomous eVTOLs without on-board pilot
Airspace	UAM interference with existing air traffic Loss of safety separation due to high demand
External environment	Rapid weather changes in the urban environment Proximity to power lines, buildings and population
Control of the vehicle	Inadequate pilot training Loss of pilot's situational awareness
Ground infraestructure	Lack of experience in new infraestructures Lack of vertiport availability Inadequate ground staff training
Passengers	Pilot and pax sharing small habitacle: possible interference
Cibersecurity	Hijacking of used communications channels

Table. 3.1 UAM Specific Hazards [31]

3.5. Need for UAM airspace

As it have been reasoned throughout this chapter, due to the expected high density of UAM-related operations that will be held in cities, the task of hosting all the demand while maintaining enough separation between aircraft and obstacles, and more than a good level of safety, as EASA demands, will be a tough job.

Not only has the difficulty of the actual ATC and ATM systems to manage UAV and UAM operations seen in section “3.3 Air Traffic Control scalability to UAM operations” driven to the creation of a specific UAV airspace, but also the specific design of eVTOLs and the hazards associated with their design and type of operations have had a significant impact.

Also, the fact that the ICAO annexes and aviation regulations were not created with neither drones, eVTOLs, nor UAM operations in mind, but with commercial airplanes and their specific operations lead to the idea that the creation of an airspace and legal framework with at the core of it will be the most logical action to take.

Despite the accepted idea of the needed urban airspace, there is no clear consensus on how it has to be done. Some studies affirm that the more structured the airspace is, the better it is in terms of safety, while others says that predefined paths only decrease capacity and it should be a free-route space. [20] But the proposition that the airspace structure must be optimized for capacity and safety over other factors seems to be widely accepted.

The aim of the following chapters is to study which have to be the main determining factors that national authorities and aviation organizations have to take into account when creating and defining the new urban airspace.

CHAPTER 4. CHALLENGES IN UAM AIRSPACE DESIGN AND POTENTIAL SOLUTIONS I

The process of designing an airspace specifically thought for urban air operations is not an easy task as multiple constraints and challenges have to be solved during the process; proof of that is that a wide amount of studies have been carried out but any consensus on how to do it has been achieved [21].

The main difference between the urban airspace and the general aviation, or ICAO's, airspace is the amount of space available [21]. While in aviation the airspace goes from a lower limit to thousands of meters high [18], the UAM airspace will have to be designed within a much smaller space, located between the ground (where a lot of obstacles will have to be taken into account) or buildings up to a higher limit, high enough to allow air urban operations but with enough separation from the commercial aviation operations. VTOLs will have to fly inside this spatial envelope, which will be referred to as the "fly zone".

But not all the remaining space between the ground or buildings and commercial airspace will be suitable for UAM operations. Most of the studies and papers [21] agree on the same restricting factors that have to be taken into account, as they will notoriously limit the space in which UAVs or eVTOLs will be allowed to fly. These limitations are always defined with safety in consideration. The image below explains in simple terms how these limiting factors can affect the fly zone definition:

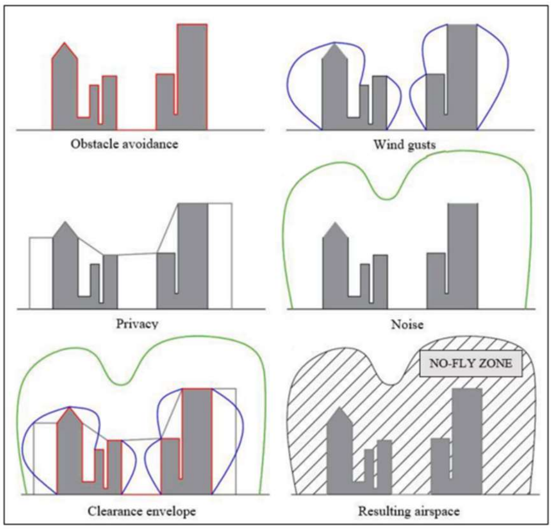


Fig. 4.1 Urban airspace limitations [21]

The image above depicts how the mix of different factors such as obstacle avoidance, wind gusts, privacy, noise, and the clearance envelope or safety margin results in a no-fly layer in which UAVs will not be allowed to fly.

The aim of Chapters 4 and 5 is to analyze some of the main problems that the UAM airspace definition faces and, at the same time, some possible solutions to those problems by implementing different technological systems. Note that there are a lot more limiting features and solutions, but only the most studied and cited ones in reference papers will be included.

4.1. Safety factors

In Europe and the USA, EASA [23] and FAA [5], respectively, identified the safety of people, vehicles and property as the top priority in UAM and UAV operations. It was to be expected, as safety is also the top priority in commercial aviation operations. If the risk of accident is reduced, then safety is improved. To minimize risk in operations, the likelihood of an accident happening must be reduced (by applying more restrictive technical features to vehicles, for example) as well as the gravity of an accident [21]. In the context of air operations, it is impossible to completely eliminate the risk of an operation, but some guidelines, recommendations, and obligations can be defined by national aviation authorities to, at least, decrease it.

4.1.1. Aircraft separation and avoidance

As it was explained in Chapter 3, “3.3 Air Traffic Control scalability to UAM operations”, the safety distance between eVTOLs, VTOL to UAV, or UAV to UAV, will need to be smaller compared to the one defined in aviation, so new standards have to be defined in the field of urban air operations. The survey “Designing airspace for urban mobility: A review of concepts and approaches” [21] has collected two different approaches to UAM separation proposed in various studies:

1. Fixed separation: this idea consists in defining some fixed separations, both vertical and horizontal, that all the aircraft will have to maintain between them at any time of the flight. A minimum separation of 0.3 NM (555.6 m) or even 0.1 NM (185.2 m) may be required to safely separate aircraft horizontally, while a vertical distance of 400 ft (121.92 m) or, in some cases, 100 ft (30.48 m) should be maintained. Technological advancements may allow smaller separation distances in a near future.
2. Dynamic separation: specific separation will be determined by classifying UAVs and VTOLs in different classes based on their capabilities and technological equipment. An aircraft equipped with systems that allow it to detect and avoid nearby aircraft will be considered a high-capability aircraft and will need to maintain smaller distances than a poorly equipped aircraft, which will be considered a low-capability aircraft.

To ensure previously explained separations the “sense-and-avoid” system, which is the UAM equivalent to the aviation “see-and-avoid” procedure used in VFR flights, may be a suitable solution. The sense-and-avoid method is performed by combining highly developed software with hardware like sensor, cameras or

LIDAR[2] onboard the drone. The problem is that this hardware can be heavy enough to exceed the maximum payload of certain smaller UAVs. Regardless of the weight problem, sense-and-avoid is expected to be a must in UAM operations.

Sense-and-avoid is also a good method to increase safety while navigating through a dense urban environment, as its main purpose is to detect possible imminent collisions with other vehicles, buildings, or objects and hence avoid them. This can be translated as an increase in safety as the probability of a collision is reduced.

4.1.2. Restricted zones

UAM operations can entail a potential hazard if aircraft overfly certain zones [21]. On the one hand, there are some critical areas such as airports, hospitals, or power plants where a large-sized UAV or an eVTOL could cause damage to a considerable number of people and have a big economic impact. On the other hand, restricted areas have to be considered, as they should not be overflown because of the activity that is developed; some examples could be police stations or military bases.

Some kind of preventive action should be taken in order to avoid that any UAV or VTOL intentionally or by mistake overflies these restricted areas. A solution can be geofencing [21]. Geofencing is a commonly deployed method whose aim is to contain drones within an operational region, or “stay-in region”, and outside a specific region, or “stay-out region” [33].

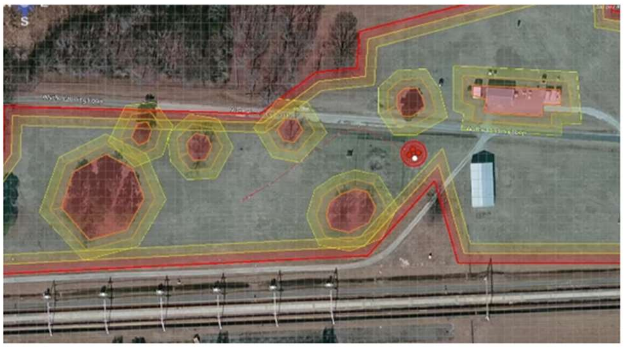


Fig. 4.2 Geofencing example, the stay-in region is the land parcel, while several stay-out regions are defined to avoid obstacles [34]

Most of the UAVs that are sold nowadays are equipped with an autopilot and different geofencing techniques [33]. These available geofencing solutions can

[2] Light Detection and Ranging (LIDAR) sensors use the energy of light, emitted by a laser, to scan the ground or surrounding objects and measure variable distances. The result is a cloud of data points that can be used to produce high-resolution maps and extremely detailed 3D models of natural and artificial objects. Useful in UAM field to detect incoming aircraft [32].

be a good first approach to avoid flying over a forbidden zone; however, neither UAV autopilots nor geofencing techniques are generally manufactured in compliance with conventional certification standards for safety-critical systems, resulting in either unknown or not enough realiability on this systems [33]. Also, it has to be taken into account that actual geofencing systems are dependent on the autopilot system, meaning that a hardware failure would cause a failure in both systems.

A solution to that problem is implementing geofencing systems independent of any other avionics equipment, guaranteeing that the flying vehicle will not enter a restricted or critical region in any phase of the flight, even if the autopilot or any other system fails [34]. NASA has developed a geofencing system called "Safeguard" of this kind.

EASA has not only considered geofencing as an option but has also implemented its technology in the design of the U-space (see section "3.1 Introduction to a specific UAM airspace concept"). In the following picture it can be seen how EASA has defined different types of regions depending on the level of allowance that UAVs and eVTOLS will have to overfly them.

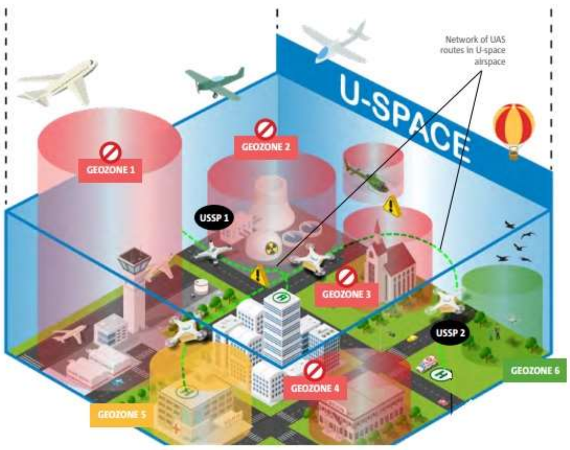


Fig. 4.3 U-space implementation of geofencing [35]

4.1.3. De-conflicting by flight phases

An eVTOL flight aimed to carry passengers, or a UAV flight to move cargo from one point to another, can be divided into three different flight phases: the Pre-flight, the Flight, and the Post-Flight. [36] Each of these phases is divided, in turn, into other sub-phases, as can be seen hereunder:

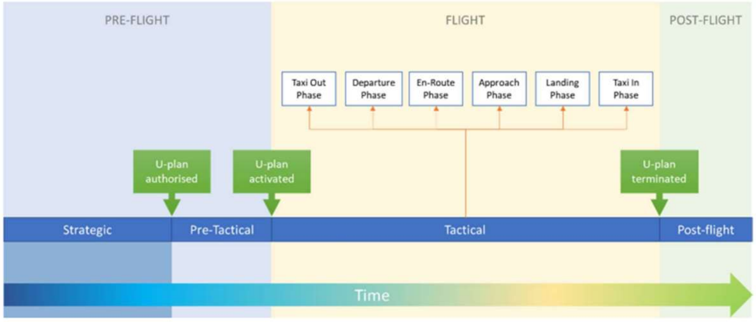


Fig. 4.4 Timeline of a U-flight [36]

The strategic part is a long-term phase in which the operator prepares the necessary equipment for the operation and in which corresponding authorities design or modify the airspace, flight rules, and other related aspects. The Pre-tactical phase refers to a short period before the realization of the flight, which is called the tactical phase, until the flight comes to an end and the post-flight phase starts [36].

As it happens in commercial aviation (see chapter 2), all the flights to be carried out inside the U-space (in the European case) or inside other urban airspace structures, are expected to be obliged to fill a flight plan during the strategic part. This flight plan will enable the “strategic de-conflicting”, which consists of the operator modifying the initial flight plan at the request of the competent authority in response to a possible collision in mid-flight with another flight, which has its own corresponding flight plan, being detected. The aim of strategic de-conflicting is to increase safety by reducing the risk of the operations in the pre-flight phase.

4.1.4. Meteorological conditions

Weather conditions are one of the main hazards in the aviation industry, causing between 25% and 50% of all the accidents reported each year [21]. The sensitivity of the meteorological inclemencies increases in a notorious way when the size of the airplane is drastically reduced, as it happens with UAVs and eVTOLs compared to commercial aircraft [37].

Despite the fact that weather-related incidents in commercial operations have been significantly reduced over the last few years thanks to the new weather predicting and warning systems introduced [21], it is still a concern in UAM as the actual systems do not provide accurate enough predictions in cities and urban environments. This lack of accuracy in urban weather prediction can significantly affect some critical flight phases in UAM operations such as takeoff, landing, and the transition from horizontal to vertical flight, which, coupled with the low en-route altitude of the flights and the proximity to obstacles, can compromise the safety of the flight [37].

Several ways of disseminating meteorological information to aviation operators such as pilots, airline coordinators or air traffic controllers have been designed by aviation authorities. The Meteorological Terminal Air Report (METAR) and the Terminal Aerodrome Forecast (TAF) are the two most commonly used to inform of aerodrome conditions. These reports provide, in a standardized way, all the relevant information that should be taken into account [38]. The following table has classified all the weather conditions that can be shown in METARs or TAFs on a scale from 1 to 10, in order of the impact they may have on safety during UAM operations [37]:

Weather condition	Impact on UAM	Weather condition	Impact on UAM
Drizzle	1	Winds of 20 to 25 kts	7
Rain	1	Smoke	7
Haze	1	Non-VFR Visibility	7
Ice Crystals	1	Wind greater than 25 kts	8
Sand Whirls	1	Sleet	8
Sand	2	Squalls	8
Snow Grains	2	Fog	8,5
Temperature ≤ 0ºC	3	Freezing Fog	8,5
Temperature ≥ 38ºC	3	Freezing Drizzle	9
Non-VFR Ceiling	4	Thunderstorms	9
Dust	5	Dust Storm	10
Snow	5	Funnel Cloud or Tornado	10
Sandstorm	5	Freezing Rain	10
Winds of 15 to 20 kts	5	Hail	10
Mist	6	Volcanic Ash	10
Snow Pellets	6		

Table. 4.1 Weather phenomena impact on UAM [37]

Not all the weather phenomena mentioned above have the same likelihood to happen in cities; some of them will be encountered very often in metropolitan areas, while others will practically never occur. The ones that are more concerning for UAM operations due to their probability of occurring and their consequences are the ones that follow [21, 37]:

- Wind: if it blows in the opposite direction of the aircraft path, it will decrease the endurance of the mission. Furthermore, the flight's integrity will be affected due to proximity to obstacles and lack of space for position corrections.
- Visibility: fog, low clouds, and air pollution are the main reasons for low visibility situations in cities. These situations could reduce the effectiveness of sense-and-avoid avionics.
- Storms and thunderstorms: precipitation may cause onboard electronics to malfunction and increase resistance to aircraft movement. The changes in barometric pressure associated with these phenomena may cause miscalibration of the altimeter and hence altitude errors.
- Extreme temperatures: both high and low temperatures affect the performance of batteries, decreasing their life expectancy and reducing the aircraft's autonomy.

- Ice: ice and snow tend to stick to surfaces, which is a problem for moving ones like propellers or other actuators. On the other hand, it will also cause an increase in the weight of the drone.

From all the meteorological phenomena listed above, the most critical factor for UAV operations is, by far, wind. One reason it is considered so dangerous is the unpredictability of wind gusts, which may entail great hazards to the operation.

Wind gusts are brief and sudden increase in wind speed, in other words, a wind burst [21]. In cities and urban environments, there is a lot of friction between wind and large surfaces like a building's façade, roads and other artificial constructions that results in the creation of eddies that alter the direction and speed of the wind unexpectedly and suddenly. The uneven space between buildings is called "urban canyon".

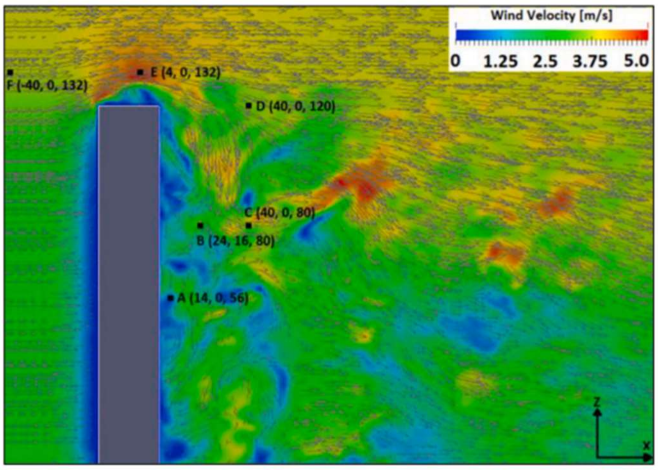


Fig. 4.5 Wind eddies around a building [21]

If the eVTOL flies through a wind spiral like the ones in the previous figure, the aircraft will be prone to losing stability, having more difficulty maintaining position and altitude, and even losing the control. To overcome these adversities, some corrections will have to be performed, resulting in higher power consumption. The corrections performed by the autopilot can be oversized, which will move the drone out of the flight plan and cause a collision [21].

Implementing dynamic geofences to avoid certain zones with adverse meteorological conditions could be a solution to reduce risk, but as far as the prediction techniques in urban environments are not reliable enough, the solution will not be either.

4.2. UAM Traffic Management

The main challenges identified, which have already been solved, in the commercial aviation ATM system are airspace integration, vehicle separation, emergency situation management, capacity management, flight scheduling, implementing delays, and traffic flow management [21]. So the UAM Traffic Management (UTM) is expected to encounter similar difficulties in its implementation, some of which may be solved similarly, but others, due to the differences in vehicles and operations, will have to be approached in a different way.

In recent years, UAV operations have been conducted in areas where no interference with commercial aviation was possible or, in the case of proximity to commercial airplane-controlled areas, segregated airspace or coordination with ATC was required, reinforcing the idea that UTM should be separated and independent from ATM while retaining the possibility of aircraft coordination between them when needed [39].

According to the FAA [39], UAM implementation creates a potential risk to commercial operations; to reduce the risk and enable these new type of operations, some airspace integration principles and UTM specifications for urban airspace design have been defined:

- Will not impose extra workload on ATM’s air traffic controllers.
- Will not restrict general airspace users or operators.
- Safety requirements and thresholds will be met.
- Will be a flexible system, allowing modifications when the demand requires it.

Having in mind these generic guidelines, two main approaches to managing urban air traffic in the UTM system can be distinguished [21]. The first, proposed by the FAA or NASA [21, 39], proposes UTM as a centralized and technologically capable system to accommodate aircraft of all levels of performance and types of equipment. The second approach, mainly supported by the industry, states that operators should select their preferred routes (most commonly the most efficient one) while ensuring safety and separation with on-board technology such as a sense-and-avoid system [21]; poorly equipped eVTOLs or UAVs will not be allowed to fly as no separation, safety, or collision avoidance can be guaranteed.

The decision of which approach should be chosen or which one will be more suitable is still not clear, but regardless of which of the two is chosen, it is clear that UTM is expected to have highly automated systems, programming interfaces, advanced software (using techniques like machine learning or artificial intelligence; see subsection “4.2.2 Artificial Intelligence in ATM/UTM”), non-voice communications between aircraft and control centers, and fully autonomous VTOLS in the near future [39].

Among all the factors that will influence the UTM design, at least in its early stages, a quite popular topic in papers and research articles on the field is the level of automatization of the vehicles [21]. A generally accepted classification is going to be needed in order to distinguish the associated properties of a man-manned VTOL from a fully autonomous one. Subsection “4.2.1 Automatization level” provides further details.

Future urban airspace scenarios will benefit from the convergence of technologies and the integration of data from on-board and on-ground sensors, artificial intelligence for route design and flight time optimization, robust telecommunications, and real-time representation of flights for situational awareness, among other features, as technology advances [39].

4.2.1. Automatization level

The autonomy of an aircraft, can be defined as the ability of the aircraft to aviate, navigate and communicate on its own [40]; that includes not only following predetermined orders, but also making decisions on the fly.

The level of automation of air vehicles sparks interest in UAM airspace design because the more autonomy an eVTOL has, the more vehicles that can be allocated in the airspace; it could also address some shortcomings of existing ATM systems and increase the system's robustness against interferences [21].

Despite the fact that there is no single national authority that determines the definition or the different levels of automation of UAVs, there is a quite clear consensus on the topic as different organizations or companies like Wisk, the Canadian Advanced Air Mobility Consortium (CAAM), Drone Industry Insights, or the National Institute of Standards and Technology use the same five-level classification detailed in the following scheme [41].

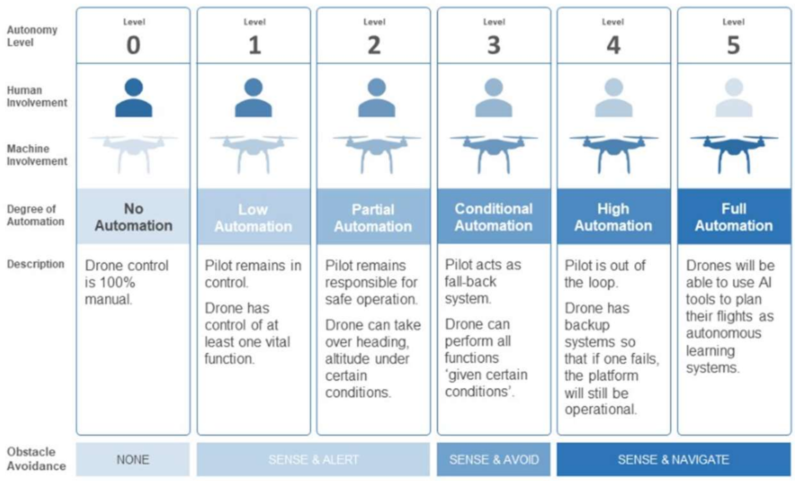


Fig. 4.6 Five levels of classification of drone automation [42]

From the picture below it can be seen that as the level gets higher, the human presence diminishes and the drone act more on its own. The creation of a single classification is implied in the design of the UAM airspace as, from that classification the different procedures and rules of flying will be established and defined [21].

Some eVTOL manufacturers, like Wisk [40], go for the fabrication of fully automated fleets to perform UAM operations, as they see huge benefits like avoiding potential pilot shortages, reducing operational costs, easing short- and long-term maintenance, and also avoiding the number one cause of aviation accidents: the human factor [41].

4.2.2. Artificial Intelligence in ATM/UTM

Recent years have been determinant for the development of Artificial Intelligence, or AI, as it has become a transformative technology due to advances in computing capacity and data availability; however, it has been around for more than 60 years [43].

Actual ATM systems generate huge amounts of data from their repetitive procedures that, through Artificial Intelligence (AI), can be mined by applying different techniques such as machine learning and deep learning. With the information obtained from using that data, ATM could achieve higher levels of automatization to improve the efficiency of their operations and, hence, take better decisions, reducing the workload for human operators and allowing them to focus more on critical tasks that still require human intervention or decision [43]. Having these key concepts about AI in mind, along with the expectation that ATM and UTM systems will be highly automated in the near future, SESAR has published a paper with an extensive analysis of some of the benefits obtained by applying AI intelligence to ATM [43].

The use of AI in conjunction with highly automated processes could serve as the foundation for a highly autonomous UTM system, making UAM operations less reliant on human decisions. This independence of UTM will permit a more resilient system able to rapidly and autonomously adapt to different types of operations or densities of vehicles throughout the urban airspace.

CHAPTER 5. CHALLENGES IN UAM AIRSPACE DESIGN AND POTENTIAL SOLUTIONS II

5.1. Technological limitations

Apart from the safety and traffic management factors seen in Chapter 4, technology will also be an essential part of the set, so a very important process is identifying the strong and weak points of the technology planned to be applied and, from there, designing the airspace to take advantage of the greatest benefits it can offer. Additionally, a resilient design that can quickly adapt to sudden or significant modifications or changes is required due to the expectation of continuous technological advancement in the coming years [21].

Innovative technological systems in the CNS (Communication, Navigation, and Surveillance) field will be required to implement the stated design while accommodating the expected capacity coupled with the specific type of operations in cities or urban areas [21]. The principal purpose of this section is to explain why the actual CNS systems working in aviation need to be changed in order to provide reliable results in the UAM sector.

5.1.1. Communication, Navigation and Surveillance

Significant technological advancements are required to ensure in UAM operations the same quality levels in the field of Communication, Navigation and Surveillance (CNS) that commercial aviation has today. The main issue is that the reliability and efficiency of these devices decrease in urban zones, followed by the negative effect that high vehicle densities have on these services [21]. Because it is beyond the scope of this project, this subsection will only briefly outline some factors to consider when creating a UAM airspace within the CNS ambit.

5.1.1.1. Communication

Actual UAV communications are based on basic point-to-point communication over the unlicensed band, which cannot be used in future UAM operations as it is unreliable, insecure, and can only operate over a very limited range [21]. These hazards force the creation or implementation of new methods.

In order to cover communications in UAM airspace, cutting-edge technologies that have not yet been implemented in aviation, such as LTE (Long Term Evolution), satellite connectivity, and particularly 5G, may be the front-runners [21]. These new cellular network applications could solve the communication problems in urban areas as they are widely available in cities and can handle several users at a time [39].

In this application, 5G communications present interesting services like ultra-low latency, the possibility of communicating the vehicle with any other device (so-called vehicle-to-X communications), and, most importantly, high reliability at every stage of the flight. However, these innovative ways of wireless communication still present a lot of challenges that need to be faced, among them availability and cybersecurity [39].

5.1.1.2. Navigation

In urban areas, the availability and accuracy of GNSS navigation methods is a big issue. On one hand, there are availability problems due to the presence of big buildings and artificial constructions that can completely or partially block satellites from the direct line of sight of the GNSS receiver, the UAV in this case, causing errors in position computation by not being able to calculate where the drone is [21].

On the other hand, there are accuracy problems, which are also caused by the problems stated above and other technical issues like multipath or atmospherical conditions that can alter the emitted signal. Different experiments on UAV positioning with GNSS in cities have shown that the drone deviated from two to more than five meters from the expected flight path due to this phenomenon, and when the signal was totally blocked, the error climbed to more than 20 meters [21].

This lack of both availability and accuracy is not acceptable in any navigation system, especially in UAM due to the eVTOLs' proximity to buildings, terrain, and other vehicles [44].

Despite the fact that no national or international organization has established an official maximum deviation, it is clear that GNSS systems must be improved or combined with other technologies. The following list shows some alternatives that could be considered [21, 44]:

- Vision or image-based navigation: the drone will analyze the previously scanned terrain to obtain position and altitude.
- Cooperative navigation systems: mixing GNSS signals from different satellite constellations, like the American GPS (Global Positioning System) and the European one, GALILEO, could improve the results.
- Assisted navigation systems: ground-based or air-based systems used to improve the accuracy of satellite-based positioning systems in areas where it is needed.

5.1.1.3. Surveillance

The use of conventional radars, like the ones used in commercial aviation operations to detect the position and altitude of the aircraft, is also not possible in highly populated areas because both the emitted and returned signals mostly do not reach their destination device due to the presence of buildings and other constructions [21]. That is why different methods are proposed in UAM field studies.

The method that most authors talk about is the use of ADS-B[3] (Automatic Dependent Surveillance - Broadcast) as a possible alternative [21], but it has been shown that it will likely not provide sufficient reliability and availability for different reasons related to the operating frequency and the required transmission power [44].

Surveillance in UAM operations may have to rely on alternative datalinks and networks to offer good accuracy and achieve the safety threshold expected.

5.2. Vehicle limitations

As it has been said, the air vehicle in charge of performing UAM operations, carrying people or cargo, is the eVTOL; furthermore, in Section 3.2, "Electric Vertical Takeoff and Landing (eVTOL)" its main characteristics were introduced, as well as the differences that distinguish them from a helicopter. But now, as this current section deals with the main factors to be considered when designing the urban airspace, it will be explained how the vehicle itself will also affect the way of defining different details such as procedures, the takeoff and landing zone, and separations between vehicles, among others.

5.2.1. Engine layout

During the last decade, several companies have designed, prototyped, and even tested their eVTOL concepts to show the world that technology is already here and that UAM is closer than anyone could imagine [46]. Every eVTOL manufacturing company has designed the vehicle in its own way, as different approaches to figuring out how to allow air vehicles to fly in both hover and horizontal flight in the most effective way have been taken. This results in some concepts being very similar to others or, on the contrary, having notable differences.

Despite the disparity in designs, three main strategies can be distinguished from all the eVTOLs so far presented based on the engine configuration [6, 39, 46]:

1. Multirotor or wingless: vehicles generate lift only with fixed rotating propellers during all flight phases. The absence of wings can be its main characteristic, and this is the model that could result in something more similar to a traditional UAV but adapted for people and freight transportation.
2. Lift and cruise: these aircraft have some engines that are used only in hover flight (takeoff and landing) and other engines that are activated

[3] Automatic Dependent Surveillance–Broadcast (ADS-B) is an advanced surveillance technology that combines the position of the aircraft source, aircraft avionics, and ground infrastructure to create an accurate surveillance interface between aircraft and ATC. It offers better and more precise results than radar technology [45].

during the cruise phase. The engines do not move and alternate during flight. This model does have wings.

3. Tilt wing/rotor: in this case, the same engines will be used for hovering stages and for horizontal flight when cruising. This is possible thanks to the automatic 90-degree rotation (or tilt) that wings perform between flight phases.

The advantages and disadvantages of each approach are summarized in the following table [6, 39, 46]:

Multirotor or Wingless 	Lift & Cruise 	Tilt Wing/Rotor 
Effortless flight control	Medium efforts to flight control	Highest energy efficiency
Good hover characteristics	Medium energy efficiency	Highest cruise speed
Inherent engine redundancy	Higher cruising speed	Effective use of propulsion
Low complexity of the system	Presence of wings allows gliding	No extra weight (engines used at all time)
Smaller size and quieter		Presence of wings allows gliding
		Optimised for both hover and cruise
Least energy efficient model in cruise	Ineffective use of generated propulsion	Highest effort in flight control
Slowest cruising speed	Extra weight due to unused engines	More complex design due engine rotation
No gliding capabilites	Increased drag in cruise due to rotors	Greatest mechanical maintenance
	Suboptimal performance in hover/cruise	Increased airframe weight

Table. 5.1 Comparison of different eVTOL concepts [6, 39, 46]

The multirotor approach is ideal for use in UAM intraurban operations, which means flights performed within the same urban area or city, as these operations are expected to have several hover phases with multiple takeoffs and landings. The facility of this kind of eVTOL to perform hover flight and the inefficient performance in cruise flight for long distances are the determining factors that make this model suitable for these kinds of operations. Also, the lower level of noise emitted could help to obtain social acceptance [39].

Meanwhile, the Lift&Cruise strategy is in between the characteristics of the multirotor and the tilt wing or rotor, making it a good option for operators that do not have clearly defined kinds of operations, and both intraurban and interurban flights will have to be performed [39].

Finally, the eVTOLs with tilting wings or engines are the most adequate ones to carry out long flights between cities or different urban areas, as they have optimized the energy consumption and use of propulsion for both stages of flight, especially the cruise stage, in which high speeds can be achieved and will be the most extensive throughout the flight. Using engines throughout the flight stages also reduces unnecessary weight, allowing for more cargo or passengers [39].

The images below show a multirotor, a Lift&Cruise, and a tilting motor example from Volocopter [7], Boeing [47] and Wisk [40], in that order:

Fig. 5.1 From left to right, Volocopter's model Volocity, performing flight test in Paris, Boeing's PAV (Personal Air Vehicle) during its first flight test on January 20, 2022, and Wisk's Generation 6 presentation [7, 47, 40].

5.2.2. eVTOL endurance

UAM have been approached as a new, modern, and remarkable green mode of urban transportation [6]. Another significant constraint arises from this, and that is the endurance of the batteries used in eVTOLs [21]. As is the case in the automobile industry, the endurance of electric vehicles tends to be lower than that of those equipped with conventional combustion engines, and while a car can park and charge, for an eVTOL it would not be that feasible or easy.

Various studies have been conducted in the UAM field in order to determine the best way to address this problem. Some solutions, such as more efficient rotor configurations, the use of new lightweight and resistant materials, and installing outside modules with extra batteries, have been considered [21]. However, the most realistic solution is to plan the flightpath with the goal of minimizing energy consumption. To do so, the aircraft will have to fly at the lowest altitudes possible, with the shallowest ascends and descents possible, as the cruise efficiency drops with altitude and more power is consumed in abrupt changes of flight level. Nevertheless, flying at lower altitudes will cause conflict, as will be seen in the following sub-section, related to noise and social acceptance as well as capacity, as concentrating all the operations at lower altitudes will significantly decrease airspace capacity.

The conclusion is that UAM route design will not only be influenced by the variety of eVTOL performance but will also be affected by their endurance and how the flight should be optimized in energy consumption terms while dealing with associated capacity and noise problems.

5.3. Social Acceptance

Until this point, different factors that will directly influence the design of the urban airspace have been listed and briefly explained. So far, we have discussed the different safety measures that have to be contemplated, the technological limitations and advances that will have to be considered in order to create an efficient UTM, as well as how the vehicles will affect the airspace design. However, no consideration has been given to learning the public's feelings about the concept and gaining their approval for UAM implementation over their homes and properties. This is what this section is about: getting to know people's opinions about UAM as well as their major concerns and fears.

In traditional aviation, both local and regional communities and associations, like the ARC [20], have traditionally had much to say and to influence airline and airport operations [21]. In the case of UAM, it is expected not to be otherwise, as aircraft will be flying at low altitudes near residential neighborhoods, which may expose individuals to negative externalities, hence increasing the likelihood of social opposition to urban airspace implementation. A significant social backlash against UAM may present difficult challenges for those in charge of operating vehicles, manufacturing equipment, and maintaining infrastructure [48].

5.3.1. Principal UAM concerns

In May 2018, EASA published an important paper about how European society saw the possible near implementation of UAM. In that study, seventeen main challenges for the sector were identified regarding previous literature, but social acceptance was not even in the top five [49]. Despite the low position in the ranking, EASA emphasizes a lot on this subject for two main reasons: on the one hand. There are several companies, researchers, and other organisms working hard on all the challenges identified but very little on social acceptance; and on the other hand, as the role of EASA is to serve the general public with its action, it was considered that they had to put effort into knowing populations' opinions.

In said document the following graphic about the factors playing a major role in social acceptance, from which key work-point can be extracted, was published:

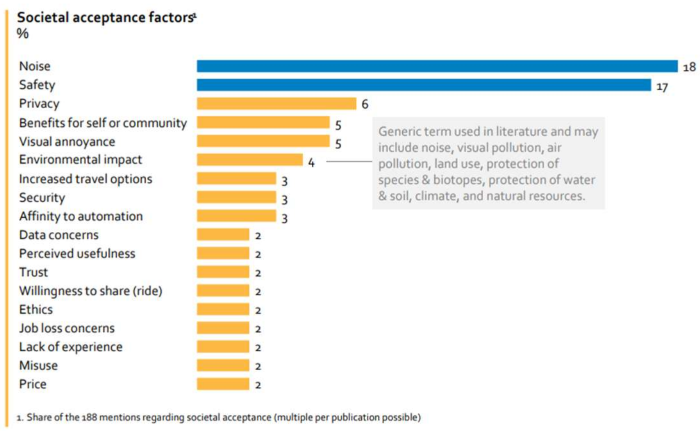


Fig. 5.2 Societal acceptance factors, figure 6 on EASA's paper [49]

Previous figure support the idea of some studies like [21] or [48] that the final definition of urban airspace structures for UAM deployment will mostly depend on three social factors: noise, visual pollution, and privacy. It is true that safety is the second factor in Figure 5.2, but some guidelines about the principal safety

considerations have been provided at the beginning of the Chapter 4. The subsections that follow will explain how the three aspects mentioned affect the population and how they might be mitigated.
The EASA survey has been used to detect the principal concerns of the European population about the UAM introduction. To know more about the survey, how the interviews were done, which questions were asked, and the results as well as the conclusions extracted from them, check Annex A, “European social acceptance in numbers”.

5.3.1.1. Noise

As Figure 5.2 depicts, noise can be defined as one of the greatest threats and constraints to the implementation of UAM operations, while at the same time being a key development goal of eVTOL manufacturing. To reinforce the idea, the ICAO has recently affirmed that the noise originated from these urban aerial operations will cause a significant level of annoyance in people’s lives [21].

From the concept of urban air mobility, what most concerns the population is the noise that these vehicles will emit, but why are people so concerned about it? The numerous side effects that high levels of noise can cause are one of the principal reasons [48]:

- Speech interference: eVTOL noise could affect the development of normal speech, which will cause people to shout.
- Sleep disturbance: being exposed to noise for long periods at nighttime has been found to influence the quality of sleep, hence causing stress-related symptoms and fatigue.
- Fear: aircraft performing low-level flyovers, loud flights, and rapid onsets of eVTOL noise may lead to sudden fear and developing fear of operations.
- Health issues: long-term noise exposure is directly related to an increase in suffering from hypertension, cardiovascular disease, stroke, and in some extreme cases, reducing cognitive performance.

Some of the limitations that several stakeholder groups, particularly aircraft operators and infrastructure managers, may face as a result of widespread opposition to UAM implementation caused by aircraft noise are summarized in the table below:

Aircraft operators	Infrastructure management
Legal actions against them	Limitations to new construction or expansion of existing structures
Geofencing or other methods to restrict some residential areas	Closure of existing structures due to residential area proximity
Required noise contingency procedures	Limited operating hours
Fees for surpassing determined noise threshold	Limitation of noise level on arrival and departure procedures

More expensive eVTOLs due to stricter certification requirements	Loss of national funding if the social rejection was considerable

Table. 5.2 Potential limitations from the social acceptance of noise constraint [48]

Reducing the noise emitted by the eVTOLs will be a difficult task that will have to take several items into account. On one hand, noise will have to be attacked at its source, which is motors, propellers, and airframes [21]. New technology and research will have to be developed to make the aircraft itself quieter. But on the other hand, some studies like [48] state that noise reduction can also be achieved in other ways, like by implementing low-noise procedures and operations, analyzing the land use at take-off and landing to avoid the proximity of operations to residential areas, or designing operational restrictions such as flight quotas, curfews, or timetables.

Finally, other factors known as “non-acoustic factors” or “virtual noise” will have a significant impact on the population’s perception of noise annoyance. A clear example of a non-acoustic factor is the season of the year in which the operations are held: in the summer, due to heat, windows are usually open, making the UAM more likely to cause sleep disruption than in the winter, when most of the windows are closed at night [48]. Virtual noise can be classified into three different groups [48]:

- Situational factors: related with to the time of the day, week, or season in which operations are held, they also include meteorological factors.
- Community factors: include the attitudes, personality traits, and demographic characteristics of the population. More or less importance will be given to constraints depending on the population’s profile.
- Secondary effects: other characteristics related to the pollution in the air and the presence of fumes in the cities affect the propagation of the noise vibrations.

These non-acoustic effects have to be considered when designing the airspace in each city or country, as the factors to which the population gives more importance may change from one neighbor to another.

5.3.1.2. Privacy

Privacy is another concern for the population living in cities where UAM operations may be implemented, mainly in residential and business areas, in which people could have the sensation that eVTOLs or UAVs are “spying” on them or create a sense of intrusion on everyday actions [21].

In this highly technological age, it is very likely that any of us has considered and even concerned about the privacy regulations of used devices. To better understand the importance of privacy, it has to be taken into account that there are multiple types of privacy that should be protected: the privacy of the person, of behavior and action, the privacy of communication, of data and image, the privacy of thoughts and feelings, location, space, and association [21]. A UAV equipped with cameras capturing images of the street for navigation purposes may be able to trace a person and provide information about people's location, pattern of movement, and behavior; using this information with illicit purpose would violate those people privacy.

In the case of the UAM privacy problem, is more about the perception of privacy being violated than about the ownership and use of the collected data. The major two characteristics that may enhance the impression of privacy loss are the frequency of flights and their altitude [21].

5.3.1.3. Visual Pollution

The last of the three social factors identified as the most influential in UAM implementation is visual pollution [49]. In residential neighborhoods, any new implementation causing visual disturbances is likely to create refusal [21], so low-level flights could be considered visually undesirable by neighbors.

Not many articles on the topic have been conducted, but in one of them [21], it has been discovered that the public will tend to be annoyed by eVTOLs or UAVs overflying their residential areas as they will interfere with their visual field and create shadows.

Unlike the problem with noise, in this case very limited, or even any, adjustments can be made to the aircraft, as reducing its size until it does not affect the visual field is not an option. The most realistic solution is, once again, taking into account this social concern and designing the UAM routes to minimize the negative impact on the population [21].

CHAPTER 6. REQUIRED GROUND INFRASTRUCTURE

On Chapters 4 and 5, “Challenges in UAM airspace design and potential solutions”, some of the most determining factors when designing the urban airspace that will allow UAM operation were explained and detailed in the manner in which they have to be considered to make urban air operations feasible. Any of those major challenges considered the physical or ground infrastructure that these operations will necessitate; this entire chapter will be devoted to explain the takeoff and landing structures that it has been shown that UAM will require [38].

6.1. Vertiports: definition and need

Considering that eVTOLs and UAVs will be the aircraft dedicated to urban air operations, it seems logical and useful to define and design a new type of airport based on these new vehicles’ characteristics and operations [38]. These new aeronautical infrastructures have been named as “vertiports.”

EASA has defined vertiports as “an area of land, water, or structure used or intended to be used for the landing and take-off of VTOL aircraft” [50]. From this definition, it can be understood that vertiports are dedicated areas that will supply the infrastructure needed to safely perform commercial air transportation of both passengers and freight with VTOLs. Also, EASA adds that to fully realize the potential of UAM, vertiports need to be accessible, with good connecting services to streets, train stations, buses, and other transport systems [50].

At first glance, the vertiport concept appears to be what was previously defined as a heliport due to the similarities in takeoff and landing between helicopters and UAVs, so anyone might question the need for defining a new specific infrastructure [51]. Despite this resemblance, UAM operations will have some distinct characteristics that have necessitated the development of vertiports, along with new procedures and safety definitions [51].

UAM operations have affordable access as one of the main targets, which means that a large number of throughputs have to be achieved, requiring larger and, most probably, more complex ground infrastructure than the one currently in use at heliports [51]. Some of these throughputs may include reduced separation between vehicles, ground taxiing of VTOL aircraft, simultaneous and autonomous operations, as well as steep departure and arrival profiles to operate in densely populated areas [51].

To emphasize the importance of vertiport definition and design, it is important to note that a significant portion of UAM operations are expected to be on-demand, with high arrival and departure frequencies, operating primarily in urban environments very close to people and buildings, and with short flight phases, which are significant differences from traditional aviation operations [51].

6.2. Main vertiport terminology

As UAM pretends to define their airspace and operations in coexistence with a well-established transportation system, which is the traditional aviation one, their operations and structures have to, as it has been said throughout the project, be aligned with their safety standards. For that and other reasons, national authorities who are also involved in UAM airspace design have been key participants in vertiport design [51].

In recent years, various approaches to vertiport guidelines have been developed in Europe, The United States, and internationally. Despite the differences that can be noticed between the different approaches, there are also many similarities that reflect the desire to integrate UAM into existing airspace regulations and existing structures [51]. The following image depicts typical terminology used in the context of UAM and vertiports:

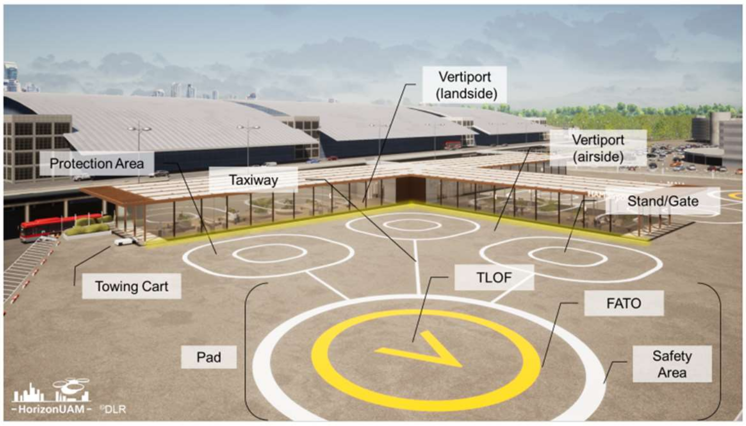


Fig. 6.1 Main Vertiports terms used in the context of UAM [51]

Due to their use throughout this chapter, some of the abbreviations and terms in the image are defined below by following the EASA paper on Vertiports Design [52]:

- Touchdown and lift-off area (TLOF): area where a VTOL-capable aircraft may touch down or lift off. Note that EASA terminology for VTOL landing point consists of a letter “V” inside a circle.
- Final Approach and Take-Off Area (FATO) : an area free of obstacles except for essential objects which because of their functions are located in, and of sufficient size and shape to ensure containment of every part of the VTOL-capable aircraft in the final phase of the approach and at the commencement of the takeoff. Each FATO have to be associated to a Safety Area (SA).
- Safety Area (SA): defined area on a vertiport, which surrounds the final-approach and takeoff area (FATO) and is free of obstacles, other than those required for air navigation purposes. It is also intended to reduce the

risk of damage to VTOL-capable aircraft accidentally diverging from the FATO.

6.3. Vertiport design characteristics in Europe

As previously stated, there are some differences between the European and American approaches to the design of vertiports. As the present project is currently being developed in Europe, only the European guidelines for the vertiports designed will be explained. EASA published on March 2022 the first document about Vertiport design in the European Union, reference [52], which will be used as a guide to develop this present chapter.

6.3.1. Takeoff and landing trajectories

VTOLs, by definition, are vehicles that can perform the takeoff and landing phases following a vertical path, but this path can be limited to the very first part of the takeoff or the very last part of the landing, with the rest of the maneuvering being more or less shallow [50].

EASA has defined three different takeoff profiles in order to provide the broadest requirements and ensure that a wider range of UAM vehicles can support their requirements while maintaining the required safety levels [50]:

1. Elevated conventional takeoff: the VTOL takes off from an elevated point in an urban area, allowing a possible dip in trajectory in case of failure.
2. Conventional takeoff: the case where the VTOL takes off from an obstacle-free area. As in the previous case, failures allow for possible dips in trajectory with no risk.
3. Vertical takeoff: this profile is specifically designed for areas with a great number of tall obstacles near the vertiport where no shallow profile would be suitable. The procedure is performed vertically until the obstacles are saved. Also, under these circumstances, certain failures would be manageable.

Fig. 6.2 From left to right, Elevated conventional, conventional and vertical takeoff profiles [50]

It is important to note this shallow part of the procedure to adjust the trajectory of the flight in a manner to avoid possible collisions or obstacles. The same VTOL with the same performance and trajectory would be more likely to maintain a "clear path" (without obstructions) if launched from an elevated vertiport rather than a ground-based vertiport, where taller obstacles would most likely cause an obstruction [50].

6.3.2. Operation Classes

In Europe, EASA has classified UAS operations into three different classes based on the performance involved and the risk that the operation entails. These categories are open, specific, and certified [51]. Open and specific categories refer to those operations entailing, respectively, a low and medium level of risks, and there is already a European regulatory framework, while the certified category caters to operations with a higher level of risk, therefore requiring the highest safety standards compared to the other two classes. Aircraft flying in the specific category will be required to have a type certificate and a certificate of airworthiness and will be the ones performing UAM operations [51].

At the moment, no regulatory framework exists in Europe for the certified category, despite the fact that EASA is currently working on it under the rule-making task RMT.0230(C), which initially has two subcategories and contemplates three types of operations [51].

The distinction between the two sub-categories is based on the capabilities that the VTOL must have in order to operate safely in the event of an emergency, such as an engine failure. On the one hand, the basic sub-category includes VTOLs that fly in non-congested areas and have more options for performing a controlled emergency landing outside a vertiport. Similar to what helicopters or aeroplanes can do in the event of power-loss [50]. On the other hand, the enhanced sub-category of certified operation classes is intended for VTOLs flying in highly-congested areas such as cities where, in case of engine failure, the VTOL would not be able to land outside a vertiport due to the high density of people and buildings, so it will be requested to perform a "continued safe flight and landing" (CSFL) to the nearest vertiport [50].

The three defined operation types are Type 1 for IFR cargo UAS operations in Class A-C airspace; Type 2 for UAS operations in a congested environment inside the U-Space, including unmanned passenger and cargo transportation; and finally Type 3, which includes the same characteristics as Type 2 but with a pilot on-board and considers operations outside the U-Space [51].

6.3.3. D-Value for VTOL aircraft

In the heliport design guidelines, the so-called D-value has been used to dimension a heliport's airside size, safety margins, and operating constraints among others. In that field, the D-value refers to the largest overall dimension of the helicopter when the rotors are turning [51, 52].

For vertiport dimensions, corresponding authorities pretended to do the same process, but they found out that the smallest enclosing circle of the VTOL, being the D-value for rotorcraft, could be off by 15% [51]. To ensure adequate obstacle clearance in vertiports, EASA re-defined the D-value for VTOL aircraft, stating two definitions, the D and the D-value [52]:

- D: diameter of the smallest circle enclosing the VTOL aircraft projection on a horizontal plane, while the aircraft is in the takeoff or landing configuration, with rotor(s) turning, if applicable.
- D-value: limiting dimension, in terms of D, for a vertiport or for a defined area within a vertiport.

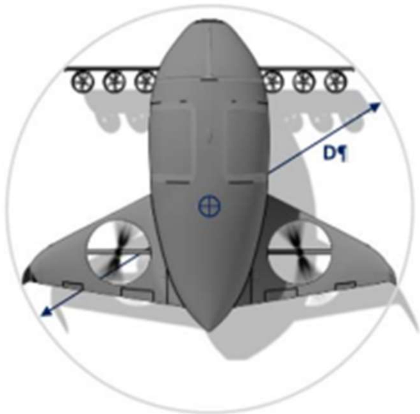


Fig. 6.3 Center and diameter “D” of the smallest enclosing circle for a given VTOL [52]

It is important for the vertiport design to note that if the VTOL changes in dimension during taxi or parking (due to engine rotation or folding wings, for example), a corresponding D for taxi and D for parking should also be provided [52].

6.3.4. Vertiport Physical Characteristics

In the present sub-section, the main vertiport physical characteristics present in the AESA Vertiport Specifications Paper [52] that the vertiport operator must design and publish, some of them in function of the D-value, are going to be detailed but not deeply explained, as it would go out the scope of the present paper. For further detail on the vertiports’ size, consult both the EASA reference [52] and Annex B, “Vertiport Design in Europe: Detailed Information.”

Once the new D-Value definition has been specifically adapted for VTOL operations, it has to be taken into account when dimensioning the key elements of a vertiport in order to ensure a safe operating environment [51]. That is, the D-Value will directly determine the characteristics, dimensions, and topology of a vertiport. From all the VTOLs intended to operate at a vertiport, the one with the highest D-value will be chosen as the most restrictive, ensuring that all the aircraft can operate there, and will be known as “Design D”.

Any vertiport has to offer at least one FATO in order to provide an area free of obstacles and of sufficient size and shape to ensure containment of every part of a VTOL-capable aircraft in the final phase of the approach and the beginning of the takeoff maneuver [52]. The Design D will directly determine the size of the FATO [51].

Also, at least one TLOF has to be provided on a vertiport, which needs to be associated with a FATO, a stand, or a portion of a taxiway. It should provide an obstacle-free area of sufficient size and shape to ensure containment of the undercarriage (or landing gear) of the VTOL [52].

Furthermore, the FATO should be surrounded by a SA and a protected side slope [52]. On one hand, the SA has to provide a free-of-obstacles area that extends beyond the FATO to compensate for maneuvering errors under challenging environmental conditions. On the other hand, the side slope is a protecting virtual surface rising from the edge of the SA, which should not be penetrated by any obstacle [52].

The vertiport might also offer taxiways and stands for additional operations. Taxiways may be associated with either air taxi-routes or ground taxi-routes. Ground taxi-routes are intended for use by VTOLs that have their own power and ground movement equipment, whereas air taxi-routes are intended solely for use by air taxiing [52]. Stands have to permit the safe loading and off-loading of passengers and/or cargo while providing an area free of obstacles and of sufficient size and shape to ensure VTOL containment when the aircraft is positioned within the stand [52].

Finally, other vertiport characteristics will be required depending on the intended operations. Some examples could be the identification marking of a letter V, the FATO identification number, approach and departure lightning systems, flight alignment path guidance, and several markings, among others [51].

6.3.5. Obstacle Free Volume

Not only the vertiport’s airside ground needs to be characterized and defined, but the airspace directly attached to the vertiport also needs to be structured. As in the previous subsection, only generic information and explanations will be given, for further details consult both the EASA reference [52] and Annex B, “Vertiport Design in Europe: Detailed Information.”

The airspace around vertiports must guarantee that VTOL operations can be conducted safely and prevent vertiports from becoming unusable due to the growth of surrounding obstacles. To achieve it, in general aviation, the OLS, or Obstacle Limitation Surfaces, are defined in ICAO’s Annex 14, which are virtual surfaces that limit the presence of any obstacle in aircraft procedures [52]. For

UAM operations, EASA has defined a new OLS system that proposes an Obstacle Free Volume, or OFV, around the vertiport.

The OFV is a funnel-shaped area above the vertiport that ensures that VTOLs can perform takeoffs and landings with a significant vertical segment (see vertical takeoff profile at Figure 6.2) and therefore take account of environmental and noise restrictions in an urban environment [50]. Manufacturers will have to proof that their VTOLs can fly in a volume of the OFV shape. Also, they will be able to adapt the size of OFV and also define additional reference volumes [51].

Given the large number of VTOL designs that are currently being developed, EASA designed and proposed the “Reference Volume Type 1”, which is an standardized reference volume designed with the intention of harmonizing the OFV shape and concept [50, 51, 52].

6.4. Urban versus interurban operations

On January 1, 2022, the population of the European Union (EU) was estimated at 446.8 million inhabitants [53]. The following picture depicts the population density in Europe, marking with red the most populated areas (cities) and with yellow and green the less populated zones like suburbs and rural areas, respectively:

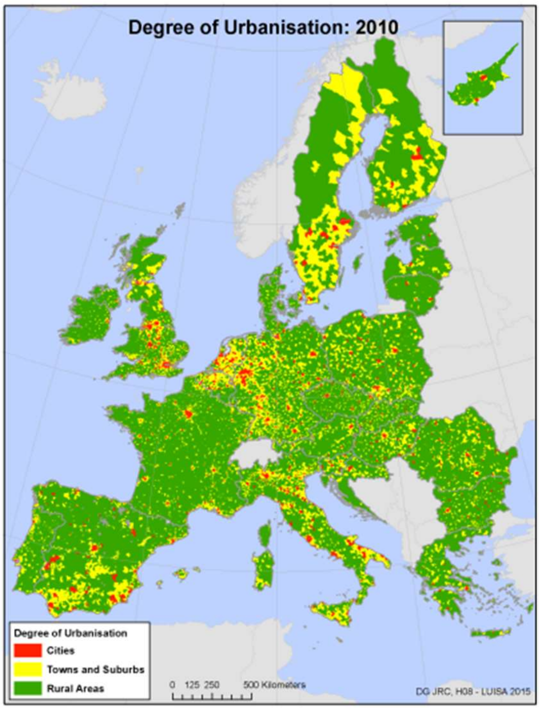


Fig. 6.4 Degree of urbanization of the European Union in 2010 [54]

The notoriously large number of rural zones in comparison to the actual population gives raise to the concept of highly dense cities, where a sizable portion of the population lives [54]. This will necessitate a significant level of edification, as well as the presence of artificial constructions and other obstacles that VTOLs and UAVs will encounter when performing UAM urban operations. However, focusing on interurban UAM operation may facilitate some operational aspects as vertiports allocation, OFV requirement compliance, more social acceptance and less structures and obstacles to avoid.

Most of the bibliography consulted centers on developing UAM airspace in highly populated areas, where most of the demand will be located. The first edition of the European project Metropolis is a clear example: four different ways of structuring the UAM airspace for extreme traffic densities above cities are proposed [55].

A student from the same university as the author of the present project dedicated his final degree project to analyzing how possible it will be to decongest a big city like Barcelona by using VTOLs [56]. On said project, a network of nearly 30 vertiports was proposed in the city and its metropolitan area, defining VTOL operating lines between the different city districts and surrounding towns. Deciding where to locate the vertiports is one of the main challenges encountered in the project, as there are several buildings and critical zones in a highly populated city like Barcelona; however, it was not studied whether the OFVs could be accommodated in this urban area.

Some benefits were demonstrated, even though at a very small scale in comparison to what it would have to be in a real-life implementation of UAM in cities; in spite of that, the cost per passenger results were quite elevated, which cannot compete with public transport prices. Social acceptance is also said to be a major concern, as operations will take place in the most populated region in Catalonia.

In the following chapter, a new possible UAM operation type will be introduced and briefly described. These UAM operation have been designed to avoid overflying cities and residential buildings and use already existing aviation structures to perform the takeoffs and landings, as well as ground infrastructures to perform the cruise phase, reducing the cost and the negative effects on the population around the operation areas.

CHAPTER 7. USE CASE: REPLACING HELICOPTERS WITH EVTOLS TO TRANSPORT PEOPLE TO THE “CIRCUIT DE CATALUNYA”

This final chapter is aimed at designing the main characteristics of a very specific case of UAM operation, in a way that does not pretend to be a professional application but rather serves as inspiration,

It is clear that a lot of experts should be involved in designing an operation of this magnitude with such airports involved, but this first approach that will be made thanks to the knowledge obtained in the first chapters may be useful to future TFGs (Treball de Final de Grau) due to the open lines of work that will be specified at the end.

Because the technological components that should be used in a UAM airspace have only been introduced in a very generic manner, and there are still many advances to be made (in the CNS field, for example), special attention will be paid to the safety factors. Specifically, how the operation will interfere with commercial aviation operations near airports, the eVTOL that would be used, and the dimensions of the required vertiport.

Annex C, “UAM use case: Additional information”, contains additional information and visual material to the explanations present in this chapter.

7.1. Use case contextualization

The Circuit of Barcelona-Catalunya, also known as “Circuit de Montmeló”, is a race circuit located outside Barcelona, in the Catalan town of Montmeló [57]. It was inaugurated on September 10, 1991. Since then, the Circuit of Catalunya has been positioned as one of the best permanent circuits around the globe, and nowadays it hosts some worldwide tournaments like the Moto GP Grand Prix or the famous Spanish Formula 1 Grand Prix [57].

Fig. 7.1 Circuit de Barcelona-Catalunya aerial view [own source, Google Earth]

These grand events last no more than three to four days and attract thousands of spectators from around the world; the movement of people, hence the economic impact, on the area is significantly elevated. Most of the fans go to the circuit mainly in their own cars or by public transport; however, a small group of people get there by helicopter, a more exclusive and expensive way within the reach of a few [58, 59]. Arriving at the circuit by helicopter is considered a luxury item aimed at wealthy people due to the high prices, which range from 800 to 900 euros per person.

The number of corporate operations at Barcelona, Sabadell, and Girona airports has registered a notorious increase in the last few years during the days on which a Grand Prix is held at the Montmeló circuit due to the arrival of VIPs; at least 17 helicopter movements per day are recorded at Sabadell airport, the smallest of the three [58]. Helicopters are used to get to the circuit from the airport and the other way around.

The use case stated in this chapter proposes substituting helicopters by eVTOLs to perform the transportation of VIPs from the Catalan airports to the circuit, making it cheaper and greener while maintaining the feeling of exclusivity that is sought.

7.2. Involved airports and airspace

The eVTOL flights have been designed in such a manner as to re-use already existing and operating aeronautical infrastructure. As mentioned previously, people arriving at the circuit will come from three airports: the Barcelona, Sabadell, and Girona ones. The ICAO assigns to every airport a four-digit code, which due to its simplicity and shortness will be used throughout this chapter. The codes for the involved airports and the circuit's heliport are [60]:

- Josep Tarradelles Barcelona-El Prat airport: LEBL
- Girona Airport: LEGE
- Sabadell Airport: LELL
- “Circuit de Catalunya” heliport: LETA

The location of the four mentioned aeronautical bases is depicted in Figure 7.2:

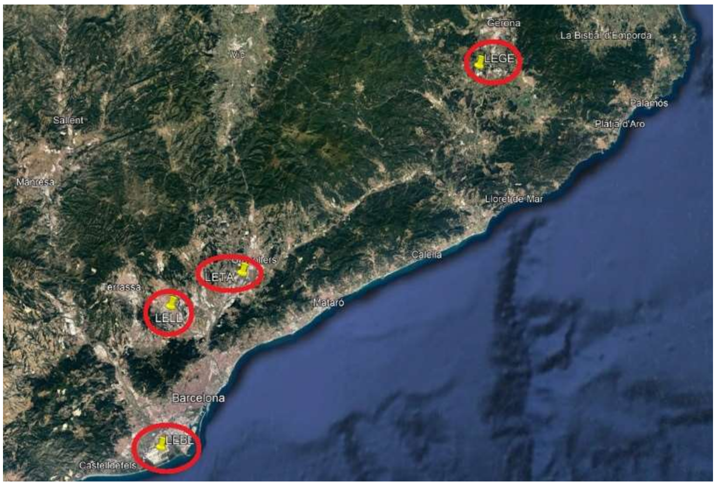


Fig. 7.2 Location of the four used airports [own source, Google Earth]

LEGE is the furthest airport from LETA, which could have a negative impact in the autonomy aspect, as the eVTOL may not be able to perform a full round trip without charging the batteries.

Apart from the location and distance between them, it is also important to analyze the airport runway distribution and use, as well as the type of operations and location of the actual heliports that will be taken as possible vertiports, to propose a realistic and less-invasive eVTOL operation in relation to the airports’ current use. See Annex C, “UAM use case: Additional information”, subsection 1, where a detailed diagram of each airport is provided.

When analyzing the operation zones for the current use case, it is critical to check which controlled airspaces the eVTOLs will have to fly through, as well as any prohibited area that cannot be overflown.

To perform the checks, the online tool “Insignia” by ENAIRE is used [61]. The tool shows two different maps: the aeronautical ones and the UAV-concerning maps. In this case, it was decided to only check the aeronautical maps, as it is assumed that UAM operations with eVTOLs will have to follow other requirements and types of coordination with control centers that are expected to be stricter than those of recreational and professional operations with UAVs.

On the one hand, there are no dangerous, restricted, or prohibited zones in the areas between the airports, so when designing the routes, no deviations from the fastest and most direct path will have to be considered. On the other hand, different controlled airspaces will have to be flown through. This could be a problem because the zones closest to the airport are the most restrictive for UAV operations due to the danger they can pose to airplanes during critical parts of the flight. These controlled zones are the Aerodrome Traffic Zone (ATZ) and the Control Zone (CTR).

Because there is currently no legal framework defining UAM operations, as well as no legal specifications for certified UAVs (as eVTOLs will be), the restrictions of UAV flights over these zones is ignored, as it is assumed that regulations for urban flights will take into account the coexistence of UAM and aviation airspace.

7.3. Air-Route design

The following step is to design the air route that the eVTOLS will use to safely perform the flight, avoiding overflying highly populated areas and the proximity of the terrain; furthermore, a unique route for all the aircraft is expected to help manage and control the flights.

The proposed air-route not only connects all the airports with the LETA vertiport but also connects all the airports of the network between them, allowing the movement of eVTOLs between them all, which can be useful for several reasons during the mission's development.

The ends of the route are located in the proximities of LEBL and LEGE, where a point named "Procedure Point" has been defined. The takeoff and landing procedures at Barcelona and Girona airports will start and finish, respectively, at this point. In the case of LELL and LETA, there is no Procedure Point because these vertiports are located around the route and not at its extremes; instead, different "Deviation Points" have been established. These points mark where in the route the eVTOL can deviate towards LELL and LETA to start the landing procedure, and otherwise where the eVTOL can incorporate the route when performing the departure procedure.

As this use case seeks to provide an alternative way of transportation to some VIPs going to the circuit without causing collateral effects to those not involved in the operation, the air-route has been designed to reduce the impact on nearby populated areas by taking into account the population concerns about UAM operations seen in Chapter 5. Whenever possible, the route will be located along rivers. In the rest of the route, which is the major part, the eVTOLs will overfly highways, more specifically the AP-7, which is one of the main highways in Catalonia, with a great presence of cars and trucks throughout the whole day. In some specific cases, some industrial zones are overflown, especially during takeoff and landing procedures due to their proximity to airports.

The decision to overfly rivers and highways but never residential areas has been taken for safety and social reasons. In terms of safety, if an eVTOL fails, it may follow a similar procedure as recreational planes, in which pilots look for fields or even highways to perform emergency landings, but never in populated areas due to the risks and danger it may entail. Also, this type of UAM airway design is supported by EASA [62] and some flight tests, like the EIT Belgrade Trial [63]. And in terms of social acceptance, the fact that eVTOLs will overfly an already existing source of noise, as the AP-7 is, will reduce the perceived sound to neighbors, making them more likely to accept it.

Figure 7.3 shows the route from LEBL to LEGE Procedure Points, as well as the Deviation Points from LELL and LETA:

Fig. 7.3 Procedure and Deviation Points along the defined air-route [own source, Google Earth]

Note that in LETA, two different deviation points have been defined: one on the airfield’s west side (W) and the other on the east side (E). This has been done because LETA will be the vertiport receiving a larger number of operations (as VIPs coming to three different airports will go to the circuit), and depending on the origin airport, the eVTOL will arrive at LETA on the E or W side. So two independent takeoff and landing procedures have been designed.

The distances between the different vertiports to LETA are shown in the table below:

	Kilometers	Nautical Miles
LEBL – LETA W	40.9	21.6
LEBL – LETA E	46	24.84
LELL – LETA W	12.2	6.48
LELL – LETA E	17.3	9.18
LEGE – LETA W	62.1	33.48
LEGE – LETA E	57	30.78

Table 7.1 Distances between the different airports to LETA Deviation Points

To the distances shown in table 6.1, the length of the takeoff and landing procedures will have to be added, but in comparison to the previous, these are small distances.

7.3.1. Lane Definition

The previously defined air-route will contain two lanes, one going from LEBL to LEGE and the other going otherwise, from LEGE to LEBL. Like in the roads of the European Union, the eVTOL will circulate on the lane located on its right side.

Not only will there be horizontal separation, but also vertical separation between the lanes, with the one from LEBL to LEGE being at a higher altitude. This double axis separation is proposed as a way of avoiding mid-air collisions in case of the positioning system or the altitude system failure; one of them could fail, but the separation with the eVTOLs flying in the other direction is still guaranteed.

The corridor in which the eVTOLs will circulate by has rectangular shape of 20 meters width by six meters high. The altitude of the higher lane is proposed to be 150 meters above ground level (AGL), while the lower lane will be 15 meters below at 135 meters AGL. The horizontal distance between the centerlines of the lanes will be separated by 30 meters. These safety separations will allow the used eVTOL to vertically deviate 5 times its height and to deviate its full width from the lane edge horizontally without colliding with the other line eVTOL. The following image shows schematically the line distribution:

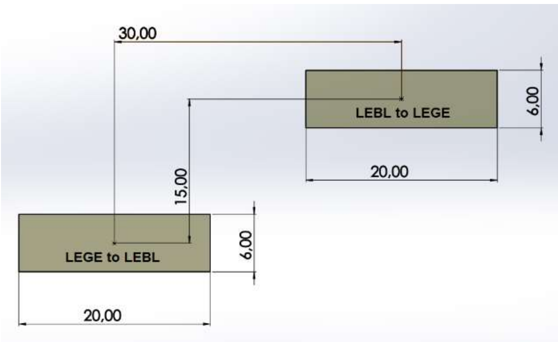


Fig. 7.4 Measures and distribution of the air route lanes

7.3.2. Safety Areas

If an eVTOL experiences a failure on one of its systems, requiring an emergency landing, there will be several areas around the route where an emergency landing could be performed, as the AP-7 has a lot of rural zones around, and a crop field may be a good spot to land if necessary.

Another valid option would be to adapt a landing spot at a certain distance from each other, every 10 kilometers, for example, that does not have to imply major construction but an asphalt pad with the appropriate FATO size and easy access to the emergency services. The remaining useless areas where the old tolls were located may be an ideal location to place these emergency vertiports.

7.4. Takeoff and landing procedures

In the previous sub-section, the route was presented and described; now the procedures at each airport are going to be shown. In Annex C, the compatibility of the designed UAM procedures with the aviation operations that are held at the LEBL, LELL, and LEGE airports is shown.

7.4.1. LEBL area and procedures

As LEBL is located at the end of the air route, the procedures start and finish, as previously explained, at the Procedure Point.

The approach maneuver goes from the Procedure Point to the “Entry Procedure Point” following an established route that overflies different roads around the airport. From that point, a straight line will be followed until the “Takeoff (T/O) and Landing Point” is reached, and from there, the final part of the procedure to the vertiport has to be performed. This last section will be the most critical due to the low altitude and proximity to the ground.

The departure procedure will start with the eVTOL taking off from the FATO and flying away in the opposite direction that the landings are performed. Once in the air, a left turn will be performed, followed by a straight section to reach the T/O and Landing Point. By following a road located on the right, the “Departure Procedure Point” will be reached, and from there, the Procedure Point.

Fig. 7.5 Arrival and Departure Procedures at LEBL [own source, Google Earth]

Any of the procedure points can be used as a waiting point where the eVTOL will have to hover in order to wait for another eVTOL to clear the path before performing the landing or the departure maneuver.

7.4.2. LELL area and procedures

At LELL the first part of the Entry Procedure is shared with the last part of the Departure Procedure. This shared section goes from the Deviation Point to the

“Airway Incorporation Point”, where eVTOLs can perform a hover before joining the airway. The road is overflown from there to the Procedure Point.

Once at the Procedure Point, eVTOLs willing to land will make a right turn to the Entry Procedure Point to perform a left turn to the vertiport.

For departing aircraft, from the vertiport, a left turn will be made to reach the Departure Procedure Point. From there, a nearly straight line will have to be followed to the Procedure Point, where the shared section has to be performed the other way around.

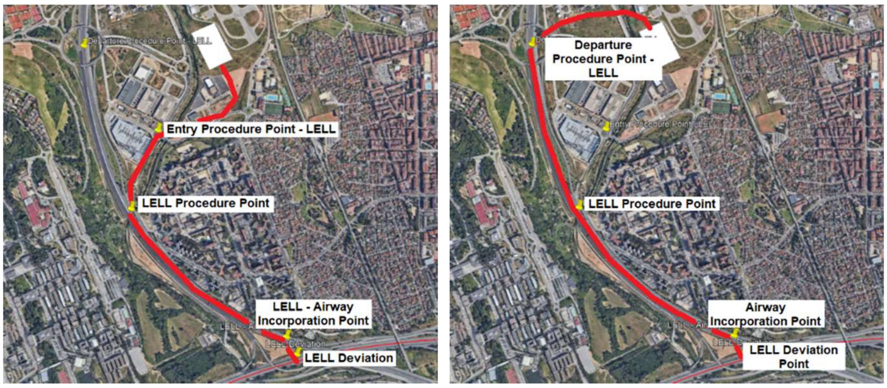


Fig. 7.6 Arrival and Departure Procedures at LELL [own source, Google Earth]

To develop these procedures, it has been assumed that a vertiport could be constructed on the left side of the airfield (white surface on figure 7.6). These new part with the FATO’s have been done instead of using some airport’s surface has been done to avoid overflying the city of Sabadell and to reduce any interference with the runway and stands.

7.4.3. LETA area and procedures

Due to the expected traffic of eVTOLs at LETA, which will be the epicenter of the operations, both takeoff and landing procedures have been duplicated on the left (west) and right (east) sides. Despite the duplicity, the E and W procedures follow the same order and go through points with the same name, some marked with a W and the others with an E.

For the arrival procedures, the eVTOL will leave the route at the Deviation Point and head to the Entry Procedure Point, where it will fly to the T/O and Landing Point. The final section toward the FATO will be performed from that last point.

On the other side, the departure procedure starts with the takeoff at the vertiport, then the aircraft will fly following the pre-established routes towards the Departure Procedure Point, going through the T/O and Landing Point, and finally joining the route via the Deviation Point. The following pictures show both the E and W procedures:

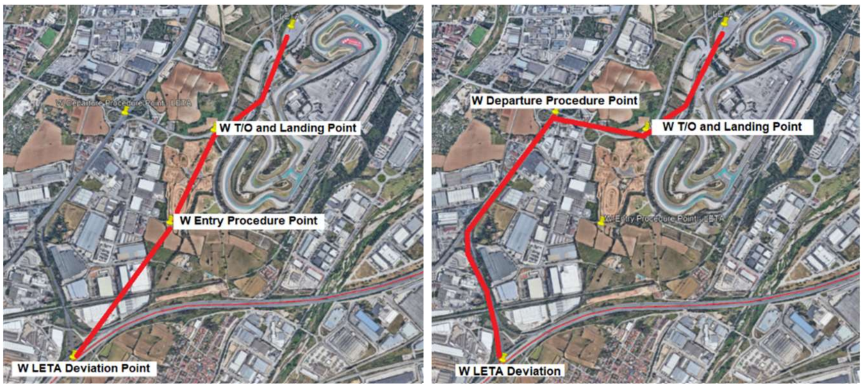


Fig. 7.7 West Arrival and Departure Procedures at LETA [own source, Google Earth]

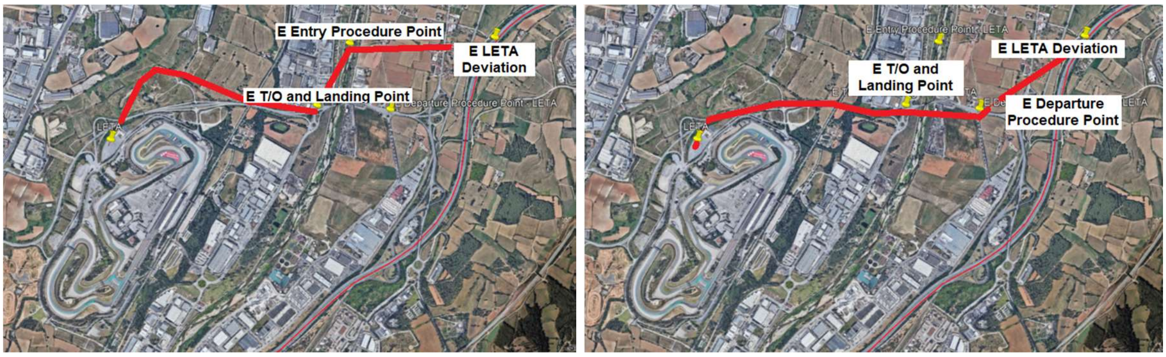


Fig. 7.8 East Arrival and Departure Procedures at LETA [own source, Google Earth]

In the event that the number of operations is very large, an alternate method of landing and taking off using west procedures has been designed. The difference from the already seen W procedures is that the other end of the vertiport will be used, taking off northward and landing southward. An extra point named “West to North Connecting Point” has been defined.

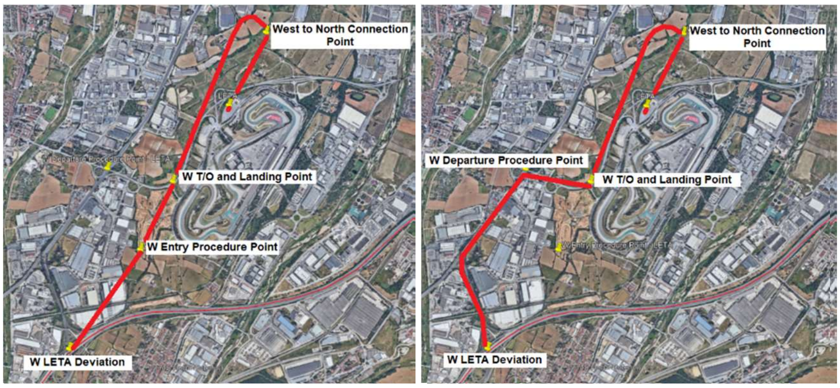


Fig. 7.9 North to West Arrival and Departure Procedures at LETA [own source, Google Earth]

7.4.4. LEGE area and procedures

The procedures at LEGE are very similar to the ones used at LEBL due to the presence of a Procedure Point at the end of the airway. Before entering into details, it is important to remark that they have been designed assuming that the part where the stands are, which is located at the north extreme (used by general aviation), will be adapted as a vertiport.

The Entry Procedure will start overflying the road N-II from the Procedure Point towards the Entry Procedure Point. To avoid overflying a few houses, a straight section followed by a 180-degree left turn will be done to arrive at the T/O and Landing Point, and finally perform the landing at the vertiport.

The Departure Procedure will start at the vertiport and head towards the T/O and Landing Point, from where the eVTOL will follow the route through the Departure Point to finally reach the Procedure Point.

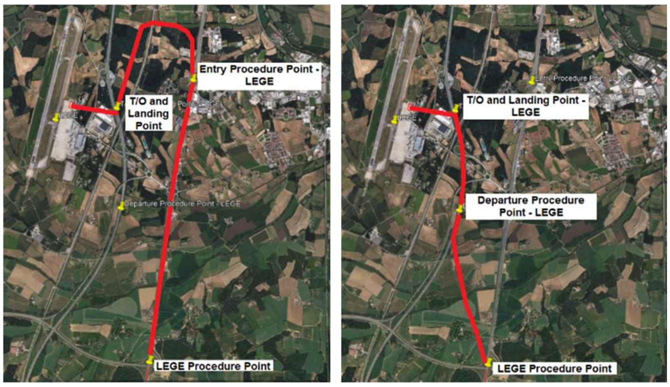


Fig. 7.10 Arrival and Departure Procedures at LEGE [own source, Google Earth]

7.4. Proposed eVTOL characteristics

Several companies have presented their eVTOL prototype, claiming to be the future of UAM; some of them have even been tested in real-life flights beyond simulations. From all of those models, the Wisk Generation 6 is thought to be the best fit for the type of operation being developed.

The company Wisk presented in 2022 its sixth generation of air taxi, representing the first-ever candidate for FAA certification of an autonomous, passenger-carrying eVTOL air taxi [64]. This model combines industry-leading autonomous technology, human oversight of every flight, and an overall simplified design to meet and exceed rigorous commercial safety standards.

The main flight characteristics of Generation 6 are listed hereunder [64]:

- Cruising speed: 120 knots (222.24 km/h)
- Range: 77.75 nautical miles (144 km) with reserves

- Wingspan dimension: <50 foot (<15.24 meters)
- Power: electric
- Charging time: 15 minutes
- Number of seats: 4
- Number of propellers: 12
- Type of operation: autonomous with human oversight from the ground

The range will allow for the longest round trip (from LEGE to LETA), but for safety, reasons it would be highly recommended to charge the batteries, although it would not be necessary to charge them at all, before doing the return trip. The capacity of the batteries will be a major constraint in this type of operations, and despite the fact that the estimated charging time is quite short, it would be necessary to locate enough chargers in each terminal to ensure the continued operation of the entire fleet.

Fig. 7.11 Wisk Generation 6 exterior and interior [64]

7.5. Vertiport Dimensions

In Chapter 6, “Required Ground Infrastructure”, the vertiport dimensions as well as the OFV dimensions were given in function of the D value. Now that the Generation 6 is proposed as the eVTOL used in this operation, the D value takes on a value, and the vertiport measures can be calculated.

Despite the fact that D-value, which is the smallest circle enclosing the VTOL, can vary from the longest VTOL distance, as no D-value is provided by Wisk, the wingspan will be taken, resulting in a D-value of 15.25 meters.

The basic ground dimensions that should be taken into account when designing the vertiport ground area are the following

- Squared FATO side: 1.5 times D, which results in 22.875 meters
- D-value-based stand: diameter of 1.2 times D, resulting in 18.3 meters

In Annex B, “Vertiport Design in Europe: Detailed Information”, two tables with both the squared and circular OFV (Reference Volume Type 1) dimensions were given in function of D; hereunder the same tables are provided with D being substituted by 15.25:

Parameter	Reference Volume Type 1
h_1	3 m
h_2	30.5 m
TO_{width}	45.75 m
TO_{front}	30.5 m
TO_{back}	30.5 m
$FATO_{width}$	30.5 m
$FATO_{front}$	15.25 m
$FATO_{back}$	15.25 m
θ_{app}	12.5%
θ_{dep}	12,50%

Parameter	Omnidirectional Volume
h_1	3 m
h_2	30.5 m
$\emptyset\ TO_{omnidirection}$	76.25 m
$\emptyset\ FATO_{omnidirection}$	43.158 m
$\theta_{omnidirection}$	12.5%

Table 7.2 Squared and circular OFV dimensioned parameters [own source]

7.6. Open continuity lines

The use case definition was not the main aim of this project; it has been developed only in a generic way, taking into account all the different knowledge that was discussed in the previous chapters. To go into detail in this type of operations design, a full project could be done; even one of the sub-sections could be enough to conduct a full study.

Hereunder some continuity lines detected during the elaboration of this last chapter are listed and briefly explained:

1. Study the required CNS equipment. Researching what type of equipment will be required both in the eVTOL and on the ground to safely communicate with the aircraft, know its position and altitude at any moment of the flight, and allow the aircraft to correctly follow the pre-established routes. It would be necessary to determine whether the CNS technology used in aviation meets the requirements for these operations.
2. Design the route in 3D, that is, not only defining the path on a map but also defining the vertical profile that will be required to take into account the orography of the surrounding terrain.
3. Elaborate the procedure charts, like the ones published in the AIP, by indicating the distances between the points, the altitude at each point, emergency and contingency procedures, etc.
4. Design the entire vertiport, including not only the measurements and OFV dimensions published by EASA, but also calculating the approximate number of stands and FATOs required or determining which extra-infrastructures are required.
5. Elaborate a full study of the economic viability of the project, indicating the necessary investments versus the minimum necessary income for the project to be viable. Also, the business model could be indicated.
6. Analyze if the route is optimal in terms of energy consumption and time savings; if not, propose some route modifications.
7. Examine whether the inconvenience caused by the eVTOLs will result in social rejection of the implementation of this use case. Follow EASA guidelines to compute noise levels.

CONCLUSIONS

Drones are here to stay. UAV technology has exploded into several fields over the last decade, becoming an assisting tool for workers to perform their jobs or even the primary tool to carry out tasks that were previously done by other means or using other vehicles such as helicopters. But now that professionals in the sector plan to go further, transporting people and cargo by air in the following years may become a reality. This is how the Urban Air Mobility (UAM) concept appears as a possible solution to connecting remote rural zones with difficult access or decongesting the ground traffic of cities.

The UAM sector can have a huge economic and societal impact worldwide, creating thousands of new workplaces, expediting medical transport, assisting emergency equipment, or providing greener solutions to urban mobility, among others. But to allow its full implementation, an international legal framework that defines air rules and ensures a safety standard is needed; this is how aviation has achieved transporting thousands of passengers and tons of freight around the world every day in an efficient and safe way.

One of the first steps to be taken in UAM implementation can be defining a new airspace with the drone and the eVTOL at the center of the design, which allows the safe development of urban air transport while never interfering with traditional aviation operations that will be held only a few hundred meters higher. Adapting the aviation airspace and flight rules, as well as its ATM methodology, has been shown not to be a feasible task, as the types of operations, hazards entailed, and size and performance of aircraft are notoriously different than those in UAM.

The design of the UAM dedicated airspace will necessitate the involvement of a multidisciplinary team of professionals, as numerous factors must be considered. Safety will be the main requirement; to minimize operational risks, meteorological phenomena, aircraft separation, and dangerous zones will need to be considered. Also, the type of eVTOL engine layout and automatization level will have something to say, as will the development of new CNS equipment that fits into the UAM type of operations. But apart from the technological considerations, the opinion of the citizens will need to be studied; a hard social refusal to accept UAM will lead to multiple challenges and barriers to the sector. To avoid it, operations and procedures should be designed so that they have the minimum negative impact on society.

Defining the airspace alone will not be enough to carry out UAM operations, as due to the potential presence of obstacles to eVTOLs in urban areas, the ground infrastructure will also play a major role. Enough space has to be provided in vertiports to allow for safe takeoff and landing, as well as the ground movement of the aircraft.

The UAM operation design performed in the project's final chapter demonstrated that coexistence of UAM operations with traditional aviation operations may be possible, provided that the procedures for urban air operations do not directly interfere with the airplane's operation area in such a way that it implies a direct threat. It has also been shown that if the procedure design tries to overfly already existing ground transport infrastructures, like highways, or other geographic features, like rivers, a minimum social impact can be achieved in terms of not directly overflying urban areas.

The explained use case is far from being a well-designed UAM operation, but it has been developed with two aims: showing the potential of UAM in turning traditional transport methods greener and serving as inspiration for future projects to develop a more precise approach to this operation.

BIBLIOGRAPHY

[1] Z. Sarris, "Survey of UAV applications in civil markets" in Proceedings of the 9th IEEE Mediterranean Conference on Control and Automation, 2001.

[2] United Nations, "Population" article, part of the "Global Issues" papers. https://www.un.org/en/global-issues/population (last access on 11/10/2022).

[3] EIT Urban Mobility, initiative of the European Institute of Innovation and Technology (EIT), approach on the future of urban mobility. https://www.eiturbanmobility.eu/about-us/ (last access on 11/10/2022).

[4] Barcelona New Economy Week (BNEW) discussion panel about Urban Air Mobility, with the participation of Tecnalia, Bluenest, EIT Urban Air Mobility, Capgemini Engineering and Digital Catalonia Alliance. https://www.bnewbarcelona.com/session.php?id=76 .

[5] Federal Aviation Administration (FAA), Urban Air Mobility (UAM), "Concept of Operations", V1.0, US Department of Transportation, Office NextGen, 2020.

[6] European union Aviation Safety Agency (EASA) infographic about "What is UAM". https://www.easa.europa.eu/en/what-is-uam (last access on 11/10/2022).

[7] Volocopter webpage. Company dedicated on UAM infrastructure design. https://www.volocopter.com/

[8] G. Warwick, "Unmanned Community Making Progress On Airspace Access," Aviation Week and Space Technology, 05- Aug-2013.

[9] Aviation Benefits Report 2019 , Document published by the global aviation Industry High-level Group (HLG), formed by the International Civil Aviation Organization (ICAO), the Airports Council International (ACI), the Civil Air Navigation Services Organization (CANSO), the International Air Transport Association (IATA) and the International Coordinating Council of Aerospace Industries Associations (ICCAIA).

[10] Benefits Beyond Borders (ABBB), 2018, Air Transport Action Group (ATAG), https://aviationbenefits.org/media/166344/ abbb18_full-report_web.pdf

[11] Convention on International Civil Aviation, Document 7300, International Civil Aviation Organization (ICAO). https://www.icao.int/publications/pages/doc7300.aspx

[12] International Civil Aviation Organization (ICAO) webpage, https://www.icao.int/Pages/default.aspx (consulted on October 2022).

[13] Convention on International Civil Aviation - Annexes 1 to 18, International Civil Aviation Organization (ICAO).

[14] Annex 2 to the Convention on International Civil Aviation: Rules of the air, Tenth Edition, July 2005, International Civil Aviation Organization (ICAO).

[15] Aeronautical Information Manual, Chapter 7-Section 4: Wake Turbulence, Federal Aviation Administration (FAA). https://www.faa.gov/air_traffic/publications/atpubs/aim_html/

[16] Aircraft Type Designators, Document 8643/37, Edition number 37, International Civil Aviation Organization (ICAO).

[17] Air Traffic Management Terminology and Communications, Asia/Pacific Steering Group, International Civil Aviation Organization (ICAO).

[18] Annex 11 to the Convention on International Civil Aviation: Air Traffic Services, Fifteenth Edition, July 2018, International Civil Aviation Organization (ICAO).

[19] Australia Air Services webpage, blog “How airspace is managed”, https://www.airservicesaustralia.com/about-us/our-services/how-air-traffic-control-works/how-airspace-is-managed/

[20] Airports Regional Council (ARC) Position paper on Urban Air Mobility, post on ARC webpage, https://www.airportregions.org/post/arc-position-paper-on-urban-air-mobility

[21] Aleksandar Bauranov, Jasenka Rakas, Designing airspace for urban mobility: A review of concepts and approaches, June 8, 2021. https://www.sciencedirect.com/science/article/pii/S0376042121000312

[22] Single European Sky ATM Research (SESAR) official webpage, U-space article. https://www.sesarju.eu/U-space (last access October 2022).

[23] European Aviation Safety Agency (EASA), Frequently Asked Questions on Urban Air Mobility (UAM), EASA webpage, https://www.easa.europa.eu/sites/default/files/dfu/uam_-_faqs.pdf

[24] European Aviation Safety Agency (EASA) article on “Vertical Take-off and Landing (VTOL)”, EASA webpage, https://www.easa.europa.eu/en/light/topics/vertical-take-and-landing-vtol, (last access October 19, 2022).

[25] European Aviation Safety Agency (EASA) article on “VTOL designs for Urban Air Mobility”, EASA webpage, https://www.easa.europa.eu/en/light/topics/vtol-designs-urban-air-mobility (last access October 19, 2022).

[26] Parker D. Vascik, Hamsa Balakrishnan, R. John Hansman, Massachusetts Institute of Technology (MIT) International Center for Air Transportation, Assessment of air mobility control for urban air mobility and unmanned systems, in 8th International Conference for Research in Air Transportation, 2018.

[27] Institute of Catalonia, Generalitat de Catalunya (Catalonia's Government) webpage, https://www.idescat.cat/emex/?id=080193&lang=en

[28] M. Guterres, S. Jones, G. Orrell, and R. Strain, "ADS-B surveillance system performance with small UAS at low altitudes," in AIAA SciTech Forum, 2017.

[29] International Civil Aviation Organization (ICAO), Document 4444, "Procedures for air navigation services – Air Traffic Management", Sixteenth Edition, 2016.

[30] Spanish Aeronautical Information Provided (AIP), ENAIRE, Part 2: En-Route (ENR), ENR 1.6-1, "ATC Surveillance services and procedures", Edition of 24-February, 2022. https://aip.enaire.es/AIP/contenido_AIP/ENR/LE_ENR_1_6_en.pdf

[31] D.P. Thipphavong, R.D. Apaza, B.E. Barmore, V. Battiste, C.M. Belcastro, B. K. Burian, Q.V. Dao, M.S. Feary, S. Go, K.H. Goodrich, J.R. Homola, H.R. Idris, P. H. Kopardekar, J.B. Lachter, N.A. Neogi, H.K. Ng, R.M. Oseguera-Lohr, M. D. Patterson, S.A. Verma, Urban air mobility airspace integration concepts and considerations, in: 2018 Aviat. Technol. Integr. Oper. Conf., 2018.

[32] LIDAR Sensors, article on Precision Hawk website, https://www.precisionhawk.com/sensors/advanced-sensors-and-data-collection/lidar (last access November 2022).

[33] Evan T. Dill, Steven D. Young, and Kelly J. Hayhurst,, SAFEGUARD: an assured safety net technology for UAS, Safety-Critical Avionics Systems Branch, NASA Langley Research Center.

[34] National Aeronautics and Space Administration (NASA), Technology Solution, Reliable Geo-Limitation Algorithm for Unmanned Aircraft.

[35] European Union Aviation Safety Agency (EASA), Understanding how the new U-space will enable the safe integration of drones in the European airspace, article on EASA webpage, https://www.easa.europa.eu/en/document-library/general-publications/understanding-how-new-u-space-will-enable-safe-integration (last access December 2022).

[36] U-space ConOps, 4th Edition, Corus Consortium.

[37] Collen Reiche, Adam P. Cohen, and Chris Fernando, An Initial Assessment of the Potential Weather Barriers of Urban Air Mobility, IEEE Transactions on intelligent transportation systems, VOL. 22, No. 9, September 2021.

[38] United Stated Department of Transportation, Federal Aviation Administration, Advisory Circular No. 00-45H, Subject: Aviation Weather Services,14 November 2016.

[39] Anna Staubinger, Raoul Rothfeld, Michael Shamiyeh, Kai-Daniel Büchter, Jochen Kaiser, Kay Olaf Plötner, An overview of current research and

developments in urban air mobility – Setting the scene for UAM introduction, Journal of Air Transport Management, 15 June 2020.

[40] WISK webpage, article on Autonomy of VTOLs, https://wisk.aero (last access, November 2022).

[41] Giovani Izidório Cesconetto, Canadian Advanced Air Mobility (CAAM), AAM Aircraft: Levels of autonomous flying, June 7, 2022.

[42] Millie Radovic, Industry Report on Drone Industry Insights (DRONEII) webpage, https://droneii.com/drone-reports (last access, November 2022)

[43] Single European Sky ATM Research (SESAR) Joint Undertaking, CORDIS result pack on AI in air traffic management, October 2022; https://www.sesarju.eu/node/4254

[44] Raj Jain, Pedro Taboso, Fred L. Templin, Greg Sheffield, Denise Ponchak, Requirements for an integrated UAS CNS architecture, Conference Paper, April 2017.

[45] Federal Aviation Administration (FAA) webpage, Automatic Dependent Surveillance – Broadcast (ADS-B) article. https://www.faa.gov/about/office_org/headquarters_offices/avs/offices/afx/afs/afs400/afs410/ads-b (last access November 2022).

[46] EIT Urban Mobility, Expectations and success factors for Urban Air Mobility in Europe, November 2022. https://www.eiturbanmobility.eu/wp-content/uploads/2022/11/EIT-UrbanAirMobility.pdf

[47] Boeing website, Future of flight: Passenger Air Vehicle (PAV), https://www.boeingfutureofflight.com/pav (last access November 2022).

[48] Parker D. Vascik, R. Jhon Hansman, Scaling constraints for urban air mobility operations: air traffic control ground infrastructure, and noise. June 2018, MIT International Center for Air Transportation (ICAT), report for the AIAA Aviation Technology, Integration, and Operations conference in Atlanta, GA. https://doi.org/10.2514/6.2018-3849

[49] European Union Aviation Safety Agency (EASA), Study on the societal acceptance of Urban Air Mobility in Europe, May 19, 2021.

[50] European Union Aviation Safety Agency [EASA], Vertiports in the Urban Environment, article on EASA webpage, https://www.easa.europa.eu/en/light/topics/vertiports-urban-environment, (last access on January 2023).

[51] Karolin Schweiger, Lukas Preis, Urban Air Mobility: Systematic Review of Scientific Publications and Regulations for Vertiport Design and Operations, July 19, 2022.

[52] European Union Aviation Safety Agency (EASA), Prototype Technical Specifications for the Design of VFR Vertiports for Operation with Manned VTOL-Capable Aircraft Certified in the Enhanced Category (PTS-VPT-DSN), March 2022.

[53] Eurostat - Statistics Explained webpage, article on European population, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Population_and_population_change_statistics (last access on January 2023).

[54] European cities: territorial analysis of characteristics and trends, JRC technical reports, European Comission, 2015.

[55] Emmanuel Sunil, Jacco Hoekstra, Joost Ellerbroek, Frank Bussink, Dennis Nieuwenhuisen, et al.. Metropolis: Relating Airspace Structure and Capacity for Extreme Traffic Densities. ATM seminar 2015, 11th USA/EUROPE Air Traffic Management R&D Seminar, FAA & Eurocontrol, Jun 2015, Lisboa, Portugal. ffhal-01168662f

[56] Pio Presas Guitart, directed by Jordi Pons Prats, Trabajo de final de Grado, Evaluación de la implementación de la UAM en el área metropolitana de Barcelona, October 24, 2022.

[57] Circuit de Barcelona-Catalunya official webpage, https://www.circuitcat.com/en/ (last access on January 2023).

[58] Article on the aeronautical online blog “Aerotendencias”, https://www.aerotendencias.com/aeropuertos/22812-vuelos-privados-en-barcelona-girona-y-sabadell-con-motivo-del-gran-premio-de-espana-de-formula-1/ (last access on January 2023).

[59] Spanish newspaper “elDiario.es” article on VIP transportation to the circuit of Barcelona by helicopter, https://www.eldiario.es/economia/ricos-conservan-montmelo-ostentacion-fortunas_1_5671337.html (last access on January 2023).

[60] Spanish AIP (Aeronautical Information Publicated) webpage, service provided by ENAIRE, https://aip.enaire.es/AIP/ (last access on January 2023)

[61] Insignia, Aeronautical Information Service by ENAIRE, https://insignia.enaire.es/ (last access on January 2023).

[62] European Union Aviation Safety Agency (EASA), article on “Air Taxis as urban Transport” in EASA webpage, https://www.easa.europa.eu/en/light/topics/air-taxis-urban-transport (last access on January 2023).

[63] Unmanned Airspace webpage, article on flight trial over Belgrade as part of EIT Urban Mobility project, https://www.unmannedairspace.info/uncategorized/large-safety-corridors-for-urban-drone-flights-not-always-needed-belgrade-eit-trial/

[64] Wisk webpage, article on Generation 6 characteristics, https://wisk.aero/news/press-release/generation6/ (last access on January 2022).

ANNEX A. EUROPEAN SOCIAL ACCEPTANCE IN NUMBERS

A.1. EASA survey introduction

As stated in section "5.3 Social Acceptance", the EASA's paper published in May 2018 sought to learn people's perspectives on UAM implementation: understanding what concerns them most and which use cases they see as having the most potential is critical to ensure proper implementation of urban air operations in European cities [49]. It was essential that the survey and questionnaires that people were asked to complete had a European scope, that is, they consulted people from more than one country or region.

The total number of participants interviewed was 3.690 from 6 different European regions: Paris and Hamburg to represent Central Europe; Rome and Barcelona to represent South Europe; Budapest to represent East Europe; and the Oresund Region (which includes Copenhagen, Hilleroad, Helsingor, Malmo, and Lund) to represent the North European region [49]. It was also an important factor to have an equitable demographic distribution among the participants. The following picture shows that a balanced distribution was taken into account:

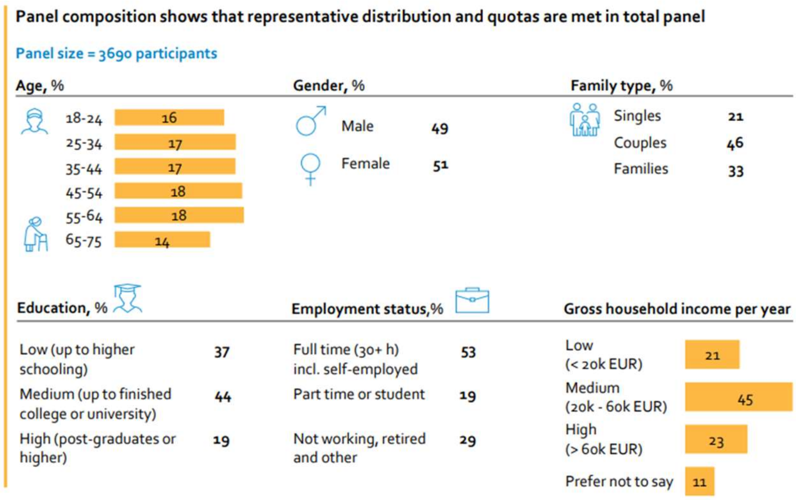


Fig. A.1 Composition of interviewed panel [49]

The online survey was translated to the official language of each country, but for the region of Oresund, that the tests were performed in English [49]. The questionnaire had six remarkable parts:

1. Making participants familiar with UAM
2. Testing the acceptance of delivery drones,
3. Testing the acceptance of passenger transportation
4. Understanding their attitude and expectations towards regulators

5. Understanding about their security and environmental aspects concerns
6. Asking them for demographic information

A.2. Survey key findings

Once the survey was performed, EASA had to analyze the results and work on them to obtain conclusions and display them in a clear way. The results were classified into 10 different conclusions or key findings; in this project, only the ones more related to the current project will be discussed; for further details, check the full study [49].

First and foremost, it is important to emphasize the unexpected homogeneity of results across Europe: no significant differences were found between respondents from the six cities, and no significant differences were found based on age, household composition, or affinity for new technologies [49]. Then, the overall perception of UAM was positive: an 83% of the respondents felt positive (very or rather) about the UAM introduction, and only an insignificant 3% had a very negative perception about it.

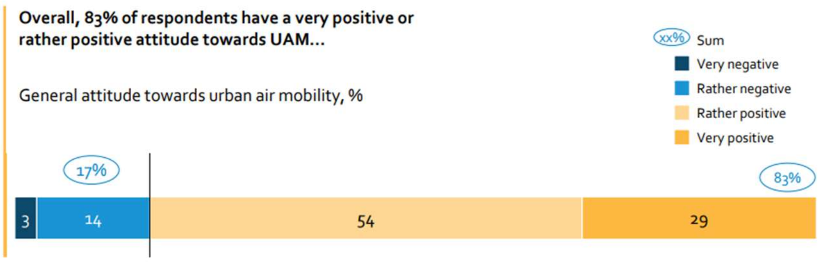


Fig. A.2 Attitude towards UAM implementation [49]

Further details on the attitude towards UAM affirm that 64% of the respondents would be interested in using drone delivery, while only 49% would be interested in using it as an air taxi; 43% would be interested in using both of the services, and 71% are likely to make use of at least one of the services [49]. From this data, it can be understood that the majority of people are confident in using eVTOLs for cargo deliveries, but the level of confidence decreases when they are the ones to be transported.

About the use cases, the following image depicts key data:

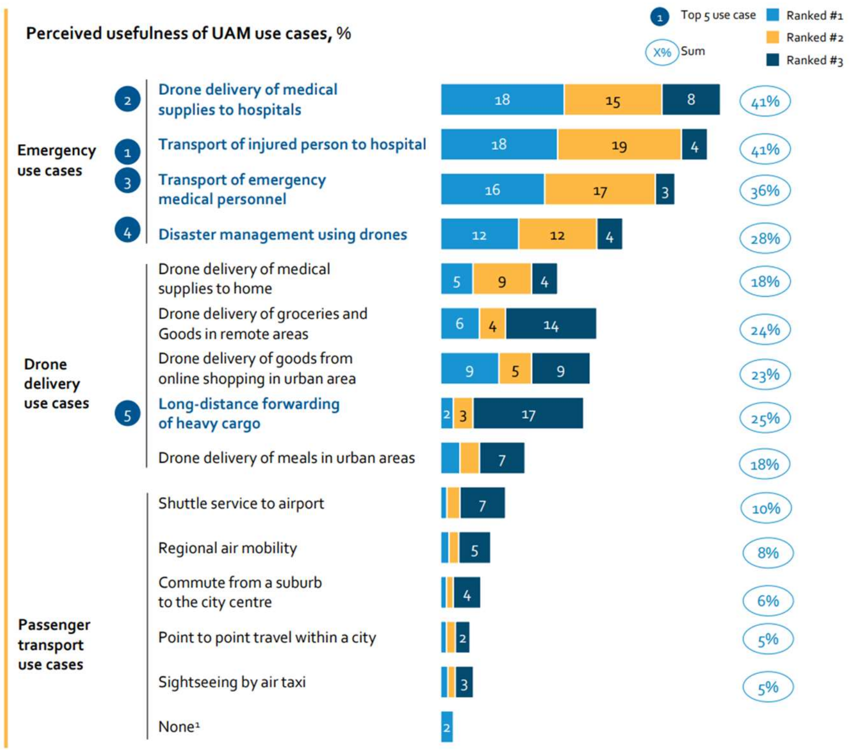


Fig. A.3 Perceived usefulness of different UAM applications [49]

As it can be seen in the previous figure, use cases related to medical and/or emergency transport are the most valuable ones for the participants. That indicates that use cases related to the public interest, notably in the health and safety domains, would be better accepted than those fulfilling private or individual needs.

People who support UAM implementation do so because they believe that the benefits provided by UAM outweigh the inconveniences that it can cause. The major benefit of eVTOL use is reducing the response time in case of an emergency, with a support rate of 71%. The following three most anticipated benefits are: reduced traffic (51% expect it), improved connectivity to remote areas, and the creation of new jobs (41% and 32% of the participants, respectively), all of which are expected to be significant community benefits [49].

In the following picture, the discussed information is displayed:

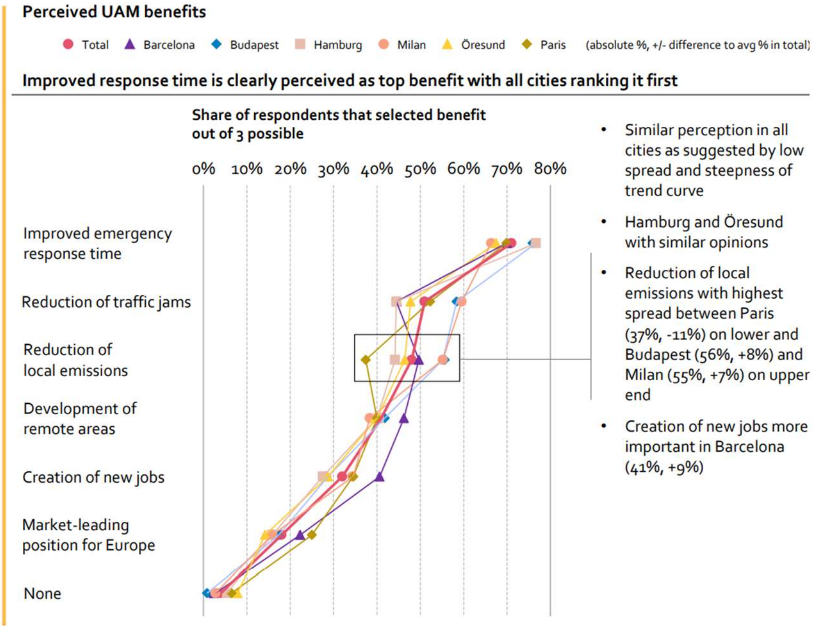


Fig. A.4 Perceived UAM benefits by participants [49]

To assess the noise acceptance in Europe towards UAM vehicles, some of the participants took a detailed noise perception test apart from the online survey in a professional 3D sound lab. Different vehicle sounds were played on top of a typical city background (approximately at 55 decibels). After that, they were asked to rate the level of annoyance that each sound caused them:

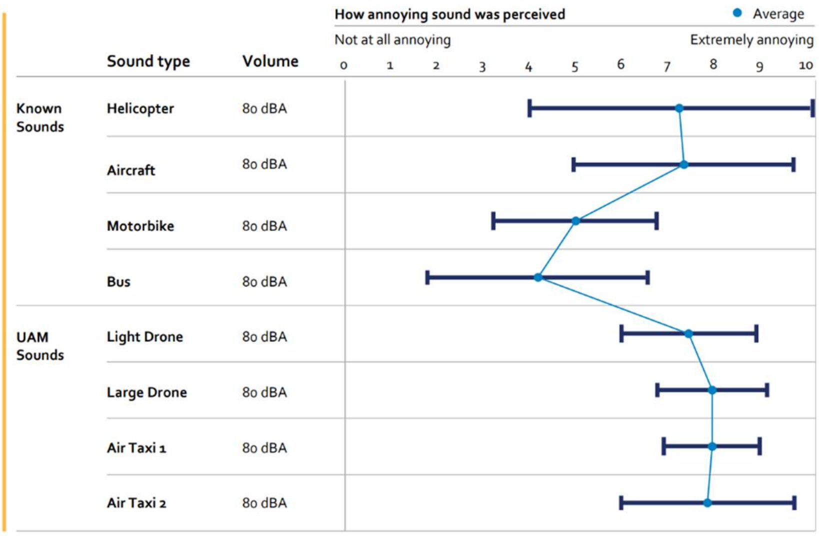


Fig. A.5 Annoyance rating of different city sounds [49]

The noise caused by UAVs or eVTOLs was rated as having a higher level of annoyance than the caused by an airplane or helicopter. This enables us to distinguish between the noise produced by ground vehicles and that produced by air vehicles, the latter being the worst rated. This consideration can lead to the conclusion that unfamiliar sounds, like UAM in this case, are perceived more negatively. An increased familiarity with these sounds may entail greater acceptability in the future [49].

To conclude this annex on the state of social acceptance in UAM operations at the European level, it was desired to note the population’s trust levels in the operations and technology itself, because not all people who accept using UAVs or eVTOLs trust in them; furthermore, as the image below depicts, only roughly 50% trust in both UAV and eVTOL technology [49]:

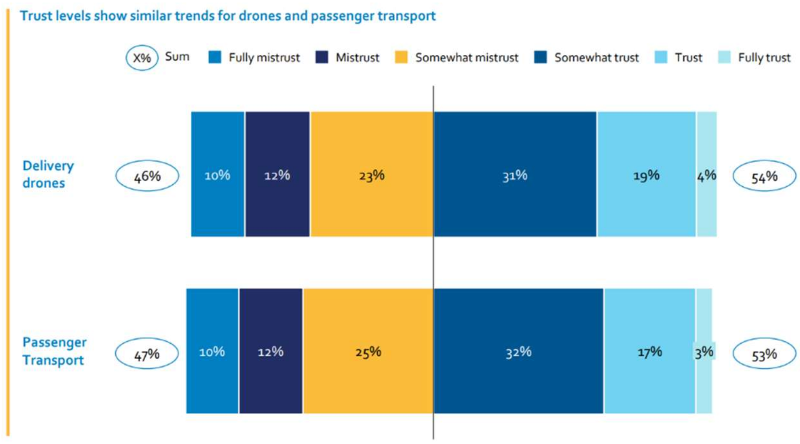


Fig. A.6 Trust level in VTOL technology [49]

ANNEX B. VERTIPORT DESIGN IN EUROPE: DETAILED INFORMATION

On this present annex, additional information, details, and pictures will be given to Chapter 6, more specifically to sub-sections 6.3.4, “Vertiport Physical Characteristics,” and 6.3.5, “Obstacle Free Volume”.

All the information detailed in this annex has been extracted from EASA Vertiports Design Paper [52] available on the EASA webpage, published on March 2022. Only principal details will be explained; for further information and specifications, it is highly recommended to read [52].

B.1. Published Vertiport Data

This sub-part of the Annex will introduce the reader to the aeronautical data that should be published by the operator of any active vertiport. EASA drafted this necessary information with reference to ICAO Annex 14, Volume II, “Vertiports”, and ICAO Document 9261, Heliport Manual.

In a simple and schematic way, the aeronautical data of a vertiport contains:

- Vertiport Reference Point (VRP): a reference point that should be located at the Vertiport’s geometric center.
- Vertiport Elevation: the VRP’s elevation and geoid undulation should be provided.
- Vertiport Dimensions and Related Information: data related to all the vertiport parts’ dimensions and location, together with geographical information.
- Vertiport Declared Distances: available distances for takeoff, landing, and other maneuvers at the vertiport.
- Coordination between aeronautical information services and vertiport authorities: all the necessary information to operate at the vertiport and to coordinate with corresponding authorities.
- Safeguarding of vertiports: topology and measures of all the protecting surfaces (such as OFVs) and obstacle-free areas of the vertiport.

B.2. Dimensions of vertiport physical characteristics

Subsection 6.3.4, “Vertiport Physical Characteristics”, explains the main necessary vertiport parts, their minimum number and their relationship with the D-value and Design D. The sizes of these physical characteristics are introduced in this annex sub-part.

The FATO can be square or round in shape. In the case of a square, the side must have a dimension of 1.5 Design D, and in the case of a circle, the diameter must be at least 1.5 Design D. The SA associated will maintain the same shape as the FATO, with the greatest width 3 meters, or 0.25 Design D.

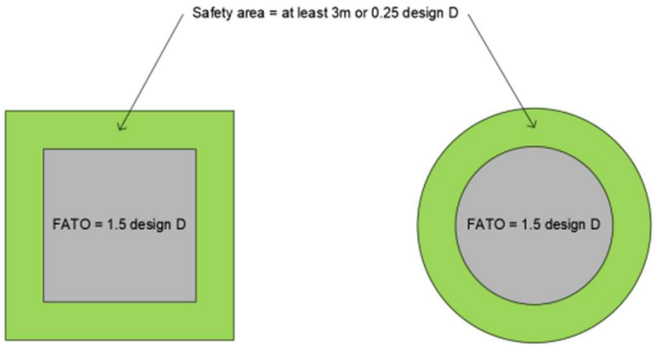


Fig. B.1 FATO and associated SA [52]

The TLOF, if associated with a FATO, will have to be centered and should be provided with markings that clearly indicate the touchdown position and any existing limitations on maneuvering. Its size will be the greatest between 0.83 D and the dimension specified on the VTOL manual provided by the operator for which the TLOF is intended.

At least one protected side slope must be provided in any vertiport, whose surface should not be penetrated by any obstacle. It will rise outwards from the edge of the SA at 45 degrees, extending to a distance of 10 meters. The following picture depicts multiple combinations of arriving and departing surfaces on both squared and circled FATO, with the corresponding SA, the mandatory side slope marked in green, and the additional ones marked in blue.

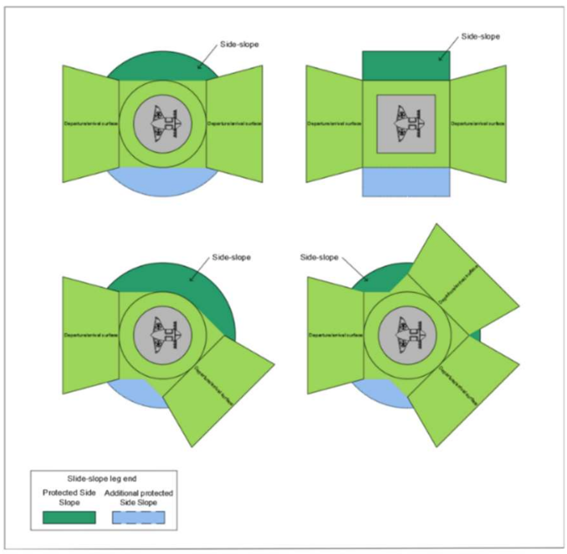


Fig. B.2 FATO configurations with simple and complex SA and side slope protection [52]

Vertiports may also contain taxi-routes to allow safe movement of VTOLs, for example, from the FATO to the gates. Two types of taxi-routes are described: the ground and the aerial ones.

A taxiway aligned with the taxi-route is required in ground taxi-routes, as the taxi-route indicates the path that a VTOL must follow in ground operations, but the taxiway allows movement on the ground, preparing the surface and ensuring no obstacles will interfere with the VTOLs and their ground movement equipment. The taxiway width must be at least two times the landing gear width of the aircraft, while the ground taxi-route has to be at least 1.5 times the overall width of the largest VTOL operating at the vertiport.

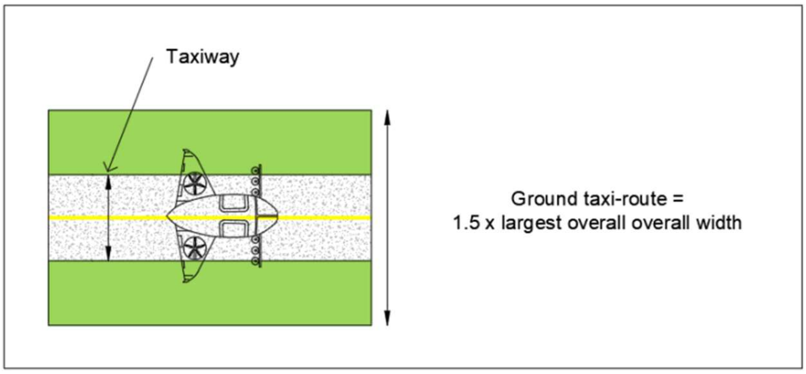


Fig. B.3 Ground taxi-route and taxiway dimensions [52]

The air taxi-routes will accommodate VTOLs capable of performing taxi maneuvers above the surface at speeds less than 37 km/h or 20 knots. No taxiway is required, but if VTOLs performing both ground and taxi operations will land at the vertiport, a taxiway can also be allocated in the air taxi-route. The width for air taxi-routes is larger than for ground ones, being the minimum width 2 times the largest overall width intended to operate at the vertiport.

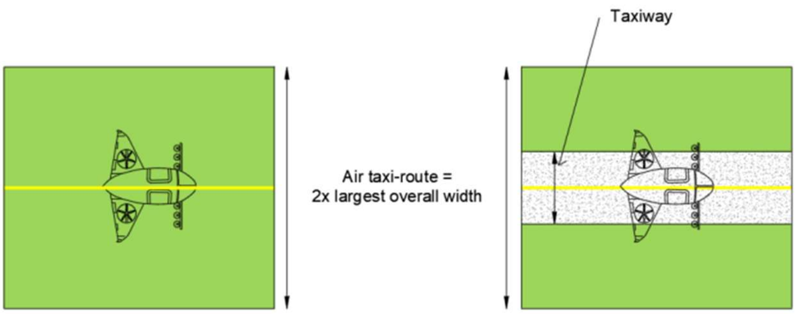


Fig. B.4 Dimensions of an air taxi-route with and without a taxiway [52]

Finally, stands may also be needed in a vertiport to allocate the VTOL during a period of time or to facilitate the loading and offloading of cargo and passengers. EASA discussed the utilization of two types of stands. On one hand, the geometry-based VTOL stands are stated, which will be stands with a safety margin dictated by the size of the VTOL. The following picture shows a VTOL with a width inferior to 24 meters, so a 3-meter clearance around the aircraft is requested.

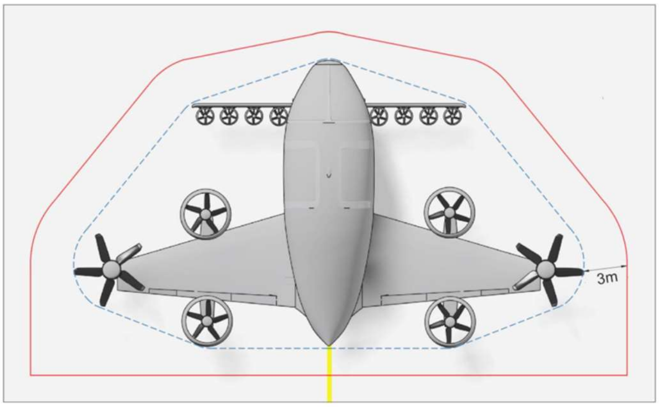


Fig. B.5 Geometry-based stand [52]

On the other hand, the D-value-based stand can be used, which will have a circular shape with a minimum dimension of 1.2 times the Design D. These types of stands should be surrounded by a protection area. If two or more stands are next to each other, their protection areas may overlap, but they will never be narrower.

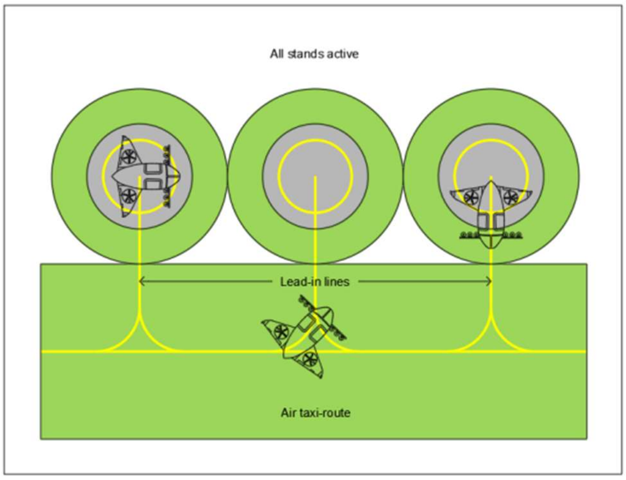
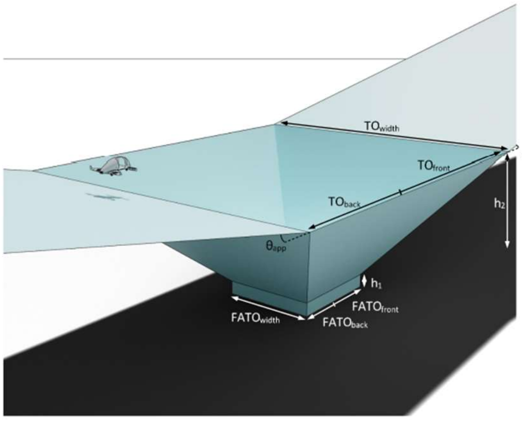


Fig. B.6 D-value-based stands [52]

B.3. OFV parameters

The following picture shows the 3D shape for a squared FATO of the Obstacle Free Volume, or OFV, designed by EASA to protect VTOLs landing and departing:



Parameter	Short description
h_1	Low hover height
h_2	High hover height
TO_{width}	Width at h_2
TO_{front}	Front distance at h_2
TO_{back}	Back distance at h_2
$FATO_{width}$	Width of the FATO
$FATO_{front}$	Front distance on FATO
$FATO_{back}$	Back distance on FATO
θ_{app}	Slope of approach surface
θ_{dep}	Slope of departure surface

Fig. B.7 OFV shape and abbreviations for a squared FATO [52]

And for a circular FATO, the OFV will have the shape that is shown hereunder:

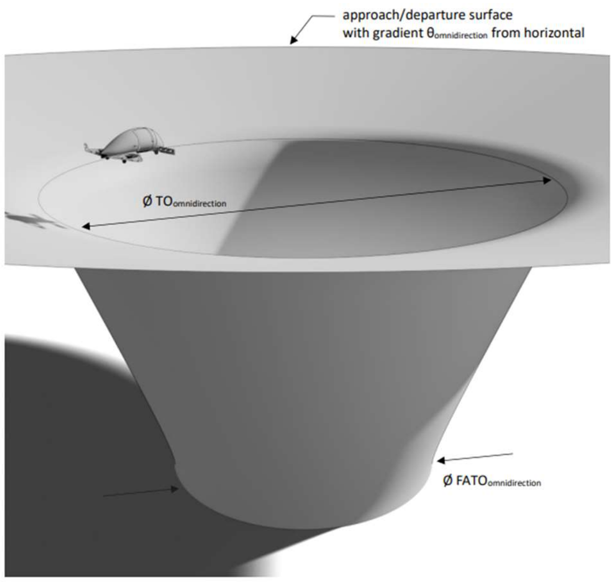


Fig. B.8 OFV shape and abbreviations for a circular FATO [52]

Consult the EASA Vertiport Guidelines [52] to get more information about circular OFV dimensions.

To conclude this annex, the dimensions of the Reference Volume Type 1 defined by EASA are given in the image below. Note that these dimensions do not affect the proportions of the OFV's previously explained:

Parameter	Reference volume Type 1
h_1	3 m (10')
h_2	30.5 m (100')
TO_{width}	3 D
TO_{front}	2 D
TO_{back}	2 D
$FATO_{width}$	2 D
$FATO_{front}$	1 D
$FATO_{back}$	1 D
θ_{app}	12.5 %
θ_{dep}	12.5 %

Parameter	omnidirectional volume
h_1	3 m (10')
h_2	30.5 m (100')
Ø $TO_{omnidirection}$	5 D
Ø $FATO_{omnidirection}$	2.83 D
$\theta_{omnidirection}$	12.5%

Fig. B.9 Reference Volume Type 1 dimensions, from left to right, for squared and for circular FATO [52]

ANNEX C. UAM USE CASE: ADDITIONAL INFORMATION

In this annex, complementary information, pictures, schemes, and tables to Chapter 7 will be provided.

C.1. Airports involved

The diagrams of LEBL, LELL, LEGE, and LETA published on the Spanish AIP [60] are shown hereunder:

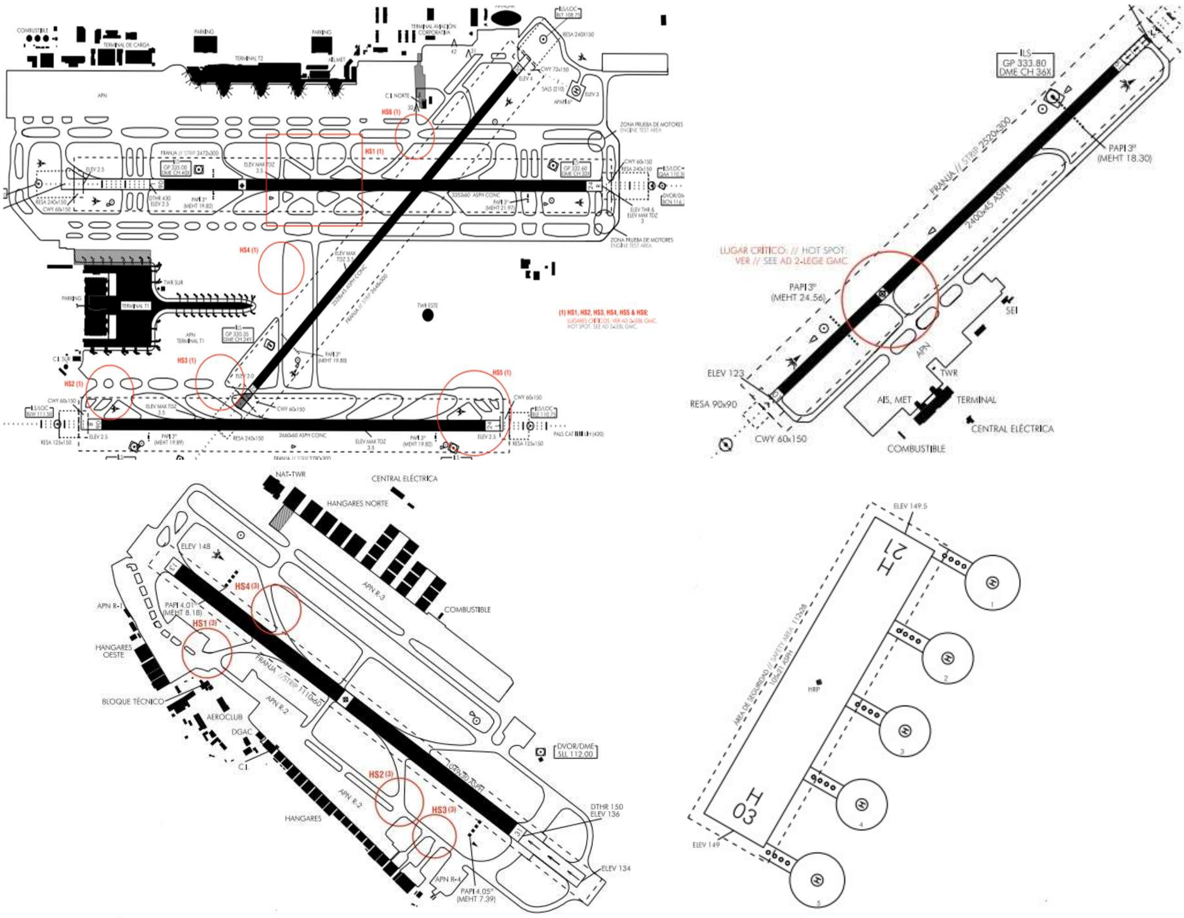


Fig. C.1 From left to right, from top to bottom, LEBL, LEGE, LELL and LETA airports diagram [60]

Figure C.2 shows that as stated in Chapter 7, no dangerous zones are located between the airports and LETA in a straight line and on the areas where the eVTOLs will fly through. Also CTR and ATZ of LEGE and LEBL, as well as the LELL ATZ are indicated [61]:

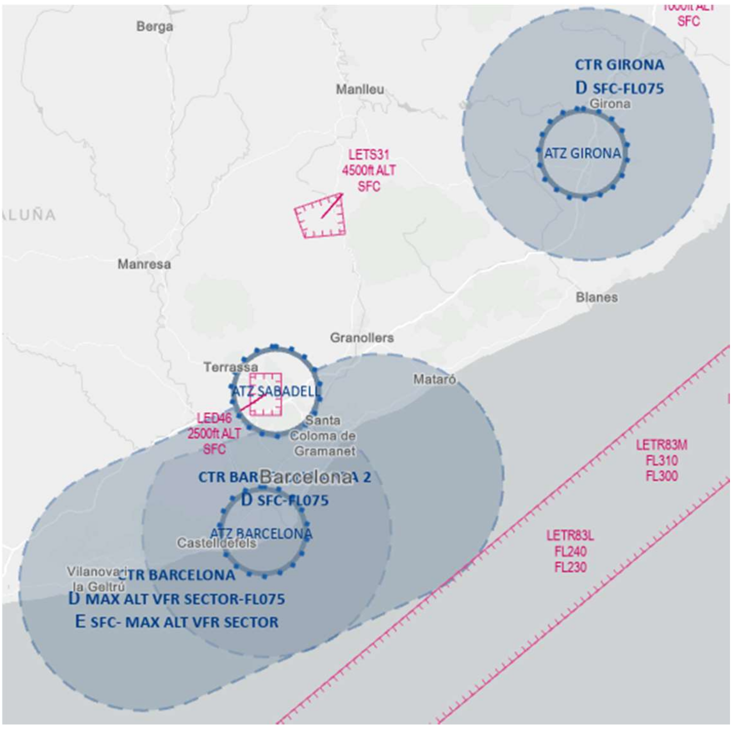


Fig. C.2 Detail of dangerous areas and controlled airspace in the operation zone [61]

C.2. Compatibility between the designed procedures and aviation operations

The procedure designed has not been a trivial process in which different routes were designed without taking into consideration any external aspects like the already existing airport operations at LEBL, LELL, and LEGE. Apart from avoiding residential areas and flying over roads, the runway distribution and operations compatibility at each airport have been considered. In the present sub-section, it will be shown how these aspects have been considered when designing the procedures.

It should be noted that these UAM operations are not intended to perform regular flights during the week, but rather for the weekends (and preceding days) when a Grand Prix is held at Montmeló.

C.2.1. LEBL

Despite what it may seem, checking the compatibility of the eVTOL procedures with the existing operations at LEBL was not the most difficult one.

To begin, according to the information provided on the AIP about the LEBL airport [60], the heliport is closed for commercial operation, with the exception of VFR flights for ambulances, rescue missions, state flights, and other local entities, which must always be non-commercial public services. This eliminates the major threat of directly interfering with commercial helicopter operations. Due to this reason, the heliport FATO will be used as the vertiport's FATO.

The eVTOL procedures were inspired by the existing helicopter procedures for this airport, assuming that eVTOLs will be permitted to operate on the actual FATO and that helicopters will still be able to operate at LEBL, possibly rehabilitating another specific area if sharing the FATO is not feasible due to the volume of the helicopter flights.

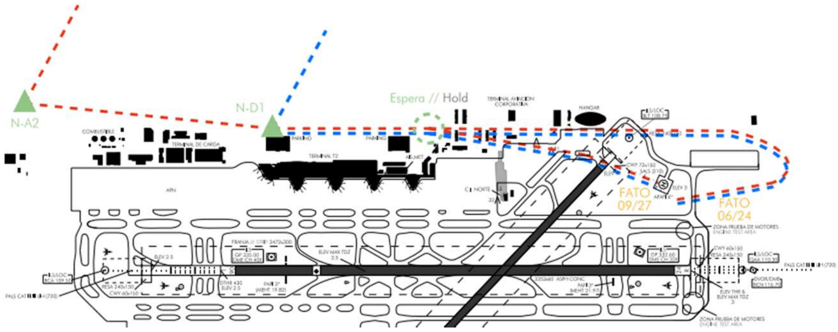


Fig. C.3 LEBL actual helicopter procedure [60]

Regarding interference with commercial aircraft, which is the most concerning due to the high volume of operations at Barcelona, demonstrating actual compatibility with eVTOL flights is relatively simple. First of all, if the helicopter procedures are designed in the northern part of the airport, it is because the competent authority has demonstrated that no major risk is entailed for commercial aircraft. The other key aspect that may be useful to defend the eVTOL operation on that part is that only a threshold (runway 20) is crossed, and on that specific runway, no takeoffs or landings are practically ever carried out due to the proximity to El Prat town.

Fig. C.4 eVTOL procedures crossing LEBL runway 20 threshold (green arrow) [own source, Google Earth]

C.2.2. LELL

At LELL the UAM procedures are designed to be carried out at the left part of the runway 31, at the side where the general aviation stands as well as the public buildings are located. This decision, of course, have been made to minimize the impact on the operations that are performed at that airport, which are mainly aviation school flights, small private jets and public services helicopters.

On the one hand, the aerodrome traffic circuit (pre-stablished circuit defined by the national authorities that VFR flight have to follow in order to fly around the airport) is defined at the right side of runway 31, so eVTOLs will not be flying under the aircraft following the circuit.

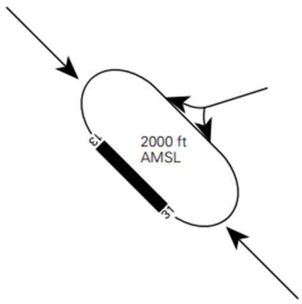


Fig. C.5 LELL VFR Traffic circuit [60]

On the other hand, the “Airway Incorporation Point” has been introduced in the eVTOL procedures as a safety measure for the traffic flying over the runway 31 threshold, more specifically the ones landing at runway 31. The visual charts indicate that planes taking off from runway 13 should turn left once the AP-7 is overflied, meaning that the plane will already have enough altitude and the eVTOL can fly along the defined route. The main issue is the planes landing on runway 31. As the procedures at LELL are VFR, no minimum altitude is indicated at any point of the landing maneuver, so a specific study on the average altitude of planes at the moment that they cross the AP-7 would be needed. In case no sufficient vertical separation between the aircraft and the air route was ensured, the eVTOL could perform a hover at the Airway Incorporation Point before starting the cruise phase.

C.2.3. LEGE

Finally, in the LEGE airport, the eVTOL activity could only pose a risk to commercial airplanes overflying the runway 01 threshold, that is, planes landing at runway 01 or taking off from runway 19. Furthermore, the runway axis is approximately parallel to the AP-7 at a distance of close to a kilometer. The first measure that was taken in the procedure design was that nearly 7 kilometers before the airport, the air route is deviated from the AP-7 to a close highway further from the runway axis to gain horizontal separation up to a minimum of 2 km.

In second place, the departure procedure was checked to see if at any moment the AP-7 was overflied, and, if so, at what altitude. Planes taking off from runway 19 can follow different departure procedures; some of them contemplate crossing the AP-7, but at a minimum distance of 6.8 km from the threshold and at a minimum altitude of 1700 feet, or 518 meters, so no realistic risk is posed by eVTOLs during this maneuver.

Fig. C.6 LEGE runway 19 departing chart, in red studied maneuver [60]

The landing procedure on runway 01 could seem problematic for the eVTOL flight. By looking at the charts published on the AIP, it can be seen that the last point where a minimum altitude is given is the MAPT, at just 1.3 km from the threshold. At that point, the airplanes will have to fly at a minimum height of 450 feet (135 meters) about the altitude of the lower lane of the air route. In this case, no vertical separation will exist, but as previously stated, the fact of using the parallel road to the AP-7 allows a horizontal distance between the MAPT and the air route of at least 2.23 km, which has been considered enough to carry out both operations at the same time.

Fig. C.7 MAPT location with respect the eVTOL procedure at LEGE [own source, Google Earth]

To finish with the compatibility of operations at LEGE, it was checked on the AIP that the approach procedure at runway 01 does not cross the highway at any point, so the MAPT would be the most critical part due to its proximity. The following picture depicts the Obstacle Limitation Chart for runway 01, where it can be seen that some roads would be crossed but not the one where the air route is located above.

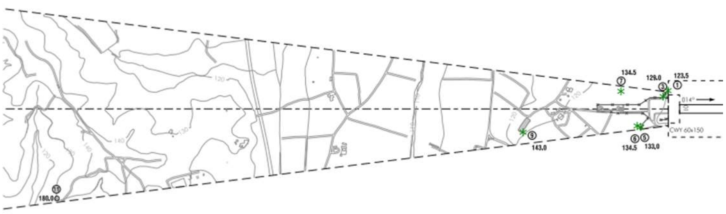


Fig. C.8 Obstacle Limitation Chart of runway 01 at LEGE [60]

C.3. Route from LEBL to LEGE Procedure Points in KML format

Hereunder the route on Google Earth going from end to end, that is, from LEBL Procedure Point to LEGE Procedure Point, is attached:

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