Innovative Air Mobility Challenges the Air Traffic Management Paradigm

A European Approach to Safe and Efficient Operation of Vertical Take-Off and Landing Capable Aircraft and Vertiports

03.07.2026

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This document is part of a project that has received funding from the SESAR 3 Joint Undertaking under grant agreement No 101114799 under European Union's Horizon Europe research and innovation programme.

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Co-funded by the European Union

Innovative Air Mobility Challenges the Air Traffic Management Paradigm: A European Approach to Safe and Efficient Operation of Vertical Take-Off and Landing Capable Aircraft and Vertiports

Karolin Schweiger[1,*], Arinc Tutku Altun[2], Aycan Mutlu[3], Jan Niklas Burgkart[4], Michael Anger[4], Akash Mishra[5], José Ignacio Rodríguez Modrono[5], Paolomaria Cappello[6], Victor Gordo[7], Alberto Mangas Pita[8], Cesar Nava Gaxiola[9], Giovanni Riccardi[10], Edoardo Fornaciari[11], Sara McNamee Freire[12], Raquel Moldes Teijeiro[13], Elisa Morales[2], Michael Hardt[2], Carlota Bettremieux Rodríguez[1], Barbara Franco García[14], Yannick Seprey[15], Marzia Corsi[16], Bernd Bassimir[16], Alvin Benjamin Owusu-Afriyie[17], Nathalie Kuehn[1], Andrew Hately[1], Bianca I. Schuchardt[16], Boyan Iliev[18], Marie Kolago[19], Emily Pfister[20]

[1] EUROCONTROL Innovation Hub, Centre du Bois des Bordes CS 41005, 91222 Brétigny sur Orge, France

[2] Boeing Aerospace Spain, Avenida Sur del Aeropuerto de Barajas 38, Edificio 4, Planta 4, 28042 Madrid, Spain

[3] EUROCONTROL Aviation Learning Centre, 12 Rue Antoine de Saint-Exupéry, 1432 Kirchberg Luxembourg

[4] UNISPHERE GmbH, Turmstraße 5, 78467 Konstanz, Germany

[5] Openvia Air SL (Bluenest), Paseo de la Castellana 259C, 28046 Madrid, Spain

[6] S.E.A. Società Esercizi Aeroportuali S.p.A., Aeroporto di Milano Linate, 20090 Segrate (MI), Italy

[7] INECO, Paseo de la Habana 138, 28036 Madrid, Spain

[8] ISDEFE, Beatriz de Bobadilla 3, 28040 Madrid, Spain

[9] AENA, Peonías 12, 28042 Madrid, Spain

[10] ENAV, Via Salaria 716, 00138 Roma, Italy

[11] D-Flight, Via Salaria 716, 00138 Roma, Italy

[12] UrbanV S.p.A., Via Generale Felice Santini Snc, Torre Epua 2, 00054 Fiumicino Roma, Italy

[13] ENAIRE, Avenida de Aragón 330, Parque Empresarial Las Mercedes, 28022 Madrid, Spain

[14] INDRA, Castilla 2, 28830 Madrid, Spain

[15] Sopra Steria, Les Ailes de l'Europe ZAC Les Ramassiers, 37 Chemin des Ramassiers, 31770 Colomiers, France

[16] German Aerospace Center (DLR), Lilienthalplatz 7, 38108 Braunschweig, Germany

[17] NAIS Srl, Via G.Porzio 4, 80143 Naples, Italy

[18] Pipistrel Vertical Solutions d.o.o., Goriska Cesta 50a, SI-5270 Ajdovscina, Slovenia

[19] Hologarde-Groupe ADP, Orlytech, 2 Allée Maryse Bastié, 94551 Paris-Orly, France

[20] Droniq GmbH, Ginnheimer Stadtweg 88, 60431 Frankfurt am Main, Germany

[*] *Correspondence: Dr.-Ing. Karolin Schweiger mailto: karolin.schweiger@eurocontrol.int*

All authors contributed equally to this work.

Abstract

Existing airspace structures, flight and operating procedures historically designed for conventional aircraft fall short of addressing the operational characteristic of vertical take-off and landing capable aircraft (VCA) and vertiports particularly with respect to manoeuvrability, automation, digitalisation, and performance. Current European regulations for VCA and vertiports impose stricter flight planning requirements, such as the selection of diversion location. However, neither existing air traffic management (ATM) nor the U-space framework provide the necessary information required by VCA operators. To address this gap, this paper examines four operational challenges: where to locate a vertiport, how to operate a vertiport, how to manage VCA at a vertiport, and how to operate and manage VCA within a network of vertiports. A consortium of 33 European partners investigated these challenges through three case studies in different operating environments (French Riviera, Balearic Islands, Rome), using ICAO's Global ATM Operational Concept as a guiding principle. The proposed concepts were validated through expert judgement, fast-time and human-in-the-loop simulation. The results show that the digital infrastructure of U-space provides an appropriate baseline for collecting and distributing vertiport-related information to all stakeholders. Nevertheless, current U-space regulation neither sufficiently addresses this use case nor supports VCA integration, instead VCA are treated as strictly segregated operations. In parallel, remotely piloted VCA lack a regulatory baseline for integration, while ATM does not yet provide the digital maturity and low-altitude coverage required for highly automated VCA operations. This paper elaborates the current European regulatory framework for VCA, identifies required evolutions in U-space and ATM, and demonstrates how vertiports can be digitally integrated into a traffic management system. The successful deployment of IAM ultimately depends on an interoperable integration of ATM and U-space, leading to a progressive digitalisation of the ATM paradigm.

Keywords: VCA; eVTOL; vertiport operation; innovative air mobility; airspace integration; ATM; U-space

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1 Introduction

The existing airspace structures and flight and operating procedures historically designed for conventional aircraft (i.e. fixed-wing aeroplanes and helicopters), airports and heliports fall short of addressing the operational scale, characteristics and complexity of innovative air mobility (IAM). Existing flight procedures do not leverage the full capabilities and respect the limitations of VCA designs in terms of manoeuvrability and performance, and the lack of representative empirical operational data further intensifies this challenge. According to the current European VCA and vertiport regulatory framework [6, 3], the regulator has put in place additional safety measures, such as identifying and booking diversion locations during flight planning, and confirming vertiport availability at the expected time of use before take-off, to compensate for current operational uncertainties of VCA. To address this, the vertiport information must be collected and shared, requiring a more integrated and collaborative traffic management system in which vertiports are a key stakeholder. Additionally, visual flight rules (VFR) and instrument flight rules (IFR), together with the concepts of visual meteorological conditions (VMC) and instrument meteorological conditions (IMC), were designed for pilot-on-board operations that rely on radio communication. These operational paradigms are therefore challenged in the context of IAM, which encompasses both manned and unmanned VCA operations carrying passenger and cargo.

In this paper, we examine how this integrated, collaborative IAM ecosystem could be developed to provide a framework that orchestrates fleet (VCA), air (airspace) and ground (vertiport) resources, and manages VCA traffic streams in the air and on the ground.

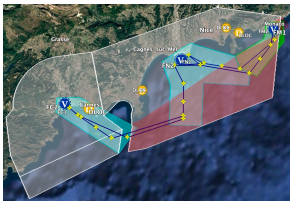
A consortium of 33 partners from the European air traffic management (ATM), U-space, VCA, airport and vertiport industries, as well as the research sector, has joined forces to examine ways of integrating new airspace users into the European airspace under the IAM framework. The EUREKA project (EUropean Key solutions for vertiports and UAM) is an industrial research initiative funded by the SESAR3 Joint Undertaking under the European Union's Horizon Europe research and innovation programme. It is among the first SESAR projects to extend the scope of the existing ATM, air operations and U-space regulatory framework, particularly for vertiport and VCA stakeholders. Understanding the short-term integration of VTOL-capable aircraft in manned configuration (MVCA) and vertiports into existing airspace and ATM structures is essential before advancing towards remotely piloted passenger-and cargo-carrying (UVCA; formerly DVCA for cargo) operations in a future digital ATM environment, both of which are addressed in this paper.

In EUREKA, we therefore investigate four operational challenges that will guide the integration of VCA and vertiports:

- Where to place a vertiport?
- How to operate a vertiport?
- How to operate and manage VCA at a vertiport?
- How to operate and manage VCA inside a vertiport network?

These four operational challenges will be researched based on three use cases in three different operating environments (see Table 1), with the aim of paving the way for concepts developed to be applicable and scalable across Europe.

Table 1: Referenced use cases and operating environments for each case study discussed in this paper. VCA = vertical take-off and landing capable aircraft; VFR = visual flight rules; IFR = instrument flight rules; FTS = fast-time simulation; RTS = real-time simulation.

	Case Study I French Riviera (France)	**Case Study II** Balearic Islands (Spain)	**Case Study III** Rome (Italy)
			
Business case	Passenger-carrying	Cargo-carrying	Passenger-carrying VCA
Vertiport location	Airport, city centre	Airport, airfield	Airport, city centre
ATS airspace	Class D	Class D	Class D
U-space airspace	Only at urban vertiport	All	All
VCA	Multirotor, tiltrotor	Vectored thrust	Multirotor
VCA Operating Mode	VFR, IFR	Remotely piloted	VFR
Validation	Expert judgement, analytical analysis, FTS, RTS	FTS	Expert judgement, analytical assessment

To ensure a systematic approach and address all ATM system components and their complex relationships, the structure of this paper and our research follow the principle of ICAO's Global Air Traffic Management Operational Concept (Doc 9854 [1]), which defines seven components of the ATM operational concept (see Figure 1).

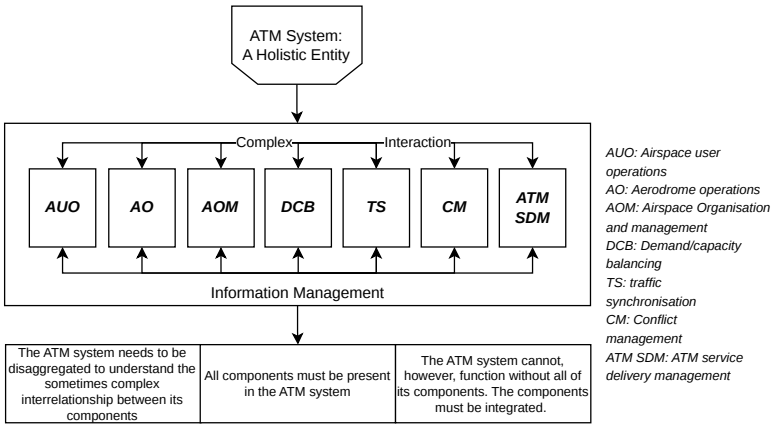


Figure 1: The seven ATM concept components on which this paper is based on. Own depiction based on ICAO's Global Air Traffic Management Operational Concept (Doc 9854) [1].

Leveraging this structure enables us to examine how IAM challenges the entire ATM paradigm. These seven ATM concept components are therefore applied to our research scope, and the original GATMOC structure is revised where necessary. Table 2 summarises the conceptual elements addressed in this paper.

This paper presents the results of the first European joint investigation into the safe

Table 2: IAM ATM/U-space concept components following ICAO GATMOC principles.

Concept Component	Topics Addressed	Section	Scope
Airspace User Operations	Background	2.1	Business Case
	Pilot in Command	2.2	System Design
	Operational Control Centre	2.3	System Design
	Flight Planning and Execution	2.4	Concept
Aerodrome Operations and Management	Background	3.1	Regulation
	Vertiport Location	3.2	Case Studies
	Vertiport Weather Systems	3.3	Case Study
	Vertiport Categories	3.4	Concept
	Vertiport Operating Systems and Management Tools	3.5	System Design
	Vertiport Network Operating Systems and Management Tools	3.6	System Design
Airspace Organisation and Management	Background	4.1	Regulation
	VCA Flight Procedure Design	4.2	Case Studies
	Vertiport Traffic Zone	4.3	Concept
Demand and Capacity Balance	Background	5.1	Regulation
	Vertiport Slot	5.2	Concept
	Vertiport Availability	5.3	Concept
Traffic Synchronisation	Background	6.1	Best Practice
	Vertiport Collaborative Traffic Management	6.2	Concept
	Vertiport Collaborative Decision-Making	6.3	Concept
	Local Vertiport Network Management	6.4	Concept
Conflict Management	Background	7.1	Regulation
	VCA Flight Plan	7.2	Concept
	Contingency and Disruption Management	7.3	Case Study
ATM and U-space Service Delivery	Background	8.1	Regulation
	Roles and Responsibilities	8.2	Concept
	Clearances and Authorisation for VCA	8.3	Concept
	ATC and U-space Handover	8.4	Case Study

and efficient integration of VCA and vertiports. It examines the operational challenges in various operating environments (see Table 1) and across national ATM and U-space implementations and multiple IAM business cases. It summarises the findings of three years of collaborative, multidisciplinary research across Europe and its lessons learnt.

Sections 1.2-1.5 introduce IAM in the European context. Sections 2-8 cover the seven concept components: airspace user operations, aerodrome operations and management, airspace organisation and management, demand and capacity balance, traffic synchronisation, conflict management, and ATM and U-space service delivery management, as introduced in detail in Table 2. The paper concludes with Section 9 and provides an outlook in Section 10 to guide future research and development. The European regulatory landscape related to VCA operations and VCA flight procedure design is outlined in Appendices A and B, respectively.

This paper is lengthy, and reflects the complexity of IAM research and development. Although each section can be read independently, we have intentionally kept all relevant concept components together to present a complete and coherent operational concept.

Where relevant, we reference applicable regulations, showcase system designs, conduct case studies, and outline recommendations for future research to help streamline the IAM development in Europe. Because this paper is the first of its kind, we encourage all readers to provide us constructive feedback, as such input is crucial for advancing the safe and efficient integration of new airspace users.

1.1 Guiding Principles

The guiding principles for EUREKA and this paper were based on three ICAO principles, extracted from the Global Air Traffic Management Operational Concept and Global Air Navigation Plan Strategy [1, 7]:

1. "Vision Statement: To achieve an interoperable global air traffic management system, for all users during all phases of flight, that meets agreed levels of safety, provides for optimum economic operations, is environmentally sustainable and meets national security requirements."[1]
2. "An operational concept is a statement of "what" is envisaged. It asks and answers the question of what outcomes are required in the case of the ATM system of the future. It is a vision statement. It is not a technical manual or blueprint nor does it detail "how" things will be enabled; that lies in a lower document in the hierarchy, which may include concepts of operation or use, technical standards and strategic plans."[1]
3. "[...] the entire focus will shift to who is best positioned and able to make decisions. Even with shared information, there are aspects of each flight that may be unique to the operator. Therefore, despite this pool of rich information, a situation in which only ANSPs make decisions based on inputs will be suboptimal. Processes and procedures will be developed to shift and enable the operator to manage the flight trajectory, while ANSPs focus on managing constraints and air navigation resources. With the move towards the Internet of things, information will no longer be the limitation, and the focus will shift to who can make the best decisions resulting in improvements to the total system performance. This will be possible because constraints will be minimised owing to the increased accuracy and availability of data, considering all inputs to the system and the absence of coordination limitations with everyone connected to the network."[7]

These guiding principles inform the primary objective of EUREKA: contributing to the long-term goal of *U-space 2.0*, as set out in the European ATM Masterplan 2025 Edition. U-space 2.0 "refers to the next evolution of U-space to fully integrate drone and ATM operations to support the scaling up of IAM and services"[5].

1.2 What is IAM?

The concepts of urban air mobility (UAM) and IAM have evolved from an initial wave of enthusiasm into a serious field of discussion on a global scale involving regulators, entrepreneurs, established aviation companies, and local communities. The European Union Aviation Safety Agency (EASA) framed the overarching category *IAM*, which is

defined as “the safe, secure and sustainable air mobility of passengers and cargo enabled by new-generation technologies integrated into a multimodal transportation system” [8]. Under this umbrella, *UAM* was characterised more narrowly as a “new air transportation system for passengers and cargo in and around densely populated and built environments” typically enabled by a new generation of VCA, either piloted or remotely piloted [9]. While the term UAM was predominantly used in literature and EASA documents until around 2022, IAM has been used more recently to acknowledge that VCA missions may benefit communities beyond pure urban environments.

However, the terminology remains inconsistent and is sometimes used ambiguously even within the most recent EASA documents. NPA 2022-06 [10] defines IAM as a subset of the broader term *IAS* (innovative aerial services), whereas the EASA IAM Hub [8], intended as a public information source, treats IAM and IAS as separate domains. Inconsistencies in terminology increase further when comparing international regulations and operational concepts. The U.S. Federal Aviation Administration (FAA), in alignment with the National Aeronautics and Space Administration (NASA), uses *advanced air mobility (AAM)* as its overarching term. “AAM is a transportation system that moves people and property by air between two points in the United States (U.S.) using aircraft with advanced technologies, including electric aircraft, or electric vertical take-off and landing (eVTOL) aircraft, in both controlled and uncontrolled airspace” [11]. UAM is considered a subset of AAM, corresponding to operations in dense metropolitan and suburban areas [12]. ICAO has also adopted the term AAM when establishing a dedicated study group in 2022 [13], signalling ongoing efforts towards internationally harmonised terminology, vision and rule making frameworks.

In this paper, IAM and IAS are considered as separate domains. EUREKA’s focus is on IAM, which involves the highly automated mobility of passengers and cargo between vertiports, regardless of location and operating environment.

1.3 What is a VCA?



Figure 2: Passenger-carying tiltrotor VCA, ©Wisk.



Figure 3: Cargo-carrying multicopter VCA, ©Pipistrel Vertical Solutions d.o.o.

Recent developments in air transportation, such as the introduction of VCA, have created a need for a clear and comprehensive regulatory framework for IAM. These new aircraft designs have unique characteristics relating to safety, certification, and operations, that are particularly relevant in densely populated areas. Their integration into existing airspace, traffic, and transport systems requires tailored regulations.

In response to this, on 10 April 2024, the European Commission adopted Commission Implementing Regulation (EU) 2024/1111. This regulation amends existing aviation legislation such as Regulations (EU) No 1178/2011 [14], No 923/2012 [15], No 965/2012 [16], and No 2017/373 [17] to introduce "requirements for the operation of manned aircraft with a vertical take-off and landing capability". The regulation came into force on 1 May 2025, allowing operators and authorities time to prepare [6].

Based on EASA's Opinion No. 03/2023, the regulation introduces new definitions and updates existing ones to reflect the operational and technical nature of these new aircraft types. It also outlines procedures for pilot licensing, air traffic integration, and safety management, to ensure that operations are conducted in a secure and orderly manner [6].

These changes are also reflected in the revised definitions of rotorcraft, helicopters and VCA provided in standardised European rules of the air (SERA) as set out in the Commission Implemented Regulation (EU) No. 923/2012 [15].

> *85. 'rotorcraft' means a power-driven, heavier-than-air aircraft that depends principally for its support in flight on the lift generated by up to two rotors;*
>
> *85a. 'helicopter' means a type of rotorcraft supported in flight chiefly by the reactions of the air on up to two power-driven rotors on substantially vertical axes;*
>
> *85b. 'vertical take-off and landing (VTOL)-capable aircraft (VCA)' means a power-driven, heavier-than-air aircraft, other than aeroplane or rotorcraft, capable of performing vertical take-off and landing by means of lift and thrust units used to provide lift during take-off and landing;*

The VCA definition excludes fixed-wing aeroplanes and rotorcraft such as helicopters because they rely on one or two rotors rotating on a vertical axis for operation. In contrast, VCA use separate lift or thrust mechanisms that are specifically designed for vertical movement during take-off and landing. The VCA definition captures innovative vertical-lift designs, such as multicopter vehicles and tilt-rotor aircraft, which differ fundamentally from conventional helicopters and aeroplanes. The VCA aircraft designs referenced in this study are displayed in Figure 2 and 3. Therefore, the VCA definition is broader than the "powered-lift" definition, which EASA discarded due to its narrow scope and lack of comprehensive certification provisions. Traditional two-rotor tiltrotor designs, such as the AW609, fall outside the scope of the current regulatory proposal. EASA intends to review tiltrotor-related rules during RMT.0731 Subtask 3. According to the proposed definitions, gyroplanes are classified as rotorcraft, and operational rules for gyroplanes will be developed under RMT.0731 Subtask 2.[18]

By adopting these definitions, distinguishing between VCA and helicopters/rotorcraft and expanding beyond the former "powered-lift" definition, EASA has supported this regulatory evolution by publishing acceptable means of compliance (AMC) and guidance material (GM) for VCA operations [18]. These regulatory references aim to ensure the safe integration of VCA into the ATM environment, support innovation and technological advancement, provide clarity for authorities, manufacturers, and operators, and enable the early adoption of IAM technologies. The AMC and GM cover operational aspects in various domains, including Air Operations (Air OPS), Flight Crew Licensing (FCL), and SERA. One notable outcome is the addition of Annex IX (Part-IAM) to Regulation (EU) No 965/2012, which specifically covers VCA operations. There also have been amendments to the AMCs and GMs of existing annexes. The guidance covers requirements that are specific to visual flight rules (VFR) VCA operations, including preflight planning,

vertiport availability and diversion locations, and energy management and reserves. These changes are also reflected in SERA, which makes clearer distinctions between previous operating methods and the new approaches designed for VCA. The aim is to integrate VCA operations into the ATM environment.

However, regulatory activities face both challenges and opportunities due to VCA's unique operational role and novel technology, which differ from those of traditional rotorcraft and aeroplanes. According to [19], the following characteristics may necessitate a revision of air traffic service provision:

- Distributed electric propulsion systems are central to VCA, offering redundancy and novel safety layers that traditional combustion engines in rotorcraft lack.
- Advanced flight control systems (fly-by-wire/fly-by-light) are necessary for VCA and present new certification and human factors challenges.
- Energy systems for VCA include batteries, hydrogen, and hybrid power sources, which require dedicated safety and operational considerations.
- High-volume urban operations necessitate strict safety standards to protect third parties.
- VCA are expected to emit less noise than traditional rotorcraft.
- Operations differ from those of conventional aircraft, impacting piloting techniques, endurance performance, infrastructure, ground handling, and flight and operating procedures.
    - Increasing automation will change the competencies and skill requirements of pilots.
    - Reduced endurance will limit operations, so aircraft must meet safety standards similar to those for helicopters.
    - Infrastructure requirements include vertiports, firefighting, fire protection, high-voltage energy grid connection, and security;
    - Ground handling requirements include battery recharge/exchange and emergency response;
    - Operational procedures include navigation procedures, the need to fly at low altitudes, flight rules, energy reserves, diversion, etc.
- Safely integrating new aircraft at scale requires coordinated standards across aviation domains such as airworthiness, operations, and traffic management.

1.4 What is a Vertiport?

Vertiports are officially classified within the EASA framework as a new, stand-alone type of infrastructure. This designation supports the needs of an emerging industry and addresses specific challenges such as urban airspace integration, implementation of digital services, VCA performance, and charging/re-fuelling. It also supports the value proposition of VCA passenger services, focused on time savings and an optimised passenger multi-modal transportation journey. EASA introduced the concept of vertiports in 2019 through the Special Condition for VTOL (SC-VTOL) [20]. Embedding vertiports within the scope of

the Basic Regulation aimed at preventing regulatory fragmentation across EU Member States, to ensure harmonisation and to support the development of the UAM ecosystem.

Initial groundwork for VCA was laid through EU-funded research programs such as SESAR and Horizon 2020, which explored operational and infrastructural requirements for VTOL aircraft. Project such as CORUS X-UAM, AIRmour highlight the need for vertiports but do not yet provide substantial technical requirements. EASA then launched consultations via SC-VTOL AMC and GM, the Notice of Proposed Amendment (NPA) for vertiports working groups. This led to the formal definition of vertiports [6]:

> *"An area of land, water, or structure used or intended to be used for the landing and take-off of VCA, and for the movement of VCA"*

Figure 4 represents one example of a vertiport displaying a dedicated pad for arrival and departure (includes touch-down and lift-off area (TLOF) and final approach and take-off area (FATO)), several stands connected through taxiways (here co-located with the gate), for passenger to board and de-board or cargo the be processed.

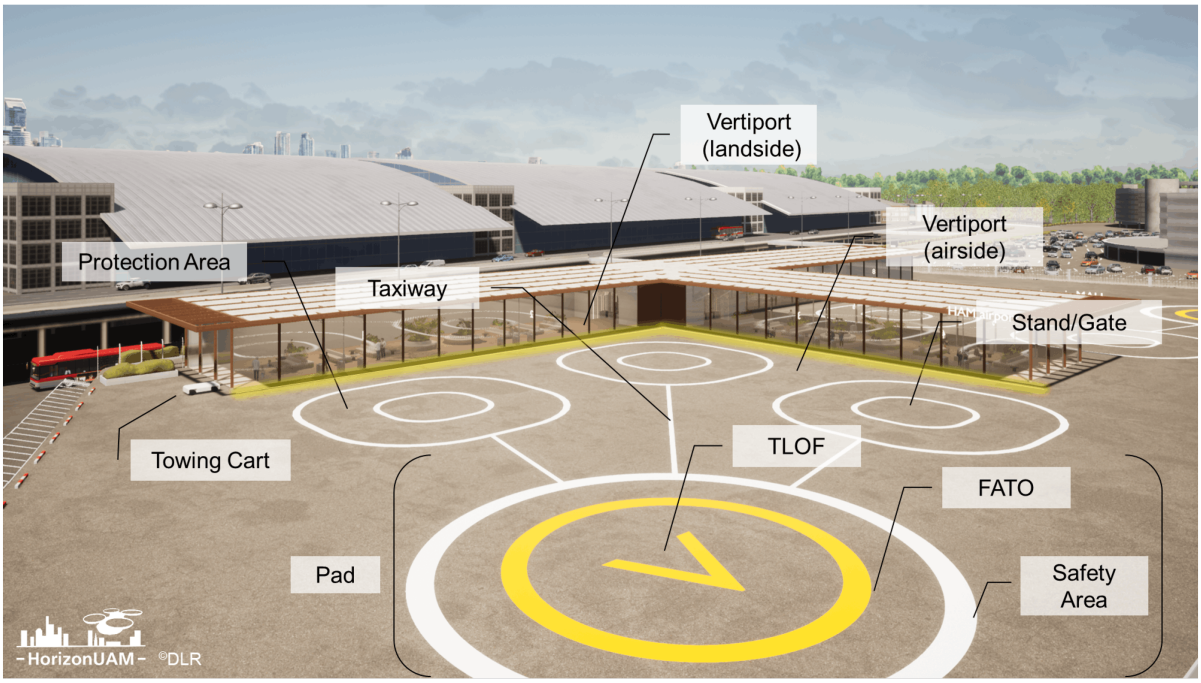


Figure 4: Vertiport example showcasing the different elements and terminologies used in the IAM context [2], ©DLR.

The vertiport definition is expanded in Annex II of ED Decision 2025/010/R and in the Prototype Technical Specifications for Vertiports (PTS-VPT-DSN) [3]. Now, vertiports are described as dedicated areas supplying the infrastructure needed for safe commercial air transport of passengers or goods, often designed under multi-modal transportation aspects and located either at ground level or on top of buildings. EASA has defined various types of VCA operations, ground-based, water-based, and elevated infrastructure, while mirroring the ICAO definition of a heliport, reinforcing international harmonisation.

The PTS-VPT-DSN introduces several VCA-specific provisions that distinguish vertiports from heliports governed by ICAO Annex 14 Vol II and EASA's HPT-DSN. A non-exhaustive summary is provided below:

– New definition of D-value (diameter of the smallest circle).

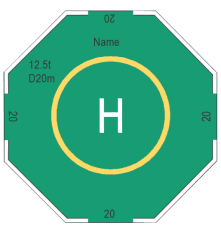
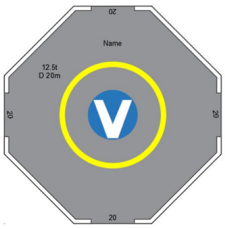
– Obstacle-Free Volume (OFV): a funnel-shaped 3D safety zone above the vertiport enabling omnidirectional vertical flight.

– Geometry-based stands.

– Infrastructure for electric propulsion (e.g., charging, re-fuelling, battery swap).

While EASA's design specifications reference ICAO Annex 14 Vol II (Heliport) [21], these standards may not fully reflect VTOL-specifics, such as quieter operations, the need for electric power supply, and multimodal integration. Also, VCA allow for vertical manoeuvrers over the final approach and take-off area (FATO), with less stringent requirements for obstacle limitation surface (OLS) compared to heliports. It should be noted that a given infrastructure may be designated as both heliport and vertiport, depending on the aircraft types it serves and the applicable regulatory framework it complies to. A high-level non-exhaustive comparison between the definition of heliports and vertiports is provided in Table 3.

Table 3: Non-exhaustive comparison of main heliport and vertiport characteristics.

Reference	**ICAO Annex 14 Vol II** [21]	**EASA PTS-VPT-DSN** [3]
Definition	An aerodrome or a defined area on a structure intended to be used wholly or in part for the arrival, departure and surface movement of helicopters.	An area of land, water, or structure that is used or intended to be used for the landing, take-off, and movement of VTOL-capable aircraft surface movement of helicopters.
Design parameter	'd' means largest overall dimension of the helicopter when rotor(s) are turning [...].	'D' means the diameter of the smallest circle enclosing the VTOL aircraft [...].
Design Surfaces	touch-down and lift-off area (TLOF), FATO, Safety Area specified	Adapted concepts; plus, funnel-shaped obstacle-free volume.
Infrastructure Needs	Basic: lighting, markings, rescue/firefighting	Expanded: charging, lounges, intermodal access, electrically tailored systems.
Marking		

Referring to helicopter operations, the FAA helicopter flying handbook recommends pilots to "always make the landing to a specific point and not to some general area. This point should be located well forward, away from the approach end of the area. The more confined the area is, the more essential it is that the helicopter lands precisely at a definite point. Keep this point in sight during the entire final approach. Use forward and lateral cues near the termination point to assist in maintaining the desired glidepath" [22].

VCA designs may challenge this practice which futher highlights that those reference dimensions used for heliport and vertiport design may differ between helicopter and VCA.

EASA addresses this challenge in ref. [3]: "For helicopter obstacle protection, the largest overall dimension of the aircraft is used when designing heliports. A key parameter for obstacle protection is however the diameter of the smallest enclosing circle as, by definition, it is the smallest circle in which the aircraft can fit, without hitting obstacles located outside the circle. [...] For helicopters, it does [...] not matter if referring to the largest overall dimension or the diameter of the smallest circle for obstacle protection, as they are equal. It is thus proposed to keep the existing definition for helicopters" which leads to the largest overall dimension that equals the diameter of the smallest enclosing circle. However, for VTOL aircraft, "if the largest overall dimension for obstacle protection is used, there could be a 15 % error in the unsafe direction". "For VTOL aircraft, the dimension D used for obstacle protection and vertiport design is thus defined as: 'D' means the diameter of the smallest circle enclosing the VTOL aircraft projection on a horizontal plane, while the aircraft is in the take-off or landing configuration, with rotor(s) turning, if applicable".

In summary, EASA's regulatory approach with respect to vertiports reflects an incremental strategy by issuing a prototype specifications before a full-scale rulemaking (RMT.0230), to allow for industry feedback and iterative refinement [23]. This contrasts with the FAA, which treats vertiports as an evolution of heliports under Engineering Brief 105A [24]. Unlike the FAA, whose interim guidance includes conventional rotorcraft, EASA maintains a clear distinction between VCA and traditional helicopters.

1.5 ATM and U-space Services for IAM

IAM demands safe, scalable and interoperable integration into existing and emerging airspace structures. In Europe, two regulatory frameworks, for ATM and U-space, describe the backbone of this integration, neither of which fully covers the low-level airspace layer where IAM operations such as air taxis and cargo VCA are expected to operate. In order for IAM to be operationally functional, VCA flights must respect existing responsibilities or follow new established ones, requiring interoperability between both frameworks. This includes potential coordination between the common information service provider (CISP), the U-space service provider (USSP), vertiport operators, the IAM operator (i.e. pilot in command (PIC) and operational control centre (OCC)) and traditional aviation stakeholders such as the airport operator and air traffic controller (ATCO).

Current air traffic services (ATS) are provided mainly in areas of higher traffic density where commercial aviation operates. IAM is targeting to bring commercial scale to operations in areas that are currently experiencing low traffic volumes, so that VCA flights can safely occur without increasing significantly the ATCO workload. Vertiport operations near airports further complicate air traffic control (ATC) oversight. This raises the central question of who should provide air traffic services and hold the legal authority and responsibility for controlling IAM flights.

The U-space airspace, established under EU Implementing Regulation 2021/664, is a digital and highly automated traffic management system designed for automated unmanned aircraft system (UAS) operations in very low level (VLL) airspace [25]. However, IAM is expected to broaden the application of U-space from its traditional VLL boundaries up to higher altitudes. The designation of U-space airspace offers dynamic airspace management,

the provision of real-time traffic information, geofencing, strategic conflict detection and resolution, capabilities potentially well suited for all low-level operations including VCA, general aviation, state operations and helicopter emergency and medical service (HEMS).

While the current U-space regulation focus on lightweight, remotely piloted and automated UAS operations with low kinetic energy and minimal risk, IAM also targets certified operations with heavier vehicles, referred to as VCA, carrying passengers and cargo over populated areas and critical infrastructure. As a result, these operations require more rigorous safety and performance standards, which are not yet addressed in the existing U-space regulatory framework. Most importantly, EU Implementing Regulation 2021/664 does not exclude certified operations, but lacks the necessary provisions and technical requirements to support them. In a future operating environment in which both frameworks, ATM and U-space exist (i.e. U-space airspace designation in controlled airspace), overlaps between ATM and U-space may create ambiguities in flight authorisation, conflict management, and traffic synchronisation.

In those sections of the paper that are U-space focused, we consider the following stakeholders as part of the IAM traffic management ecosystem: *VCA PIC*, *VCA operational control centre (OCC)*, *the CISP*, *the USSP*, the *vertiport managing entity*, and a potential *local vertiport network managing entity*. All these stakeholders have a different but interdependent role, all together ensuring flexibility, efficiency and, first and foremost, safety of IAM operations.

- The VCA pilot in command is responsible for performing all on-board operations according to the flight plan.
- The VCA operational control centre is responsible for defining safe minimum operating altitudes, preparing, submitting and filing the required flight plan, and ensuring compliance with U-space and ATS airspace rules prior to flight. During the flight, the OCC monitors and manages the flight, maintains communication, and ensures that all necessary technologies and procedures are in place for safe and compliant IAM operations.
- The USSP provides a set of fundamental U-space services, such as flight authorisation, geo-awareness, traffic information, and network identification. Although USSP services were initially created to support small unmanned aircraft systems (sUAS) operations, more rigorous performance standards are required for VCA.
- The vertiport managing entity can fulfil a multidisciplinary role, acting as both the infrastructure operator and as the local VCA ground traffic controller, overseeing all ground operations. With the appropriate certified digital platforms and data exchange facilities, they can assist with tactical flow control, such as departure sequencing and ground resource coordination, based on the principles of collaborative decision-making and total airport management.
- If in place, the local network vertiport managing entity, provides a governance level at a municipal or a regional level. This entity can be considered the operational agent of a vertiport network operated by the same entity.
- The common information service (CIS) is the single source of truth providing access to relevant aeronautical information for a designated U-space airspace (see Article 5 of [25]). This data can be shared from a single source (single CISP) or from

different sources (non-single CISP) and includes both static and dynamic aeronautical information, such as aeronautical information publication (AIP), notice to air missions (NOTAM), dynamic airspace reconfiguration (DAR). This data-sharing stakeholder is essential to ensure a streamlined and trustworthy operational image including vertiports, within the U-space airspace and among all IAM and ATM stakeholders.

The proposed concepts were developed iteratively across the EUREKA consortium and evaluated through three complementary methods: expert judgement, fast-time simulation (FTS), and real-time human-in-the-loop simulation (RTS). Expert judgement was used to assess regulatory gaps and operational feasibility across all concept areas. FTS was applied to evaluate separation safety, vertiport (network) throughput, and trajectory design at scale. RTS was used where human-machine interface design required operational validation with live participation. These methods were applied in the context of the three case studies described in Table 1, to ensure that the proposed concepts are based on representative European operating environments.

IAM introduces a new operational paradigm to an airspace layer that is currently underserved. This means that existing ATM and U-space structures must evolve to accommodate certified, commercial VCA operations, and eventually operations without a pilot on board. In the following sections, we will explore possible ways to integrate and share vertiport-related information within ATM and U-space. This will be the first step towards enabling VCA operations in the future.

2 Airspace User Operations

"Airspace user operations refer to the ATM-related aspect of flight operations."[1] Key conceptual changes include, among others, accommodation of mixed capabilities to enhance safety and efficiency; relevant airspace user operational information will be made available to the ATM system, and collaborative decision making.

2.1 Background

The most promising business case within the emerging landscape of urban and regional air mobility is a MVCA airport shuttle (also referred to as "air taxi") operating under both VFR and IFR, and cargo operations [26, 27].

An airport shuttle is a short-range, high-frequency transport between airports, city centres and business districts, leveraging the vertical take-off and landing capabilities of VCA. This aims to strengthen multimodal, and low-emission transport objectives within future smart and sustainable cities [28]. Initially, air taxi operations are expected to operate with a pilot on board (i.e. MVCA) and then transition to remotely piloted and autonomous operations (i.e. UVCA)[28]. The MVCA airport shuttle presents several business opportunities. It can complement existing transport modes, such as road, rail, and tram networks, by adding an aerial component to the transportation network. Compliance with VFR and IFR procedures in urban airspace is complex and subject to ongoing regulatory development. Additional infrastructure requirements, serving the required fast-charging energy supply and suitable communication navigation and surveillance (CNS) equipment to allow low altitude, urban IFR, will demand additional investment. Additional challenges include vertiport location, airspace integration, and adapting existing procedures to VCA operations, especially when an operation near airports is planned [29].

In addition to the airport shuttle use case, drones have presented themselves as relevant means for cargo deliveries. According to market research by Grand View Research [30], this sector may reach EUR 16 billion, driven by rapid, efficient transport of medical supplies, e-commerce products, agricultural crop sprays, spare parts and emergency goods. The global logistics market, valued at USD 3,794.4 billion in 2023, is expected to grow at 7.2% Compound Annual Growth Rate between 2024 to 2030. Cargo drone delivery offers rapid response capabilities at much lower operating costs than existing helicopters while providing greater payload and volume than most small drones provide. Large cargo drones can support search and rescue, humanitarian aid, disaster relief, offshore logistics, ship to shore operations and defence logistics.

The implementation of both business cases and their associated operational concept present both challenges and opportunities across regulatory, operational, social, environmental and economic domains. From a regulatory perspective, current frameworks do not yet facilitate such operations, as technology developments and user needs are growing faster than rulemaking; however, this also creates opportunities to shape regulations that support safe and efficient operations for a diversity of airspace users and enable vertiport network development.

Operationally, the introduction of new airspace users requires managing the synergy between manned and unmanned operations and the adherence to existing flight rules, airspace classifications, crew training requirements, while maintaining safe and efficient

operations. At the same time, the variety of drones and VCA can complement each other, improve service quality and strengthen economic potential.

Social and environmental aspects are more complex to anticipate, as increased use of unmanned, automated, and autonomous aircraft may raise concerns about noise, visual impact, privacy, and safety and security, which could lead to societal resistance. Yet, these new entrants also offer opportunities for more affordable, sustainable, and reliable services, even allowing for service delivery in unfavourable operational conditions. The SESAR project ImAFUSA is thoroughly researching the social impact of these new entrants and all research results can be found in [31].

Economically, although substantial investment is required to develop and implement vehicles and supporting infrastructure, the resulting competition and technological advancements have the potential to improve service availability and reduce the cost of applications such as humanitarian aid, search and rescue, and broader logistic operations.

In the following sections, as part of the Airspace User Section, we introduce the role of the VCA PIC, the OCC and how VCA flight planning and execution may be conducted. This should provide a general summary of how we envision VCA operations from an airspace user perspective.

2.2 VCA Pilot in Command

From take-off to landing, the PIC performs all on-board operations according to the flight plan and ensures that the aircraft is electronically conspicuous to the air navigation service provider (ANSP) while flying under ATC. Throughout the flight, the PIC establishes and maintains two-way communication with the ANSP when necessary, and maintains two-way communication (datalink or voice) with the OCC. A common phraseology for all voice communication must be established and agreed on with the OCC and ATC. The PIC also ensures compliance with ATC clearances and instructions according to the airspace class and the applicable rules of the air. Minimum flight altitudes must be established to provide the required vertical clearances from terrain and obstacles in line with the applicable requirements defined in ref. [6]. This responsibility lies either with the IAM operator (i.e. OCC) or the IAM pilot directly depending on the operational business setup. Throughout all phases of the flight, the PIC is responsible for performing all required on-board operations.

In Figure 5, the human-machine interface (HMI) of the PIC working position that was used during validation exercises of Case Study I is displayed. The PIC HMI is designed to support the supervision of multiple VCA flights through a single operational interface. The PIC can monitor and control several assigned flights at the same time, in this use case, up to three airborne aircraft simultaneously. The interface allows the PIC to select the flight to be supervised through a flight selection menu located in the dashboard. By selecting a flight from this menu, the display focuses on the chosen aircraft and presents the relevant operational information for that flight.

Once a flight is selected and the operation is active, key flight information becomes available on the PIC HMI including the VCA callsign, altitude (ft), ground speed (kts), heading (deg), remaining battery (%), and VCA status. These values are updated in real-time so that the PIC can maintain awareness of the VCA's current condition and performance.

The interface also provides a visual representation of the operational environment along with the surrounding VCA traffic to support situational awareness. Routes, waypoints,



Figure 5: HMI of the VCA pilot in command working position developed for R&D purposes, ©Wisk.

FATOs, and potential diversion locations are displayed to give the PIC a clear understanding of the current situation and available alternatives. To further assist with traffic awareness, the PIC HMI has a radar display centred on the selected aircraft. The display shows surrounding traffic within a 5 NM outer radius and a 2 NM inner radius, allowing the PIC to understand the relative positions of nearby VCA and other relevant airspace elements. The information shown on the display is based on surveillance data provided to the aircraft rather than solely on onboard sensing capabilities.

A notification system is integrated into the interface for abnormal or faulted conditions[1]. When a contingency occurs, the HMI shows a red alert notification indicating that pilot action is required. This notification remains visible until the PIC takes action, ensuring that the condition is clearly highlighted and cannot be overlooked. If another flight is selected from the list, a smaller notification on top remains visible, reminding the PIC that one of the flights is under a contingency and requires action.

In addition to monitoring functions, the HMI provides several intent-based actions that allow the PIC to intervene when necessary. Through the command panel, the PIC can initiate a missed approach procedure, command a diversion to a predefined location, or enter target values for altitude, speed, and heading. These actions allow the PIC to provide operational guidance to the VCA while maintaining awareness of the surrounding traffic and environment. Apart from that, each action is logged right after activation, which allows the system to keep track of operational events and maintain a record of the actions taken.

The PIC HMI enables the PIC to monitor and control multiple VCA operations from a single working position. By integrating flight monitoring, traffic information, critical notifications, and intent-based interaction capabilities, the interface allows the PIC to maintain situational awareness of ongoing operations and take actions when required.

[1]For a full definition of the operational condition categories, please visit Section 7.3.1

2.3 IAM Operational Control Centre

The IAM OCC (also referred to as VCA or IAM operator) is responsible, during pre-flight, to establish minimum flight altitudes that ensure the required vertical clearance from terrain and obstacles in accordance with the applicable requirements. This includes generating an operational flight plan (OFP) or submitting an ATS flight plan as required by the airspace class and the applicable rules of the air [6], and submitting the flight authorisation request (eventually defined as U-plan) as required by the USSP. From take-off to landing, the OCC must execute and monitor the flight according to the approved trajectory, react to changes (e.g. vertiport availability changes), establish and maintain a direct two-way communication with the ANSP and USSP, ensure the aircraft is continuously electronically conspicuous to the ANSP while flying under ATC (and recommended for the entire flight time), and continuously be electronically conspicuous to the USSP while operating in U-space, while also maintaining communication with the VCA PIC. At anytime, the OCC must comply with the certification requirements necessary to operate.

Figure 6 presents the HMI of the OCC working position that was used during the validation activities for Case Study I. The HMI is designed for supporting the OCC in supervising VCA operations in real-time under normal, abnormal, and faulted conditions. It combines flight monitoring, schedule-related information, booking functions, and vertiport status information within a single operational view.

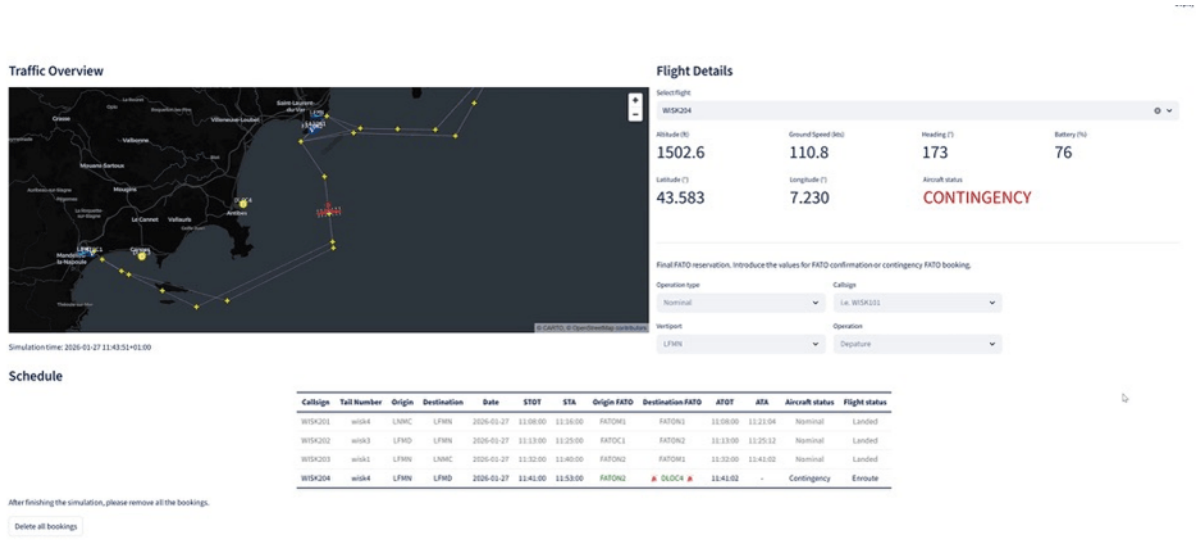


Figure 6: HMI of the operational control centre working position developed for R&D purposes, ©Wisk.

For each flying VCA, the OCC HMI provides key operational data including the VCA callsign, altitude (ft), ground speed (kts), heading (deg), latitude (deg), longitude (deg), battery left (%), and VCA status (i.e. its operational condition). This information is updated continuously so that the operator can follow the current condition of the aircraft during the flight. When an abnormal or faulted condition occurs, the VCA status changes to CONTINGENCY and is highlighted in red.

The HMI also provides a map-based view of the operational environment including routes, waypoints, FATOs, diversion locations, and real-time aircraft positions, to support the monitoring of VCA flights. This allows the OCC to maintain situational awareness and support the PIC when needed throughout the operations. If any VCA is under

CONTINGENCY status, it is also displayed in red on the map to highlight the situation.

In addition to the map display, the OCC HMI includes a table with flight schedule information such as scheduled take-off time (STOT), scheduled time of arrival (STA), and the origin and destination FATOs. This part of the interface supports the operator in following the planned movement of flights and checking the related scheduling information in parallel with the live operational view.

The OCC HMI also provides functions that allow the operator to perform pre-booking, booking, and contingency booking actions. When the operator performs the pre-booking of the FATOs, the name of the FATO appears in orange in the schedule table. After the booking is confirmed, the FATO name changes from orange to green. In case of contingency booking, the name of the destination FATO changes to the diversion FATO name, still shown in green, and two alarms are displayed on both sides of the name.

Finally, the OCC HMI provides information on FATO availability status received from the vertiport operator. The FATO symbol is shown in blue on the map when the FATO is available and turns red when it becomes unavailable. The same status change is also reflected in the schedule table, where the name of the unavailable FATO turns red.

The OCC HMI allows the OCC to carry out flight planning, fleet management tasks, and real-time response to abnormal and faulted conditions from a single working position. By combining flight monitoring, schedule information, booking functions, and FATO availability status under one interface, the HMI enhances operational awareness and allows the operator to respond effectively when needed.

2.4 Flight Planning and Execution

During the flight planning, the PIC is required to establish the legality of the intended operation in accordance with the operations manual, based on authoritative meteorological data. This process includes the consultation of area forecasts issued by national weather services and Meteorological Aerodrome Report (METAR)/Terminal Area Forecast (TAF) reports from nearby aerodromes.

However, meteorological conditions at the take-off, diversion, and destination vertiports may deviate from those reported by authoritative sources due to:

– Geographical separation from reporting stations.

– Localised phenomena such as orographic amplification of wind speed.

To address these discrepancies and enhance situational awareness, the pilot supplements authoritative data with vertiport-specific weather observations and forecasts. These localised inputs delivered via integrated vertiport systems, enable the pilot to construct a comprehensive mental model of prevailing and anticipated weather conditions at all relevant locations. This fusion of data sources supports informed decision-making and contributes to the overall safety and compliance of the operation. Figure 7 provides an overview of weather information requirements across all flight phases.

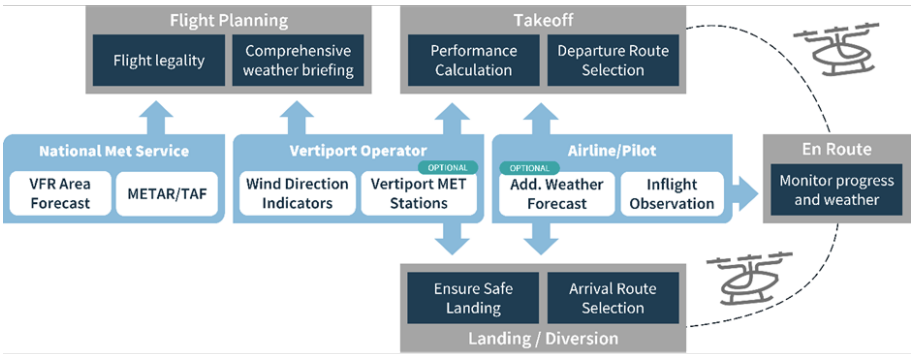


Figure 7: Weather information for VFR VTOL operators in all flight phases.

For the determination of take-off direction and departure routing, the PIC will base performance calculations on localised weather observation data provided by the vertiport. The method of data acquisition is contingent upon the operator's IT infrastructure and may include:

- VHF broadcast directly from the vertiport.
- Weather Information System as software as a service (SaaS) application accessed via mobile device.
- Operator-specific electronic flight bag software interfaced with Weather Information System via application programming interface (API).

Figure 8 illustrates the weather data sources and communication channels available for vertiport operations.

All data sources are to be cross-validated against METAR reports from proximate aerodromes and visual indicators such as the windsock installed at the FATO. In accordance with regulatory guidance and original equipment manufacturer performance documentation, steady wind components shall be corrected using standardised factors that are 50% for headwind and 150% for tailwind. These corrections are applied through operator procedures and embedded within certified performance calculation tools. Certification requirements ensure that VCA maintain adequate controllability under gust conditions, thereby supporting safe and compliant take-off operations.

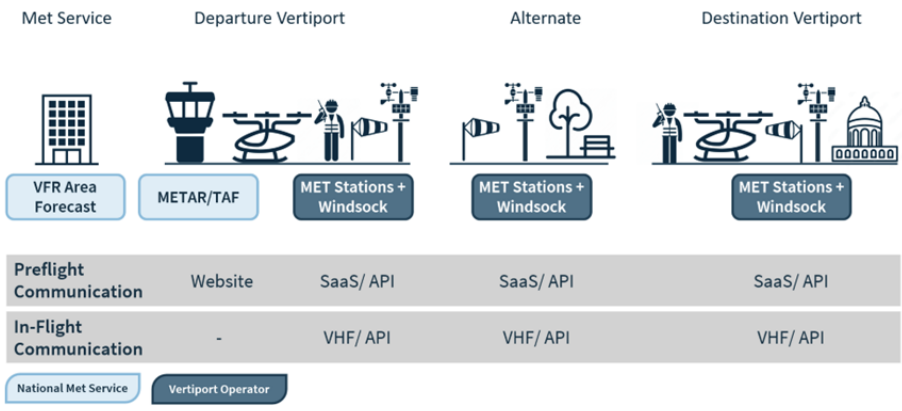


Figure 8: Weather data and communication channels for vertiports. very high frequency (VHF), application programming interface (API), software as a service (SaaS).

In the en-route phase, although no specific wind limitations are imposed, wind remains a significant factor influencing energy consumption. The PIC is required to monitor actual flight progress against the planned trajectory in accordance with the operations manual. For short-range operations, typically around 15 km in distance and 15 minutes in duration, weather deterioration is assessed visually during the flight.

For extended-range missions or longer flight durations, visual observation alone is insufficient. In such cases, additional capabilities are required to evaluate the impact of weather conditions throughout the flight. These may include real-time data feeds from onboard systems, integration with vertiport weather services via an API, and the use of flight trajectory predictions to assess evolving meteorological influences on aircraft performance and energy reserves.

For landing and diversion, weather conditions for approach and landing will be made available to the pilot in-flight either via very high frequency (VHF) from the vertiport, or through operator-specific software applications connected to the vertiport meteorological service via an API to confirm the arrival route/direction of landing. In addition, the pilot may consult the windsock on final approach.

In case of a diversion during the initially planned operation, the pilot will determine the arrival route and landing direction using the weather information available shortly before take-off, which will be no more than 15 to 20 minutes old, and the windsock on final approach.

3 Aerodrome Operations and Management

"As an integral part of the ATM system, the aerodrome operator must provide the needed ground infrastructure including, inter alia, lighting, taxiways, runways, including exits, and precise surface guidance to improve safety and maximize aerodrome capacity in all weather conditions. The ATM system will enable the efficient use of the capacity of the aerodrome airside infrastructure." [1].



Figure 9: Pianabella test vertiport in Rome Fiumicino vertiport, ©UrbanV.

3.1 Background

The integration of vertiport operations into and close to airport environment requires a re-evaluation of roles among traditional aerodrome stakeholders and potentially new actors. These roles and responsibilities must be harmonised with legacy ATM stakeholders to ensure seamless integration with existing airside and landside operations. As VCA and vertiport operations grow in traffic density, structured interactions become essential to secure safety, efficiency, and IAM service quality. Key stakeholders include the vertiport operator, responsible for infrastructure management and airside ground processes, the local vertiport network manager (L-VNM), acting as a potential central role coordinating flow and capacity across a vertiport network; and legacy ATC or third party entities eventually tasked with traffic management and control at vertiports.

Our proposed approach is based on collaboration between stakeholders rather than reallocating the responsibilities. Airport operators remain guarantors of infrastructure safety and continuity, while digital and procedural service providers contribute new capabilities for data exchange, traffic coordination, management and control. Standardised interfaces, shared situational awareness, and collaborative decision-making frameworks are critical to the successful coexistence of vertiport operations with conventional airports.

For IAM, a number of initial decisions guide and influence vertiport operations. These include where the vertiport is located relative to the airport infrastructure and conventional

IFR traffic, how it is operated under prevailing meteorological weather, and how vertiport (network) resources are managed, allocated, and monitored. Section 3.2 examines vertiport location constraints through three case studies covering meteorological usability, loss of separation and collision risk from conventional IFR traffic, and airspace containment analysis. Section 3.3 addresses the sensor and information infrastructure required to support VCA weather assessment at vertiports, including the regulatory framework for certified meteorological data. Section 3.4 introduces a conceptual vertiport categorisation framework based on operational capability levels. Sections 3.5 and 3.6 describe the digital operating and management systems needed for single vertiports and for coordinated network-level operations.

3.2 Vertiport Location

As outlined in Section 2, the airport shuttle is one of the most relevant use cases. However positioning a vertiport in close proximity to active runways of an airport poses considerable challenges, especially if the vertiport is intended to operate independently without interfering with IFR traffic streams. This is why thorough investigation is necessary to identify the most suitable vertiport location, with safety representing the primary determining factor. The following sections provide an overview of selected case studies that contribute to this assessment.

3.2.1 Case Study II: Loss of Separation and Collision Risk

To determine the right vertiport locations at an airport with respect to runway operations, the likelihood of loss of separation (LOS) between VCA and conventional traffic is analysed. Vertiport locations are classified as acceptable if a VCA departing from or arriving at the considered vertiport location has a collision risk below the target level of safety (TLS) of 10^{-7} collisions per flight hour, with conventional aircraft operating on the runway; this TLS is suggested by Howard [32] in 1992, which has been achieved by aviation in the last 15 years [33]. For the analysis of Case Study II, several Monte Carlo simulations have been conducted to quantify the collision risk associated with LOS events.

The risk of collision is obtained based on the Reich Model [34], where the frequency of LOS is multiplied by the probability (P) of collision (col) in case of LOS.

$$\text{Risk}_{\text{collision}} = \text{Frequency}_{\text{LOS}} \times P_{\text{col/LOS}} \tag{1}$$

Probability of collision given LOS is estimated through Monte Carlo simulations for four different ranges as 0-50, 50-250, 250-500, and 500-1000 metres (m). The considered ranges indicate various severity levels based on proximity. Table 4 summarises the maximum acceptable LOS rate for each range.

These analyses are conducted in Palma de Mallorca Airport for finding acceptable vertiport locations that can operate independently from runway operations. First, eighteen potential vertiport locations are selected as displayed in Figure 10. Fifteen of the initial locations are placed in rows parallel to the 06L/24R runway with 200, 350, and 500 m distances. The rest of them are located in between the two runways.

For each candidate vertiport location, various trajectories are generated with one-second intervals. Those trajectories consist of 1000 random VCA positions considering navigation system errors and flight technical error [35]. Each sampled VCA trajectory based on those 1000 random points is then compared in terms of separation distances with historic

Table 4: Case Study II: Collision probabilities and acceptable LOS rates based on range.

Range (m)	Prob. of Collision	Effect	Max Acceptable LOS Rate/FH
0–50	1/3	Near collision	3.5×10^{-7}
50–250	1/200	Near misses and wake turbulence	2×10^{-5}
250–500	1/2000	Close traffic	2×10^{-4}
500–1000	1/10000	Loss of separation	1×10^{-3}

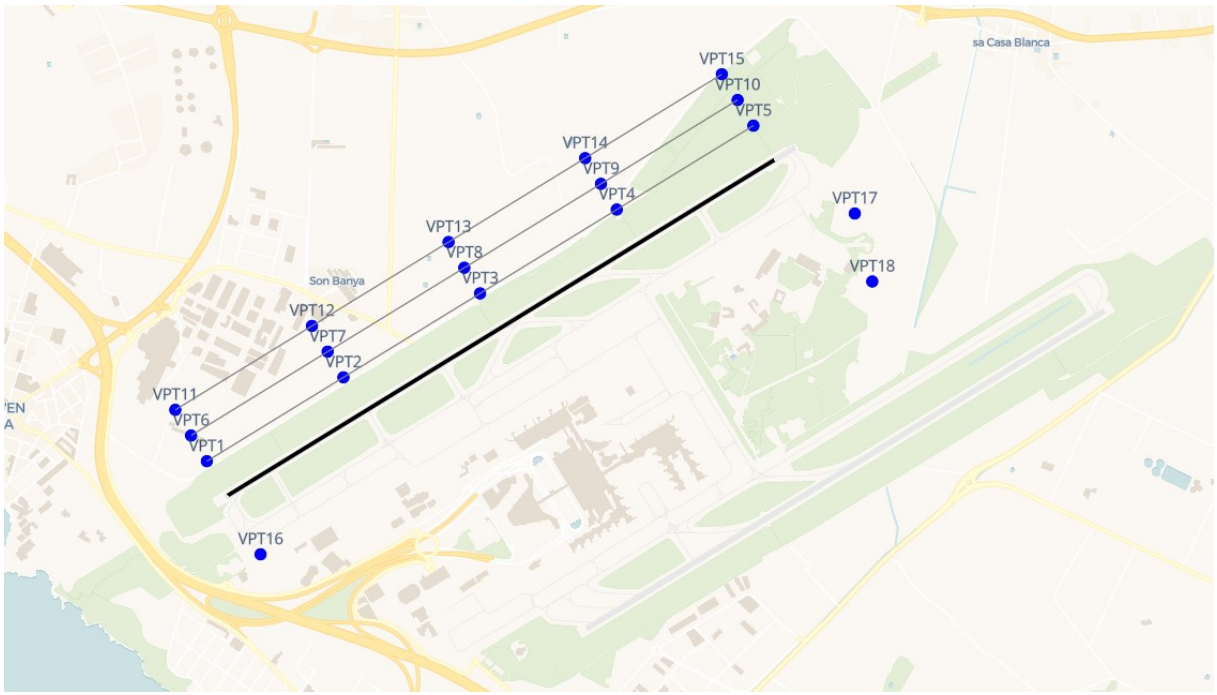


Figure 10: Case Study II: Vertiport locations evaluated at Palma de Mallorca Airport.

conventional traffic track reports for January 2024 which is provided by the Spanish air navigation service provider. The traffic density is shown in Figure 11.

After the separation distances are obtained, the number of conventional aircraft positions falling within the predefined ranges is counted for each sampled point along the VCA trajectories. To calculate the probability of collision, the total number of occurrences is divided by the total number of Monte Carlo iterations and by the potential number of aircraft tracks received over one month. An aircraft track is assumed to be generated every 2.5 seconds over one "simulation month"[2]. In that way, the instantaneous probability associated with each of the N sampled points along the trajectory is obtained.

$$\text{Prob}_{\text{sample}} = \frac{N_{\text{manned ac in } d_{\min}<D<d_{\max}}}{1000 \text{ iterations} \times \text{Minutes}_{\text{month}} \times \frac{60}{2.5} \text{ tracks/minute}} \tag{2}$$

Then the total LOS frequency is calculated for each trajectory in events per flight hour. Figure 12 shows the LOS probabilities obtained for each sample in the different candidate vertiports and outbound trajectories considered at Palma de Mallorca Airport.

[2]30 days x 24 hours x 60 min x 60/2.5 tracks per min

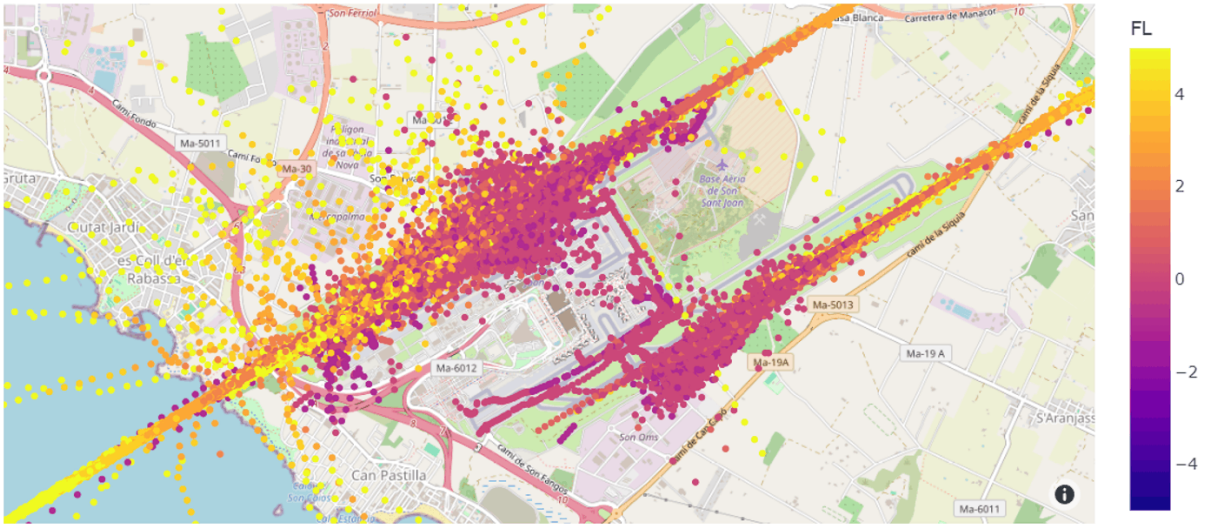


Figure 11: Palma de Mallorca Airport traffic density in January 2024.

$$\text{Freq}_{\text{LOS}} = \frac{\sum_{j=1}^{N} \text{Prob}_{\text{sample}_j} \cdot dt}{N \cdot dt} \cdot \frac{3600\,seconds}{1\,hour} \tag{3}$$

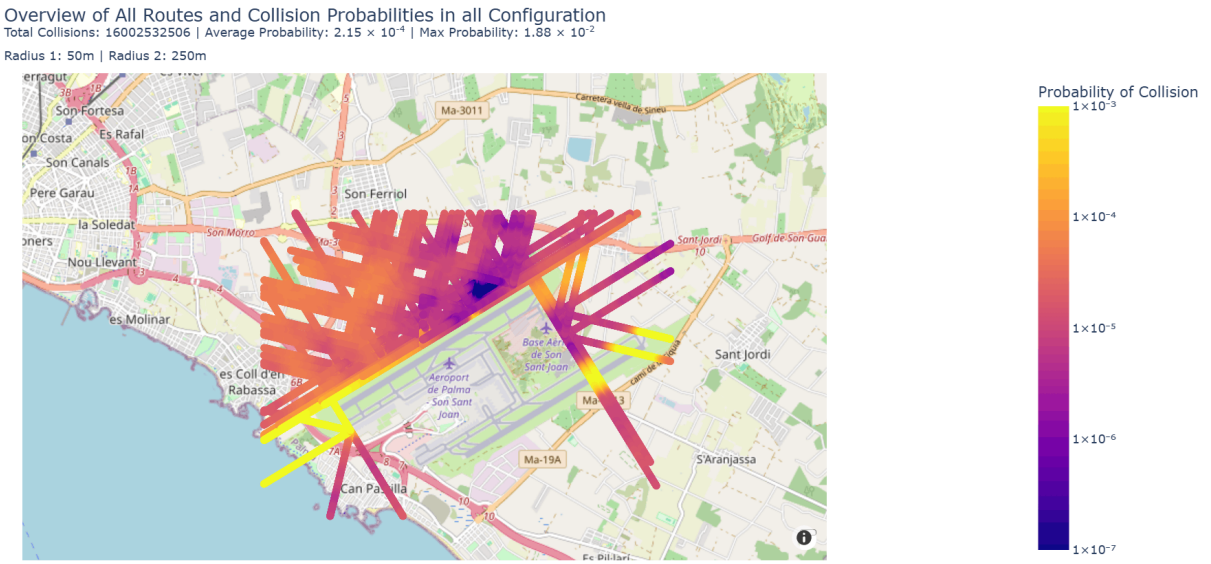


Figure 12: Case Study II: LOS probability per sample.

These results are used to identify the vertiport with the lowest LOS frequency and compare that value against the maximum acceptable rates given in Table 4. Table 5 summarises the overall comparison of the obtained results. The results suggest that a vertiport located closer than 500 m from the runway cannot operate independently from the airport operations in this particular operational environment. Additionally, the results for the vertiports located at 500 m show a small reduction in LOS frequency compared to the locations closer to the runway which indicates that the independent operations may require a range greater than 2000 m.

Table 5: Case Study II: LOS range and LOS frequency per flight hour for different vertiports.

Parallel Group	**Distance**	**LOS Range (m)**	**Best Vertiport**	**FreqLOS/FH**	**Acceptable**
200		0-50	VPT5	1.47×10^{-5}	NO
200		50-250	VPT5	3.63×10^{-3}	NO
200		250-500	VPT5	4.87×10^{-1}	NO
200		500-1000	VPT5	1.65	NO
350		0-50	VPT10	1.43×10^{-5}	NO
350		50-250	VPT10	4.48×10^{-3}	NO
350		250-500	VPT10	7.09×10^{-2}	NO
350		500-1000	VPT10	1.57	NO
500		0-50	VPT15	1.24×10^{-5}	NO
500		50-250	VPT15	4.48×10^{-3}	NO
500		250-500	VPT15	2.39×10^{-2}	NO
500		500-1000	VPT15	1.42	NO
Non parallel locations		0-50	VPT16	6.78×10^{-5}	NO
Non parallel locations		50-250	VPT18	1.18×10^{-2}	NO
Non parallel locations		250-500	VPT18	5.63×10^{-2}	NO
Non parallel locations		500-1000	VPT17	2.03	NO

3.2.2 Case Study III: Loss of Separation between VCA and IFR Arrivals

In order to determine whether the considered routes are feasible for MVCA operations, once the preliminary vertiport location is selected, IFR arrival trajectories at the considered airport are analysed. In this Case Study, the MVCA routes are considered acceptable if there is no significant overlap between the evaluated conventional aircraft trajectories and the designed MVCA routes.

For this case study, potential routes for MVCA airport shuttle operations between Rome Fiumicino Airport and the city centre of Rome are considered. The vertiport at the airport is placed around 250 m away from the 16L/34R runway[3]. Therefore, it is important to identify where exactly conventional arriving traffic operates in the terminal airspace.

The footprint of the arrival trajectories is captured using *containment boundaries* which define statistical volumes to represent the parts of the airspace used by flights [36]. The containment boundaries are obtained for the arrivals at Rome Fiumicino Airport for November 2024. Trajectory data used for analysis is retrieved from FlightRadar24. The trajectories of flights arriving at each runway and the corresponding containment boundaries are illustrated in Figure 13.

[3]Please visit Section 4.2 for further reference on the selection of 250 m.

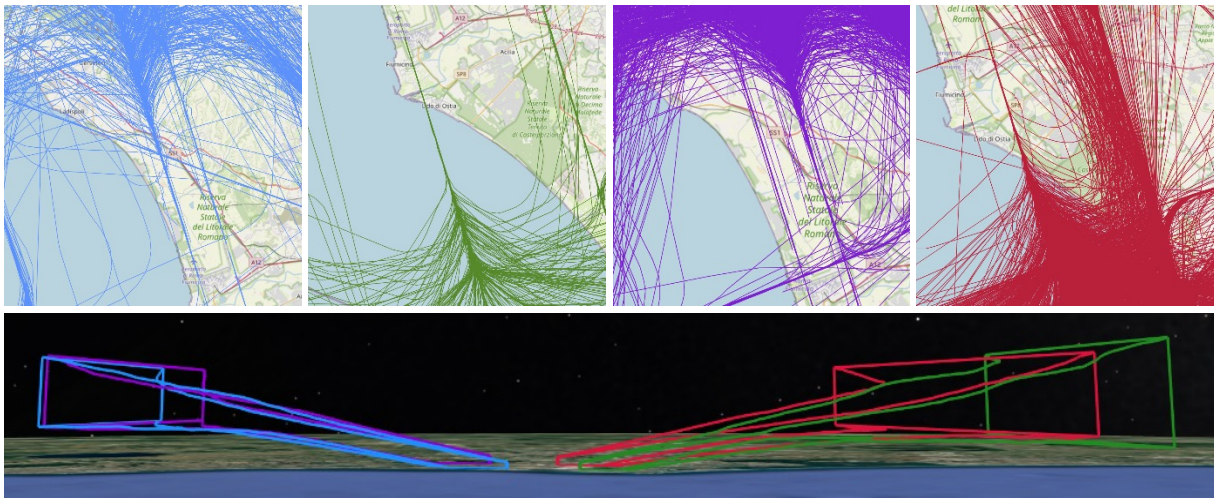


Figure 13: Case Study III: Rome Fiumicino Airport arrival trajectories for November 2024 at each runway and the obtained containment boundaries. Runway 16L (purple), Runway 16R (blue), Runway 34L (green) and Runway 34R (red).

Containment boundaries are prepared step by step as follows:

1. **Runway assignment:** Since the FlightRadar24 data does not include runway information, first, each conventional flight is assigned to a runway.
2. **Touchdown identification:** The touchdown point of each flight is identified. If this point cannot be determined from the data, the flight is excluded from the analysis.
3. **Trajectory normalisation and statistical processing:** The flight data is normalised in order to compute the mean trajectory and the corresponding percentile boundaries. This process consists of the following steps:
   (a) Each flight is indexed starting from a point approximately one minute before touchdown. The subsequent indices are assigned based on the time difference.
   (b) Since flight positions are not available at every timestamp, the missing points are interpolated.
   (c) The timestamp at which the flight crosses the beginning of the runway is then identified.
   (d) The indexing is redefined such that the runway-crossing point becomes the reference point.
   (e) At each index, the mean and percentile values of altitude, latitude, and longitude are calculated. This computation is performed only for indices up to five minutes before the flight crosses the beginning of the runway.

Based on the containment boundary analysis, conventional traffic was found not to interfere with the MVCA routes as shown in Figure 14. Therefore, MVCA operations can be accommodated within the same airspace as the existing traffic in the considered operational environment based on this particular constraint. The same methodology can also be applied to different operational environments where such an analysis is required to support the safe integration of VCA flights.



Figure 14: Case Study III: Rome Fiumicino Airport containment boundaries for each runway along with designed VCA prescribed-VFR routes.

3.2.3 Case Study III: Vertiport Usability

Once a preliminary vertiport location is selected and the VCA trajectories defined, vertiport usability can be assessed. *Vertiport usability* is defined as the percentage of time a vertiport is operationally available for VCA. It plays a central role in ensuring safe and efficient operations. In EASA's prototype design specifications for vertiports, a minimum usability target of 95% was set [3]. The following Case Study, that builds on Section 3.2.1, examines how meteorological conditions, particularly wind, affect the usability of vertiports and the layout planning for approach and departure paths. Based on the EASA guidelines given in the prototype specifications, which recommend multiple approach and departure surfaces with an angular separation between 135°and 180°, a methodology is presented to assess whether a given site can meet the usability threshold under local wind conditions. The approach combines the analysis of historical wind data with a geometric assessment of flight path orientations. The results of the study underline the importance of taking meteorological analyses into the early stage of the vertiport design.

Weather, especially wind conditions, have a significant impact on the planning of approach and departure paths as well as on the location selection of vertiports. For reliable and safe operation, it is essential to have detailed knowledge of the local wind patterns. The prevailing wind directions at potential vertiport locations influence the orientation of flight paths. In addition, crosswinds and gusts can restrict operating windows or require additional buffer zones. As part of the EUREKA project, a methodological framework was developed to assess not only the general usability of vertiports, but also the specific usability of individual approach and departure tracks. To assess compliance with EASA usability requirements, a comprehensive study was conducted using five years of historical weather data (2019–2023) for the considered vertiport locations in the area of Rome. High-resolution model output from the European Centre for Medium-Range Weather Forecasts with Integrated Forecasting System model served as weather data source for the study. The analysis focused on surface wind conditions at 10 m above ground level, which

are critical for determining track usability during the VCA operation.

The study considered the Vertiport A, situated at Rome Fiumicino Airport and the Vertiport B located in the city centre of Rome. Figure 15 illustrates the track configuration of the considered vertiports A and B. Furthermore, Table 6 give a summary of the respective track orientations of the two vertiports where the track directions were analysed in True North reference system. The scope of the study was to investigate not only yearly usability of the vertiport and its track system related to wind conditions, but also the seasonal effects on the vertiport operation.

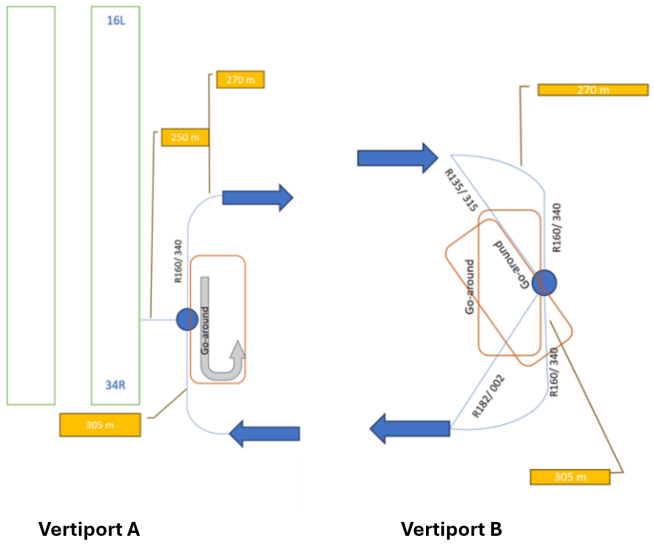


Figure 15: Case Study III: Track configurations for Vertiport A and B.

Figure 15 displays both vertiport configurations (A and B) and their VCA track systems.

Table 6: Case Study III: Vertiport A and B track configuration.

Track System	**Approach Orientation**	**Departure Orientation**
Vertiport A track configuration		
164 APP I 344 DEP	164°	344°
164 DEP I 344 APP	344°	164°
Vertiport B track configuration		
164 APP I 344 DEP	164°	344°
164 DEP I 344 APP	344°	164°
139 APP I 319 DEP	139°	319°
006 APP I 186 DEP	006°	186°

Since the Prototype Technical Specification for the Design of VFR vertiports does not define specific wind restrictions to achieve the required 95% usability, reference values were derived from EASA certification standards CS-27 for small rotorcraft and CS-25 for large aeroplanes [37, 38].

According to CS 27.143(c), rotorcraft must be capable of operating safely in wind velocities of up to 17 knots from all directions, including crosswind and rearward flight conditions [37]. To ensure that the vertiport usability analysis remains independent of specific VCA designs, this threshold was adopted as a general wind tolerance criterion. Additionally, a maximum tailwind component of 10 knots was assumed for take-off and landing, reflecting common operational practice and manufacturer performance limitations typically applied to CS-25 certified aircraft [38, 39]. Furthermore, the following assumptions were applied for the study:

- Vertiport Usability is present if one approach and one departure track during the respective analysed hour is available.
- For Vertiport Usability, accepted general operational conditions include Nominal and Moderate (see Table 7 for exact wind limitations).
- For Vertiport Usability, surface wind (10 m) is considered, since decisions on active track selection are based on surface wind conditions.
- Results are distinguished into yearly track usage distribution and monthly track usage distribution (bar chart).

In order to understand the operational usability also on VCA track system level of the vertiport, additional definitions were established:

- Dual Usability (Dual): approach and departure tracks are available (accepted conditions) for the considered hour.
- Approach only (APP): Only the approach track of the respective analysed track system is available for the considered hour.
- Departure only (DEP): Only the departure track of the respective analysed track system is available for the considered hour.
- General No Availability: No approach or departure track is available within the considered track system.

Table 7: Wind limits at 10 m (33 ft) used for the evaluation.

Wind Component	Nominal	Moderate	Severe
Mean Head Wind speed	< 10 kt	10–17 kt	> 17 kt
Mean Cross Wind speed	< 10 kt	10–17 kt	> 17 kt
Mean Tail Wind speed	< 5 kt	5–10 kt	> 10 kt

Table 8 provides an overview of the vertiport usability factors that were calculated during the analysis.

Table 8: Case Study III: Vertiport usability study results.

Usability factor	**Vertiport A**	**Vertiport B**
Overall Yearly Vertiport Usability	98.7%	99.8%
Minimum Monthly Vertiport Usability	96.5% (December)	98.8% (December)
Maximum Monthly Vertiport Usability	99.7% (June)	100% (August)

The results demonstrated that the Fiumicino Vertiport A achieved an annual usability rate of 98.7%, which significantly exceeds the EASA benchmark of 95%. Vertiport usability was highest between April and September, consistently above 99%, corresponding to periods of stable wind conditions.

To illustrate vertiport usability at the track system level, the results from track system 164 APP | 344 DEP at Vertiport A are analysed, based on the definitions established earlier. Figure 16 shows how the track system usability varies seasonally for this configuration. Over the course of the year, the system indicates consistently high dual usability, meaning that the tracks can be operated in both directions without exceeding the tailwind or crosswind limits defined in Table 7.

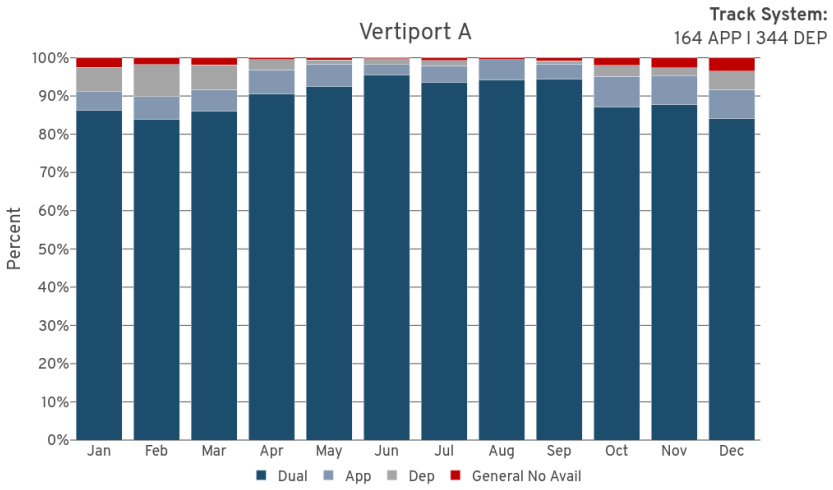


Figure 16: Case Study III: Monthly track usability (164 APP I 344 DEP).

Operational hours in which only departures are possible, while arrivals remain restricted, occur primarily during the months from October to April. This reflects seasonal constraints within the track system. It can be stated that the planned operation considering the given approach and departure paths at Vertiport A and B is suitable, as:

- For the two vertiport locations, a high overall track usability of 98.7% (Fiumicino) and 99.8% (Piccolomini) with the available approach/departure track systems can be achieved.
- In only $< 2\%$ of the time the vertiports are not available due to wind conditions considering the limits used in this study.
- For both vertiports the usability is highest between April and September ($> 99\%$), with a slight decrease during the winter months. The month with the highest non-availability for the Fiumicino vertiport is December with still only 3.5%.
- Based on the analysis results, and multiple approach and departure tracks available, an annual vertiport availability of more than 95% is expected which is in line with the EASA Prototype Technical Specifications for the Design of VFR Vertiports (PTS-VPT-DSN / March 2022).

In summary, the Case Study conducted within the EUREKA project confirmed that the two evaluated vertiports in Rome consistently exceeded EASA's 95% vertiport usability

threshold by achieving annual usability rates of 98.7% and 99.8%. Vertiport usability peaked between April and September and even during the winter months compliance could be remained, demonstrating the operational robustness of multi-track designs. Furthermore, these results confirm the feasibility of year-round high-density VTOL operations and reinforce the economic viability of IAM by showing that properly designed vertiports can provide reliable service across seasonal variations with respect to wind constraints.

However, the analysis also revealed a regulatory gap. The lack of standardised wind restrictions for VCA leads to uncertainties in the vertiport usability assessment. Since aerodynamic tolerances vary depending on aircraft type, it remains unclear which thresholds should be applied when assessing compliance with the 95% usability requirement. This also affects the comparability of sites and the planning of multi-track systems designed to ensure operational continuity.

Nevertheless, the methodology applied, which is based on historical wind data, provides a solid basis for the strategic planning of vertiports and the selection of suitable vertiport locations. It enables reliable decisions about track orientation and supports the scalable development of infrastructure.

3.3 Vertiport Weather Sensor Infrastructure

Weather Information Systems for Vertiports are a foundational element in enabling safe, scalable, and interoperable operations of VCA within the IAM ecosystem. These systems are distinct from weather information service (WIS) for U-space applications, which primarily support unmanned aircraft operations and flight authorisation services.

The regulatory framework for vertiport weather infrastructure establishes clear baseline requirements. The sensor infrastructures recommended for the vertiports proposed by PTS-VPT-DSN is illustrated in Figure 17 [3]. According to [3, 4], vertiports must provide real-time meteorological information to VCA operators. This includes:

– Mandatory wind direction indicators (WDI) at FATO/TLOF.

– Recommended meteorological stations for urban or disturbed airflow environments.

– Broadcast or radio distribution of weather data.

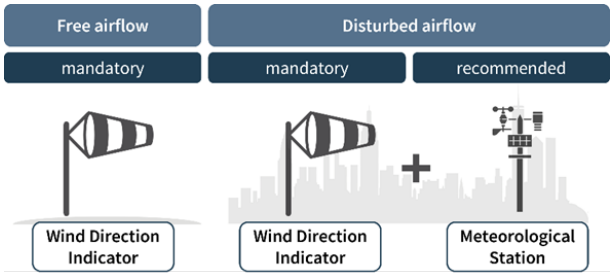


Figure 17: Mandated and recommended weather sensors at a vertiport according to [3, 4].

Opinion 03/2023 mandates that VCA operators use meteorological information from certified providers in accordance with Regulation (EU) 2017/373 [17]. Additional supplementary local data may be used to enhance situational awareness.

Reference [6] establishes a comprehensive framework for air taxi operators and pilots regarding weather-related operational duties. These provisions are critical to ensure that

vertiport weather systems are effectively utilised in both flight planning and execution, and are summarised in the following.

- **UAM.OP.VCA.245:** Operators must ensure that "the aircraft is operated within the weather operating limitations it is certified for and considering current and forecast weather conditions for the entire duration of the flight." This includes all phases, departure, en-route, arrival, and diversion, and applies to both VFR and future IFR operations.
- **UAM.OP.MVCA.245:** For manned operations, the pilot-in-command must only commence flight after confirming appropriate meteorological conditions at the departure and arrival vertiports, along the route, and at any designated diversion locations.
- **UAM.OP.MVCA.127:** Pilots must not take-off or land at a vertiport or diversion location unless the reported weather conditions are suitable. If no weather report is available, or if the pilot chooses to proceed despite adverse conditions, they must be able to determine that visibility and distance from cloud minima along the take-off area are equal to or better than the required minimum.
- **UAM.POL.VCA.110 (c):** Wind correction factors which are typically 50% for headwind and 150% for tailwind, may be reduced if "precise wind-measuring equipment enables the accurate measurement of wind velocity over the point of take-off and landing."

In practice, these mandates require that pilots consult METAR, TAF, and other aviation weather reports for locations as close as possible to the planned take-off, landing, and diversion vertiports and locations. The final "go/no-go" decision must be based on both certified meteorological data and supplementary local observations, such as those provided by vertiport weather stations. These provisions collectively reinforce the importance of integrating certified and localised weather data into vertiport systems. They also clarify the delineation of responsibilities between the operator and pilot, ensuring that weather-related risks are systematically addressed through both infrastructure and procedural safeguards.

The approach taken by the consortium of EUREKA focuses on integrating aviation-grade weather intelligence into vertiport operations through sensor fusion, centralised data management, and automated interpretation. The goal is to provide actionable, flight-relevant information that supports crewed VCA operations under VFR in VMC, and prepares for future IFR operations in IMC without requiring continuous human interpretation by meteorological experts.

Therefore, vertiports must provide a broad set of operational characteristics:

- Provide aviation-grade weather data for all flight phases: take-off, en-route, landing, and diversion.
- Ensure compliance with current and emerging EU regulations, including EU 2017/373 and Opinion 03/2023.
- Enable centralised operations and remote tower-like architectures.
- Support automated weather evaluation and risk assessment.

- Allow low-cost deployment in early-stage markets with modularity for future expansion.
- Deliver operational data to ground handling, charging, ticketing, and scheduling systems via standardised APIs.
- Provide weather information from vertiport to vertiport along a route to connect all operational nodes.
- Enable monitoring of overall network availability, including identification of partitions or segments that are temporarily unavailable due to adverse weather.
- Support strategic planning and rerouting decisions by offering a comprehensive overview of weather conditions across the entire vertiport network.
- Prepare for IFR operations in IMC by integrating high-resolution and predictive weather analytics.
- Fuse data from multiple sources to support decision-making without requiring continuous human interpretation.

The sensor strategy adopted by the consortium is designed to support scalable vertiport operations under both VFR and future IFR conditions. It is based on a function-driven architecture that prioritises operational relevance over sensor type. This approach enables modular deployment of sensor arrays that can be adapted to the specific meteorological and topographical characteristics of each vertiport.

Visibility and present weather sensors are essential for VFR operations and will become critical for IFR readiness. Lidar systems offer high-resolution vertical profiling, enabling assessment of atmospheric stability and low-level wind shear. However, lidar data interpretation remains complex and requires advanced processing to convert raw measurements into actionable insights.

To address this, the architecture emphasises automation and centralised data fusion. Weather data from multiple sources including local sensors, regional forecasts, and radar systems, is integrated with aircraft performance envelopes and operator-defined limits. This fusion enables automated evaluation of weather conditions along planned routes and supports real-time decision-making without requiring continuous human interpretation. Figure 18 depicts a mock-up visual of weather information evaluated for a vertiport network.

The resulting system provides strategic planning capabilities for network-wide operations and tactical support for individual flights. It also contributes to risk assessment frameworks and ensures compliance with emerging regulatory requirements for vertiport weather services.

WIS in U-space are designed to support drone operations and Flight Authorisation Services. They are distinct from vertiport weather systems and serve different operational and regulatory purposes.

Key characteristics of U-space WIS include:

- Support for flight authorisation service: Evaluate weather hazards such as wind, icing, and precipitation to determine flight authorisation.
- Real-time alerts: Monitor live weather changes and revoke or modify authorisations in case of adverse conditions.

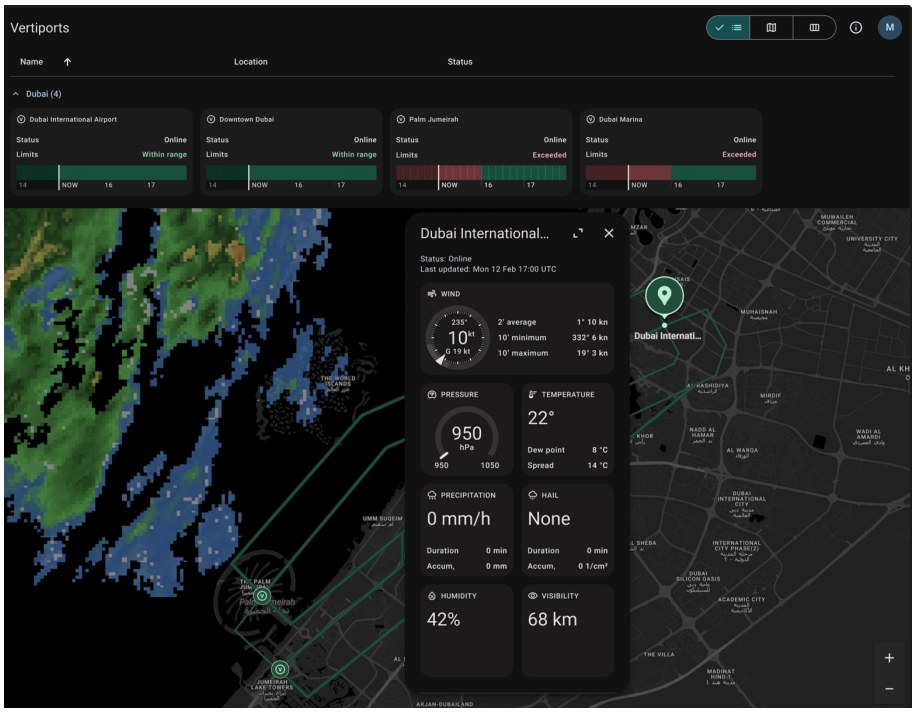


Figure 18: Mock-up of fused and evaluated weather information for route network of vertiports, ©Unisphere.

– Urban and micro-weather modelling: Account for localised phenomena affecting drone stability.

– Operational adaptability: Enable route modifications and alternate planning based on updated weather data.

Importantly, the WIS is also a supplemental, non-mandatory service within the U-space framework. Operators may operate within and outside of U-space airspace, and to date, they continue to refer to classical rules of the air and conventional flight planning procedures. This means that while WIS can enhance situational awareness and support automated services, it does not replace the operator's responsibility to comply with established aviation regulations and procedures.

The consortium emphasises that WIS should not duplicate operator responsibilities. Operators already use tailored software and procedures to manage weather risks. A mandatory, one-size-fits-all WIS would restrict innovation and impose unnecessary costs. Instead, a tiered deployment strategy is proposed based on traffic density and environmental complexity.

The range of meteorological conditions a vertiport is designed to accommodate is a key determinant of the sensor infrastructure, procedural support, and overall operational capability it must provide, which defines the basis of the vertiport categorisation framework introduced in the next section.

3.4 Vertiport Categories

Considering how vertiports may support VCA operations in both VMC and IMC, it is useful to assess a landing pad's capability within the broader framework of approach operations rather than through runway CAT I, II, and III categories alone. This is

important when adverse weather conditions occur and access to the vertiport can no longer rely only on visual procedures. Within the ICAO framework, instrument approach operations are classified more broadly than CAT I/II/III and include both 2D and 3D instrument approach operations [40, 41]. This distinction is particularly important for vertiport operations since VTOL flight operations are not necessarily expected to follow the same procedural logic as conventional runway-based arrivals. For that reason, vertiport categorisation should not be framed directly as CAT I/II/III, but instead should be discussed with reference to the wider instrument approach framework and to concepts such as point-in-space (PinS) procedures, which are more relevant to VCA operations [41, 42].

Although the PinS concept is currently defined for helicopter operations in the regulatory framework, it is still useful for VCA because it combines an IFR segment with a following visual segment to a nearby landing site. This mixed structure is closer to the kind of arrival logic that may be needed at vertiports than a conventional runway precision approach. In other words, the VCA may use instrument guidance to reach the vicinity of the destination in adverse weather conditions, while the final part of the arrival still depends on visual reference near the landing area. FAA guidance describes the same approach through the *Proceed VFR* and *Proceed Visually* variants of PinS procedures, which helps to understand how instrument guidance can be used up to a defined point before the final visual segment [43]. For that reason, PinS provides a better procedural starting point than runway CAT I/II/III when discussing how future vertiports may support operations beyond straightforward visual conditions. How PinS procedures can be adapted to VCA operating at vertiports is detailed in Section 4.2.

A vertiport also "covers" the surrounding obstacle environment, the available obstacle-free volume, and the visual aids that support the final approach and landing, rather than only considering as a landing pad. EASA's prototype vertiport design specification already reflect this broader view by addressing physical characteristics, obstacle environment, and visual aids as core parts of vertiport design [3]. In addition, ref. [44] introduces reference volumes that can support vertiport design in obstacle-rich environments. This means that the geometry of the approach, the nearby obstacles, and the quality of the local visual cues become important for vertiports, especially in the final segment close to the landing area. As a result, any future vertiport categorisation would likely need to consider not only weather, but also the local layout of the vertiport site and the infrastructure available to support safe access.

For that reason, future vertiports can be categorised based on capability levels rather than direct equivalents of runway approach categories. Reference [3] describes vertiports through a combination of physical characteristics, obstacle environment, visual aids, lights, and markings, while the current IAM regulatory material allows operators to use those specifications, or an equivalent basis, when assessing whether a vertiport is adequate for normal operations and diversions [45]. This suggests that any future categorisation should depend on the level of operational capability that a vertiport can support.

For that purpose, Table 9 presents the initial proposed conceptual vertiport categorisation. These concepts are referred as vertiport capability levels VCL I, VCL II, and VCL III, representing progressively higher levels of vertiport capability.

In summary, the proposed vertiport categories are an initial conceptual way to describe how vertiports differ based on the capabilities they can provide. EASA's prototype vertiport specifications offer an initial basis for vertiport design [3], while the regulatory framework is still evolving. Thus, any future formal categorisation of vertiports would still require further development, validation, operational experience, and regulatory harmonisation

before it can be adopted.

Table 9: Proposed conceptual vertiport categorisation based on vertiport capability levels.

Vertiport category	Typical access supported	Representative site and infrastructure characteristics	Operational implication
VCL I	Mainly visual access under less demanding conditions.	Basic vertiport layout, markings, and essential visual aids, together with a defined obstacle environment and the local information needed to support arrivals and departures.	Suitable for operations that rely largely on visual reference near the landing area and do not require a high level of local procedural or operational support.
VCL II	More supported access under a wider range of operating conditions.	Enhanced visual aids, better-defined local obstacle environment, improved local information, and additional site capability to support more structured arrivals and departures.	Suitable for operations in which access to the vertiport depends on a stronger combination of site characteristics, operational support, and approach design.
VCL III	Advanced access under more demanding conditions.	Highly capable site infrastructure, extensive local operational support, robust obstacle management, and advanced visual and supporting systems for arrivals and departures in complex environments.	Suitable for operations that require the highest level of vertiport capability, particularly where safe access depends on the close integration of procedure design, infrastructure, and operational support.

3.5 Vertiport Operating Systems and Management

The vertiport operating systems and management consists of digital tools and operational procedures that enable the safe and efficient operation of IAM at vertiports. These services are managed via the vertiport management system (VMS) which assists the vertiport operator with monitoring the vertiport status, managing key resources, and maintaining real-time operational awareness. The VMS's functionalities and implementation may vary depending on the operational concept, vertiport environment, and airspace class considered. The VMS services considered are outlined as follows:

- **Vertiport resource management:** Monitoring the availability and status of vertiport resources, such as FATO/TLOF, charging stations, parking positions, and ground equipment, in order to support the safe and efficient operation of vertiports.
- **Vertiport availability service:** Providing information on the operational availability of the vertiport, including its current status and its available capacity. This includes information on whether the vertiport is open or closed, as well as the availability of vertiport slots. This information supports strategic and tactical decision-making in the event of changes due to the availability of vertiport resources. The vertiport availability concept is detailed in Section 5.3.
- **Vertiport authorisation service:** Managing authorisation for taxi, take-off, and landing through the designated controlling authority, which may vary depending on

the operating environment. Authorisation requests may be submitted directly by the VCA operator through the USSP. In controlled ATS airspace, these authorisations become ATC clearances in accordance with the rules of the applicable airspace class. These authorisations are required for each VCA arriving and departing and are important for the safe scheduling and sequencing of VCA operations.

- **Scheduling and slot allocation:** Time slots for arrival, departure, parking, and charging activities are assigned and updated while considering the availability of pads and other vertiport resources. This supports orderly operations and helps reduce delays and resource conflicts. The vertiport slot concept is detailed in Section 5.

- **Ground movement coordination:** Coordinating the movement of aircraft and relevant ground vehicles between pads, stands, charging areas, and other operating areas. This helps prevent bottlenecks and supports efficient turnaround. The vertiport collaborative decision-making concept is detailed in Section 6.2.

- **Safety and emergency response:** Supporting the detection and management of abnormal or faulted conditions, including operational disruptions and emergency conditions, while enabling the vertiport operator to coordinate with the relevant response services in a timely manner. The contingency and disruption management service is detailed in Section 7.3.

In addition to these vertiport functionalities, vertiport operations also rely on several operational data inputs and connected service interfaces. Although these are not managed in the same way as internal VMS functions, they provide necessary information to support safe, coordinated, and efficient operations.

- **Communication, navigation, surveillance:** This provides the operational data needed to support vertiport operations, including relevant CNS information and telemetry from inbound and outbound VCA traffic, as well as other nearby relevant traffic.

- **Weather service:** Providing weather information such as now-casts, forecasts, wind conditions, and visibility data to support the assessment of vertiport availability and operational conditions.

- **Common information service:** Providing access to shared operational information relevant to the vertiport, such as status and slot availability, and other information needed to support coordination across the wider operational environment. The CIS concept is detailed in Section 8.2.6.

- **U-plan information service:** Providing the VMS with accepted U-plans (i.e. flight authorisation requests submitted through the USSP[4]) and related updates that affect the vertiport. This allows the vertiport operator to reserve the relevant slots and update local resource planning when VCA flight information changes.

Depending on the vertiport concept and operating environment, additional supporting functions may also be integrated into the vertiport system. While these functions may not always be part of the core airside management capabilities, they can still support the safe and efficient operation of the vertiport.

[4]See Section 10.1

– **Passenger flow management:** Monitoring and coordinating passenger movement within landside vertiport areas, including boarding, security screening, and waiting areas, in order to reduce congestion and support timely operations.

– **Noise monitoring and mitigation:** Monitoring noise generated by IAM operations and implementing measures to minimise its impact on surrounding communities and ensure compliance with local environmental requirements.

– **Financial and administrative services:** Supporting the tracking of vertiport usage, the processing of related charges and fees, and carrying out other administrative activities linked to vertiport operations.

All of these functions are considered as a part of the VMS. Although a high level of automation is expected, the vertiport operator remains responsible for monitoring vertiport ground operations and the real-time status of the vertiport. In practice, this requires an HMI that presents the most relevant operational information in a clear and timely manner.

Figure 19 shows an example of a VMS dashboard that supports real-time monitoring of vertiport status and key operational conditions in the future. The HMI enables the vertiport operator to oversee the overall status of the vertiport, including it operational status (open or closed) due to emergencies, abnormal or faulted conditions, maintenance activities, or other operational constraints. It also displays other operationally relevant information, such as charging status, charging infrastructure availability and key weather conditions. By combining operational, energy, and weather information in a single view, the dashboard enables timely decision-making during vertiport operations.



Figure 19: HMI Vertiport operator working position developed for R&D purposes: Overview of a single FATO, ©Bluenest.

Figure 20 shows an example of the scheduling interface used by the vertiport operator to monitor and manage arrival and departure slots. It provides an overview of slot availability across the FATOs (including both the main and contingency FATOs) and associated stands used for parking or battery charging. The HMI also shows the status of each slot, indicating whether it is booked, cancelled, or available, and displays operational conditions such as nominal operations, maintenance, or emergency closures. The interface supports planning, resource allocation, and day-to-day operational oversight at the vertiport.

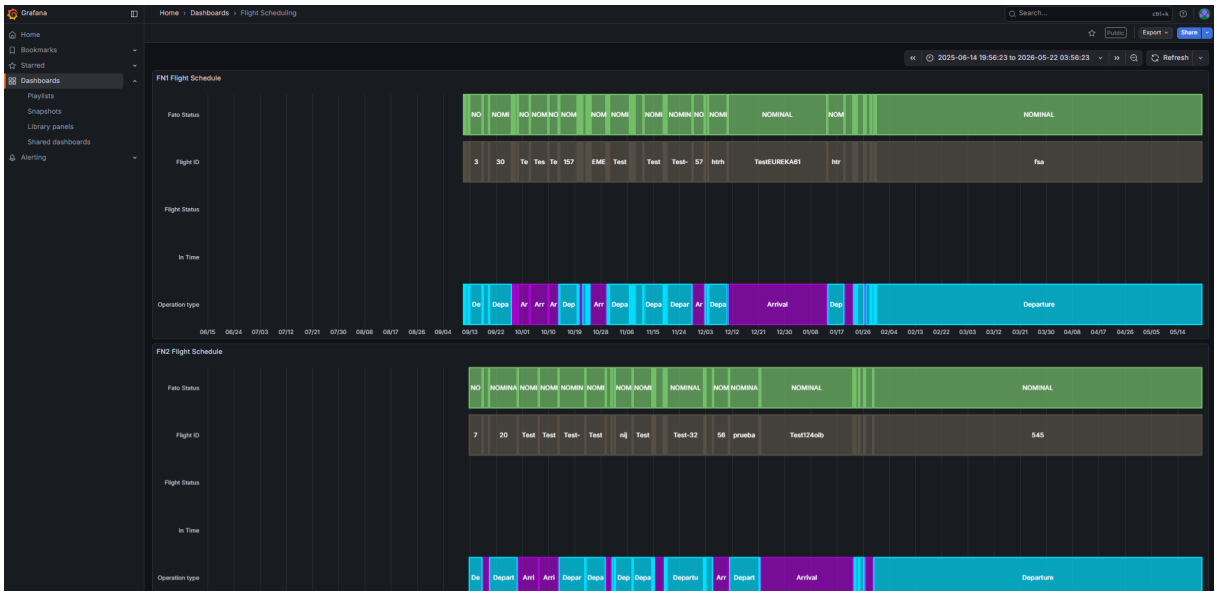


Figure 20: HMI Vertiport operator working position developed for R&D purposes: Overview of FATO booking schedule, ©Bluenest.

3.6 Local Vertiport Network Traffic Information and Management Services

In a vertiport network, vertiport operating and management tools extend beyond individual point-to-point operations to cover all VCA flights within the local network. This holistic approach is important because traffic flows, resource availability, and operational constraints at one vertiport, can affect conditions at another vertiport within the same network. Consequently, the local vertiport management functions introduced in Section 3.5 need to be coordinated for monitoring and management across the connected vertiports.

The local vertiport network manager (L-VNM) can be introduced as a central coordinator for this purpose, managing vertiport network-wide functions. The L-VNM therefore maintains an overall view of the network, supporting the coordinated management of traffic flows, capacity, resource availability, and operational constraints across the connected vertiports. The local vertiport operator is not replaced by the L-VNM, rather, the local vertiport management is extended to the wider network to support consistent and coordinated operations. In practice, L-VNM centres information such as vertiport availability, resource status, flight requests, weather conditions, and operational disruptions from each relevant vertiport, enabling disruption effects to be monitored as they propagate across the network. This is intended to facilitate consistent planning, optimise the utilisation of available ground infrastructure capacity, and enable a more effective response to changes in operational conditions change or disruptions at one or more vertiports.

The L-VNM is supported by the vertiport network management system (VNMS), which provides functionalities such as flow management, network-wide operational oversight, and capacity balancing. In practice, the VNMS builds on the local VMS functions to enable monitoring and coordination across multiple vertiports. This includes maintaining visibility of vertiport status, slot and stand availability, weather conditions, operational constraints, and other relevant information that may affect network performance.

One particularly important network-level function is demand and capacity balance (DCB). Within the VNMS, it supports the coordination of traffic demand and available

vertiport capacity across the local network, in the strategic and tactical phases of the VCA flights. This includes decisions regarding departure sequencing, slot allocation, route coordination, and re-routing within a vertiport network.

Figure 21 shows an example of a VNMS HMI used to monitor traffic movements across the vertiport network. The interface facilitates the identification of departing and arriving traffic, as well as bottlenecks based on operation status and other conditions that may require coordination at network level.

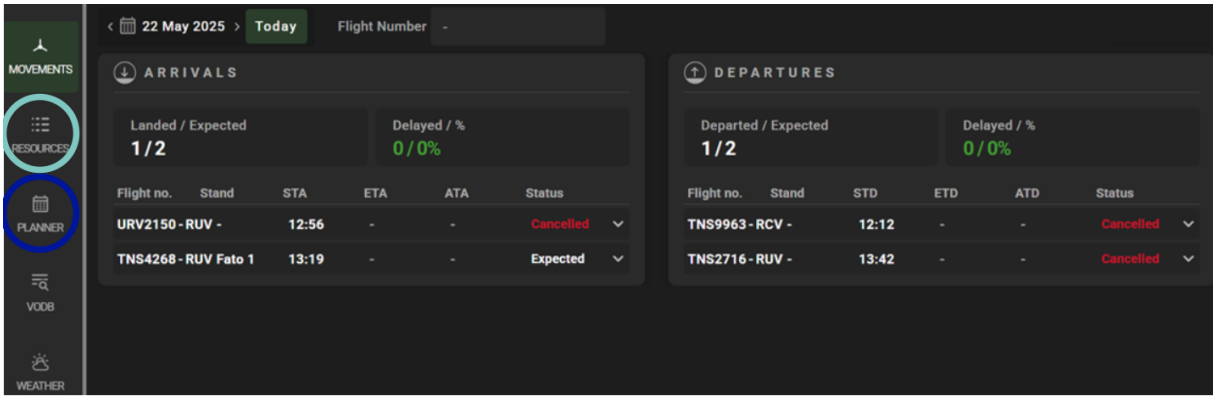


Figure 21: HMI VNMS working position snapshot developed for R&D purposes: Overview of movement status, ©UrbanV, ©SITA.

Figure 22 illustrates a VNMS view that displays the status of individual vertiports within the network. The interface enables the L-VNM to monitor local conditions at each vertiport, taking into account operational status, resource information, and weather conditions. It also enables comparison of this information across the vertiport network.

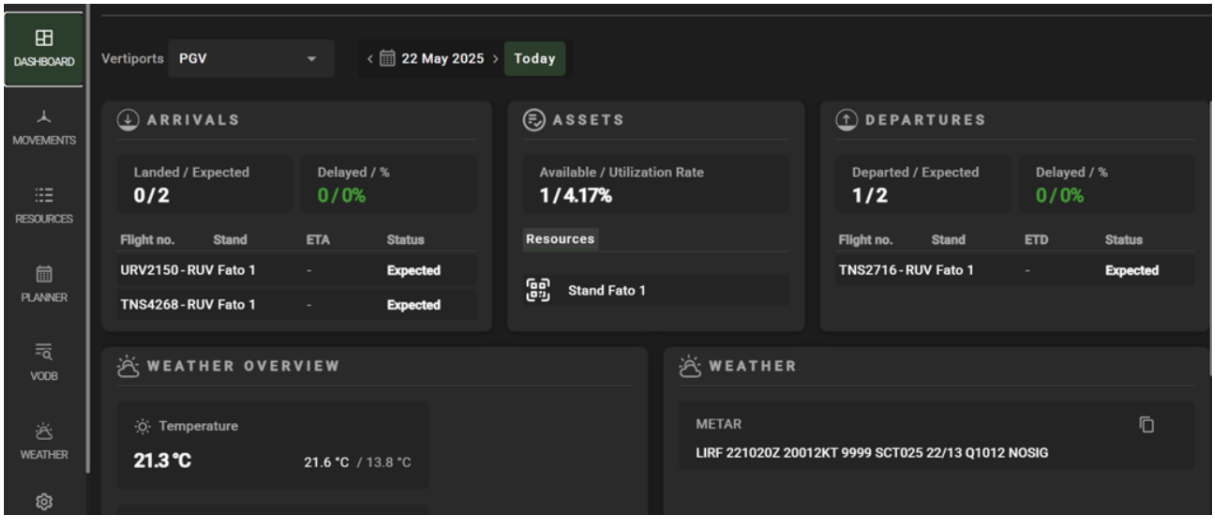


Figure 22: HMI VNMS working position snapshot developed for R&D purposes: Overview of status per vertiport, ©UrbanV, ©SITA.

In summary, Section 3 establishes the foundation for vertiport operations and demonstrates that vertiport location selection is highly site-specific and safety driven. Operationally feasible vertiport locations may conflict with the targeted business case. Placing vertiports near airports and active runways can result in significant operational constraints.

Fast-time Monte Carlo simulation analysis at Palma de Mallorca airport suggest that independent operations likely require separation distances of more than 2,000 m from the runway. However, containment boundary analysis at Rome Fiumicino Airport confirms that properly designed VCA routes could coexist with conventional traffic without interference. Wind-based usability analysis of two Rome vertiports shows that multi-track designs can exceed EASA's 95% usability threshold. However, a regulatory gap remains with respect to standardised wind restrictions for VCA. Once the vertiport location has been selected and the operating conditions defined (vertiport categories), a digital operating and management system (VMS) should be in place to efficiently allocate scarce vertiport resources. At the network level, the L-VNM and VNMS could provide the coordination layer needed to extend local vertiport management to multi-vertiport operations, balancing demand and capacity across the network, especially during contingency and emergency situations. With these aerodrome-level principles established, the following Section 4 examines how VCA and vertiports can integrate into the airspace.

4 Airspace Organisation and Management

"Airspace organization will establish airspace structures in order to accommodate the different types of air activity, volume of traffic and differing levels of service. Airspace management is the process by which airspace options are selected and applied to meet the needs of the ATM community" [1].

4.1 Background

The main incentive for establishing a designated area of airspace surrounding the vertiport is to increase safety by protecting airside and airborne operations. This includes protecting approach, departure and manoeuvring of VCA; protecting airside ground operations, vertiport personnel and the urban neighbourhood; and ensuring the protection of crossing traffic by informing other airspace users about the increased level of VCA activity in this area. Prescribed VFR routes and IFR flight procedures enhance the predictability of VCA trajectories inbound to and outbound from the vertiport. That is why flight procedure and airspace design are key subjects of safely integrating vertiports into the European airspace.

According to EUROCONTROL, three golden rules apply when designing airspace volumes and sectorisation that support ATM [46]:

– Airspace Volumes protect the IFR flight paths. They are designed AFTER the routes have been designed.

– Routes should not be designed so as to fit into pre-existing airspace volumes.

– Only delineate as much airspace volume as needed.

Current practices of airspace design and sectorisation around airports, follow several well-established airspace concepts (see Table 10 and 11).

In ATM, the airspace is divided into different structures dedicated to each phase of the flight. The en-route airspace is composed of sectors in the horizontal and vertical plane, designed for the optimisation of linear trajectories at a steady level, climb or descent and the organisation of the traffic flow. This sectorisation covers the entire European airspace mainly above flight level 195 (FL195[5]). Initial climb, arrival and approach phases are performed in a terminal control area (TMA) established around the airport, typically extending from approximately 2000 to 2500 ft up to FL195. A TMA can surround airports by several dozen kilometres and serve to organise traffic flows in the horizontal and vertical planes (e.g., standard terminal arrival (STAR), standard instrument departure (SID), global navigation satellite system (GNSS) approach) in the vicinity of what is typically the main bottleneck of the system: the airport.

Final approach, take-off, landing and aerodrome circuit operations occur in the control zone (CTR), usually established from ground to 2000 to 2500 ft. This airspace volume usually surrounds an airport by tens of kilometres. Traffic in each en-route sector, TMA and CTR is managed by different ATCO, unless, applicable only to en-route sectors and TMAs, some sectors have been grouped. The shape and size of these airspace structures are highly customised and tailored to the operational characteristics of the airport and its associated traffic patterns.

Table 10: Conventional airspace constructs (non-exhaustive).

Airspace concept	Definition	Reference
Control zone	"Controlled airspace extending upwards from the surface of the earth to a specified upper limit"	[47]
Control area	"A controlled airspace extending upwards from a specified limit above the earth"	[47]
Controlled airspace	"An airspace of defined dimensions within which air traffic control service is provided in accordance with the airspace classification"	[47]
Advisory airspace	"An airspace of defined dimensions, or designated route, within which air traffic advisory service is available"	[48]
Air traffic service airspaces	Airspaces of defined dimensions, alphabetically designated, within which specific types of flights may operate and for which air traffic services and rules of operation are specified"	[48]
Flight information region	"A service provided for the purpose of giving advice and information useful for the safe and efficient conduct of flights."	[48]

Similar to airspace design, the design of flight procedures is fundamentally guided by ICAO Document 8168, known as the Procedures for Air Navigation Services — Aircraft Operations (PANS-OPS). This document is structured into three primary volumes. Volume I [40], *Flight Procedures*, describes the operational requirements for flying the procedures designed in accordance with the criteria provided in Volume II. Volume II [50], *Construction of Visual and Instrument Flight Procedures* is intended for the guidance of procedure specialists and describes the essential areas and obstacle clearance requirements for the achievement of safe, regular instrument flight operations. It provides the basic guidelines to state authorities, and those operators and organisations producing instrument flight charts that will result in uniform practices at all aerodromes where instrument flight procedures are carried out. Volume III [51], *Aircraft Operating Procedures*, describes operational procedures recommended for the guidance of flight operations personnel and flight crew. The civil aviation authority makes sure that any published flight procedures can be safely used by every type of relevant aircraft.

For vertiports and VCA, the following three concepts are of primary interest: VFR with Prescribed Track Operations ("prescribed VFR"), PinS and IFR flight procedure design.

First, VCA VFR operations flying along prescribed tracks mean that the pilot maintains visual reference to the ground and assumes look-out responsibilities as required by VFR rules, while the automation system follows a defined lateral path (a published track, corridor centreline, or geo-fenced route) using GNSS-based navigation. These operations combine visual look-out responsibilities with adherence to specified lateral and vertical constraints, reporting points, and any route-specific procedures (noise abatement, speed limits, altitudes).

The second concept is about VCA IFR operations and PinS procedures. ICAO Doc 8168 Vol II Part IV contains the criteria applicable for Helicopter PinS procedures based on a basic GNSS receiver, which were introduced in 2004 [50]. The PinS approach is an

[5]Flight levels (FL) are standardised altitudes expressed in hundreds of feet referenced to the standard atmospheric pressure.

Table 11: Conventional airspace constructs around airports (non-exhaustive).

Airspace concept	**Definition**	**Reference**
TMA	"A control area normally established at the confluence of ATS routes in the vicinity of one or more major airports"	[47]
ATZ	"Is an airspace of defined dimensions established around an aerodrome for the protection of aerodrome traffic" – The airspace within the aerodrome traffic zone (ATZ) may be either controlled or uncontrolled, in which case aerodrome flight information service (AFIS) is offered. – This structure defines a volume in which airspace users who do not intend to operate at the aerodrome shall not enter. – Not every State deploys ATZ. – There are no criteria defined for the size or shape of the ATZ.	[49]
TA	"Is a generic term describing airspace which is part of the airspace continuum. Terminal airspace (TA) within which air traffic services are provided. It encompasses all the various terminologies currently used throughout the ECAC region. Such airspace predominantly contains traffic operating along Terminal Routes or to a lesser extent, ATS routes of the ATS route network (ARN)." TA is a generic term encompassing terminal control area (TMA), Control Area (CTA), control zone (CTR), aerodrome traffic zone (ATZ), flight information zone (FIZ) or any other nomenclature, used to describe the airspace around an airport"	[46],[49]
TSA	"Is a defined volume of airspace normally under the jurisdiction of one aviation authority and temporarily segregated, by common agreement, for the exclusive use by another aviation authority and through which other traffic will not be allowed to transit." When we consider U-space airspace, this can be seen as a temporary segregated area (TSA)	[49], [48], [15]

approach procedure designed exclusively for helicopters and includes both, a visual and an instrument segment. The same applies to a PinS departure. For departures, the PinS concept involves a visual flight phase in which the pilot navigates using visual references to an initial departure fix (IDF), followed by a transition to the instrument flight phase after passing the IDF at or above a pre-defined altitude. For approach, the PinS concept requires conducting the flight under IFR to a PinS and then either proceeding visually or executing an instrument missed approach procedure, depending on whether appropriate visual references are obtained. When adapted from helicopter PinS concepts to account for VCA characteristics, the same principles would allow for take-off and landing from vertiports that are not IFR equipped. Two types of visual flight phases can be applied: one that relies on a published visual flight procedure and can be performed under IFR without VMC, and another that requires both VFR and VMC.

The third concept is a VCA operating in full IFR. Rather than relying on VFR, standard IFR procedures are followed along established IFR routes with all required onboard equipment. Instrument flight procedures design defines the development of pre-

designed and published routes and procedures used by aircraft flying under IFR, which rely on instruments rather than visual references.

For vertiport operations, particularly those located in uncontrolled airspace, airspace structures are undefined and the design of flight procedure designs for visual operations is uncommon in Europe. As flight procedure and airspace design form the basis for VCA integration, the following sections conceptually examine VCA flight procedure and vertiport airspace design. We strongly recommend that the operational concept presented in this section is further analysed in detail for each specific use case and VCA type, supported by a thorough and rigorous safety assessment carried out in close collaboration with the VCA operator.

4.2 VCA Flight Procedure Design

Helicopter operations today are mostly constrained to VFR/VMC conditions, even when operating at major airports. Although the FLAG working group, established by European Union Agency for the Space Programme (EUSPA), is actively promoting the deployment of helicopter-specific IFR procedures across Europe, with operational implementations already in place in Switzerland, Sweden, Italy and other countries, their widespread availability remains limited though. Where tailored procedures are unavailable, rotorcraft are forced to use fixed-wing IFR routes, which are suboptimal due to significant differences in manoeuvrability, speed profiles and climb and descent rates, increasing fuel use, delays, ATC workload, and potential mission failures especially in emergency operations [52]. The FLAG working group has also started to address flight procedure design specifically for VCA.

According to EASA PTS-VPT-DSN.D.440, the obstacle-free volume was introduced to provide protection above vertiports, facilitating VCA and vertiport introduction in congested areas and obstacle-rich environments [3]. Additionally, according to PTS VPT-DSN.C.350, there are measures and limitations about the location of a FATO with respect to an aerodrome runway or taxiway. When a vertiport or heliport is situated close to a runway or taxiway and simultaneous operations of VCA and conventional IFR traffic are planned, the distance between the edge of the runway or taxiway and the edge of the FATO should be no less than 250 metres if the mass of a VCA exceeds 100,000 kg to mitigate the risk of wake turbulence encounters [52][6]. This requirement affects all VCA operating at and from vertiports that are located at airports, but there are no existing standards or guidelines for designing routes applicable to these use cases.

In the short-term, VCA are expected to operate under VFR without formal route design. Medium-term operations anticipate IFR along tailored procedures using GNSS-based navigation, possibly augmented by satellite based augmentation system (SBAS) or alternative position, navigation and timing services. VCA routes may initially be designed for use in VFR conditions only, and where possible, use existing or modified low altitude VFR routes. However, routes for MVCA can also be proposed for IFR operations, taking current helicopter standards (ICAO Doc 8168 [40, 50, 51]) as starting point. EUSPA-funded projects have already advanced this subject: the SAMVA project designed and validated the first European Geostationary Navigation Overlay Service (EGNOS) based RNP procedures for eVTOLs and conducted flight trials at Lleida Airport, while ongoing GAUSSIAN and VITOLMINS projects continue to develop GNSS-based navigation and instrument take-off and landing procedures for VCA [53, 54, 55].

[6]Also see Table 3-1. FATO minimum separation distance for simultaneous operations in ref. [21].

While these routing constructs do not inherently provide separation or segregation of participating VCA traffic, they are developed to assist pilots in avoiding major controlled traffic flows. Instrument flight procedures establish protected areas around routes based on available infrastructure and navigation specifications. Obstacle assessment may require tailored surveys or fictitious obstacle buffers. As no formally standardised performance-based navigation (PBN) or instrument flight procedure criteria exist for VCA yet, VCA are expected to comply with existing airspace requirements and may use helicopter design criteria pending the development of specific standards.

Integrating VCA routes into the airspace involves defining whether routes are segregated (i.e. no interaction) or separated from other airspace structures (i.e. managed interaction with strategic or tactical ATM interventions). Since ICAO documents are often templates or model regulations, state authorities will decide on appropriate separation criteria or develop new ones if required.

To ensure the safe integration of VCA into the airspace while considering existing operations including sUAS flights and IFR and VFR routes for conventional aircraft, we recommend to consider the following aspects:

- Developing general approach and departure procedures for vertiports based on VCA performance requirements and obstacle environment.
- Creating en-route procedures for VCA to ensure safe airspace integration in CTR and, if necessary, in TMA.
- Standardising structures and procedures for VCA to safely segregate and integrate into ATZ with the help of defining criteria for VCA routes.
- Establishing dedicated airspace structures such as blocks, segments, flyways, or corridors. These structures should be complemented by clearly defined requirements for operating within these airspace constructs. This ensures procedural deconfliction of VCA operations from sUAS operations and other relevant manned traffic.
- Providing guidelines for Letters of Agreement and Route Operating Documents, detailing communication methods and procedures.
- Establishing visual reporting points can further enhance situational awareness as an additional mitigation measure.
- Recommending new airspace classifications or reclassifications, if necessary.

To achieve these goals, recommendations from the EUROCONTROL Manual for Airspace Planning might be mirrored to VCA route design [56]. In doing so, designers of VCA routes and flight procedures should take into account a wide range of aspects, including the characteristics of the ATZ, the configuration of runways and the presence of surrounding airports or airfields as well as the specific location of the vertiport. They must also consider other airspace users, the implications of crossing different airspace classes (here, entering into U-space airspace is added) and the need to design two-way routes with appropriate vertical separation or corridors. Additionally, any restricted or prohibited zones must be thoroughly assessed during the design process.

4.2.1 VCA VFR with Prescribed Track Operations

As discussed in Section 2, the airport shuttle is the most prominent use case. This means that, in initial phases, VCA aim to operate under VFR in dense obstacle environment within controlled airspace where only IFR-to-VFR and VFR-to-VFR traffic information is provided (and traffic avoidance advice on request) according to ref. [47]. Therefore, additional mitigation measures must be developed for obstacle analysis around the nominal track to support and enhance the required safety levels.[7] For this reason, operations can be envisioned to be based on "VCA VFR with prescribed track operations" rather than simply "VCA VFR operations".

"VCA VFR with prescribed track operations" can be defined as a visual trajectory with a prescribed track based on specific terrain features, criteria and dimensions needed for vertiport operations aligned with the needs of VCA operations. The prescribed track is assumed to comply with VFR minimum height for daytime flights as defined in SERA [41].

> ***SERA.5005 Visual flight rules*** *[...]*
> *(f) Except when necessary for take-off or landing, or except by permission from the competent authority, a VFR flight shall not be flown:*
> *(1) over the congested areas of cities, towns or settlements or over an open-air assembly of persons at a height less than 300 m (1 000ft) above the highest obstacle within a radius of 600 m from the aircraft;*
> *(2) elsewhere than as specified in (1), at a height less than 150 m (500ft) above the ground or water, or 150 m (500ft) above the highest obstacle within a radius of 150 m (500ft) from the aircraft.*

In controlled airspace B, C and D, the pilot must maintain a two-way radio communication with ATC [47]. The VCA PIC must also maintain horizontal and vertical distance from cloud and have the minimum visibility as defined in the table below. These minima have been defined for allowing the pilot to see and to being seen more easily by other airspace users.

> ***SERA.5010 Special VFR in control zones***
> *Special VFR flights may be authorised to operate within a control zone, subject to an ATC clearance. Except when permitted by the competent authority for helicopters in special cases such as, but not limited to, police, medical, search and rescue operations and fire-fighting flights, the following additional conditions shall be applied: [...]*
> *(b) by the pilot:*
> *(1) clear of cloud and with the surface in sight;*
> *(2) the flight visibility is not less than 1 500 m or, for helicopters, not less than 800 m;*
> *(3) fly at a speed of 140 kts IAS or less to give adequate opportunity to observe other traffic and any obstacles in time to avoid a collision; and (c) an air traffic control unit shall not issue a special VFR clearance to aircraft to take-off or land at an aerodrome within a control zone, or enter the aerodrome traffic zone or aerodrome traffic circuit when the reported meteorological conditions at that aerodrome are below the following minima:*
> *(1) the ground visibility is less than 1 500 m or, for helicopters, less than 800 m;*
> *(2) the ceiling is less than 180 m (600ft).*

Unless flying in class B airspace where the VFR PIC receives separation instructions with all other flights from ATC, the VFR PIC manages the separation with VFR in class C and with IFR and VFR in class D airspace, supported by traffic information received

[7] The TLS for initial VFR VCA operations is expected to be comparable to that of helicopter VFR operations, which historically exhibit accidents rates one to two orders of magnitude higher than CAT IFR transport operations.

from ATC. The detect and avoid (DAA) principle applies in those cases and anytime in the air or on the ground regardless of whether the aircraft is equipped with detect and avoid systems and/or be provided with separation from ATC [48]. ICAO Annex 2 specifies that "nothing in these rules shall relieve the pilot-in-command of an aircraft from the responsibility of taking such action, including collision avoidance manoeuvrers based on resolution advisories provided by ACAS equipment, as will best avert" and "it is important that vigilance for the purpose of detecting potential collisions be exercised on board an aircraft, regardless of the type of flight or the class of airspace in which the aircraft is operating, and while operating on the movement area of an aerodrome" [48]. Furthermore, safety buffers for passenger-carrying VCAs from sUAS might be determined based on the assumption that navigational accuracy may not be achieved by appropriate navigation aids such as in assessing obstacle accountability. This assumption may be revisited if improvements in navigational accuracy occur.

According to ref. [10], which was the main reference for EUREKA's VFR VCA route and flight procedure design (predecessor of [6]), obstacle identification surface (OIS) might be developed for early VCA operations. While obstacles can penetrate this volume, they must be charted for pilot awareness. Pilots are responsible for seeing and avoiding obstacles as they would in VFR operations. The purpose of the visual OIS is to identify obstacles for charting and increase safety, thereby aiding VMC operations.

> ***UAM.POL.VCA.115 Obstacle accountability***
> *For operations to/from final approach and take-off areas (FATO), the operator shall, during preflight planning and for the purpose of obstacle-clearance calculations: [...] (c) disregard obstacles situated beyond the FATO in the take-off flight path or the missed approach flight path if their lateral distance to the nearest point on the surface below the intended flight path is further than the following:*
> *(1) 3 × D for day operations if it is assured that navigational accuracy can be achieved by reference to suitable visual cues during the climb;*
> *(2) 5 × D for night operations if it is assured that navigational accuracy can be achieved by reference to suitable visual cues during the climb;*
> *(3) 300 m if navigational accuracy can be achieved by appropriate navigation aids; or*
> *(4) 900 m in all other cases.*

Once the exact take-off and destination vertiport location is selected and each vertiport layout defined (number of FATOs and stands), the obstacle limitation surface (OLS) and the VCA routes can be designed. The main references are [3, 6, 45] that state how to evaluate the obstacle environment at a vertiport and design the routes.

4.2.2 Case Study III: OLS, Approach and Departure Design

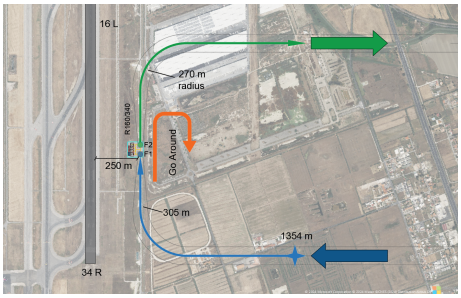
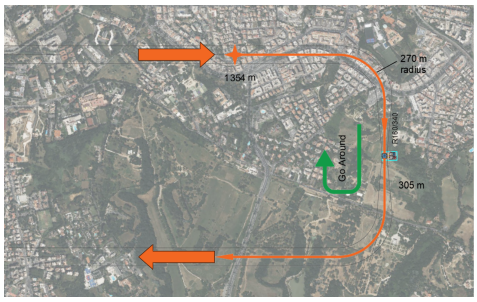
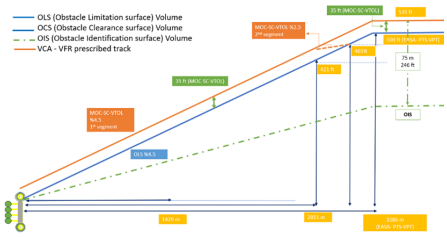
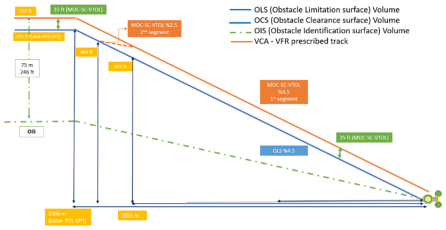
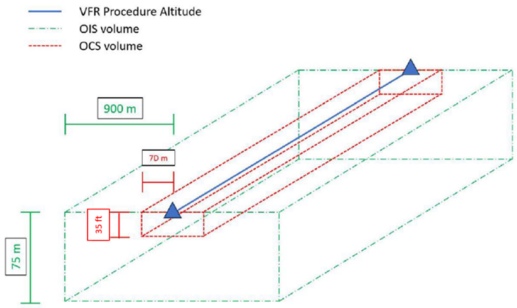
As introduced in Table 1, the use case researched for Case Study III, includes a vertiport at an airport and in an urban environment. As shown in the following Table 12, the airport vertiport is considered to have two FATOs and four independent stands. The straight portion and the radius of the approach and departure are calculated according to [3] [8] based on the criteria $S + R \geq 575\ m$ and $R \geq 270\ m$ where $S = 305\ m$ defines the length of the straight portion and R is the radius of turn with 10%-day divergence. Two different surfaces are separated by 180°, a configuration that ensures that the vertiport usability factor will be at least 95% for the VCA the vertiport is intended to serve, as required by PTS VPT-DSN.D.405 (l) [3]. The reason for using 180°separation is to avoid any intervening go-around procedures for VCA with IFR arrivals or departures. Therefore, the

[8] CHAPTER D — OBSTACLE ENVIRONMENT

orientation of surfaces is aligned with the runway orientation. The approach and take-off climb surface lengths of 3,386 m are associated with the respective slopes (4.5%) required to bring the VCA to 152 m (500 ft) above FATO elevation.

Instead, the urban vertiport has one FATO and two dependent stands and has four different surfaces orientations with a minimum separation of 135°, and a total separation of 180°ensuring that the vertiport usability factor will be at least 95 per cent for the VCA the vertiport is intended to serve.

Table 12: Case Study III: OLS, approach and departure Design for VFR multirotor MVCA.

	Airport Vertiport	Urban Vertiport
Top view		
Side view		
3D view		

After developing the approach, departure and considering the ending of OLS at both vertiports, the lateral distance between the routes is calculated as approximately 1200 m or more in some segments. This spacing is consistent in scale with the minimum lateral distance in UAM.POL.VCA.115 (c) (3), which specifies 300 m where navigational accuracy is assured by appropriate navigation aids. Also, the lateral distance found to each side of one route ensures the obstacle clearance requirements exceeds those recommended in UAM.POL.VCA.115 (a) (1). However, it is noted that this provision primarily addresses obstacle clearance in take-off and missed approach paths, not route-to-route separation, therefore this interpretation should be validated through a dedicated safety assessment.

However, several important considerations raised by safety experts should be noted to correctly interpret this spacing rationale. Although the VCA flights operate under VFR, they are expected to follow prescribed tracks on autopilot, meaning the on-board

navigation system is the primary determinant of track-keeping performance and separation assurance, rather than visual landmark-following as in conventional VFR operations. This operational characteristic, VFR classification with GNSS driven track adherence, represents a fundamental distinction of VCA prescribed track operations that may require dedicated regulatory recognition. While required navigation performance (RNP) specifications formally apply to IFR operations, an equivalent concept may be required to justify lateral route spacing for VFR on prescribed track operations. In particular, navigation accuracy (i.e. total system error), path definition error (i.e. mismatches between the database-encoded and intended trajectories) would all influence the suitability of spacing such as the 1,200 m considered here. The interpretation of UAM.POL.VCA.115 as supporting this spacing relies on treating the neighbouring VCA route as an "obstacle", which may not fully align with the intent of that provision, as it primarily addresses surface obstacles in the take-off/missed approach paths, not route-to-route corridor spacing. External experts also noted that some traditional VFR operations, particularly those following designated low-level visual routes, rely on clear, continous visual references (such as rivers, roads) to enable aircraft to self-separate by following opposite sides of a visual linear cue. Therefore, while 1,200 m could be acceptable, its justification should ideally include additional elements such as RNP-like performance requirements, pilot qualification, ATC involvement, and/or presence of robust visual reference cues along the routes. These factors should be explicitly considered when defining safe and "repeatable" VFR prescribed track spacing for initial VFR VCA operations.

Separate from the route-to-route spacing discussed above, the width of th OIS used for obstacle awareness was also determined. After conducting an expert judgement workshop with airspace and IFP Designers, ATCOs, ATM and U-space specialists as well as standardisation and regulation experts, 900 m was selected as the lateral half-width of the OIS to increase obstacle awareness for pilots. UAM.POL.VCA.115(c) (4) is considered sufficient to cover all cases between VCA and UAS so 900 m is used for the lateral dimension of OIS (see Table 12).

For the VFR en-route phase, visual reporting points are located at the end of the OLS as well as at the edge of the CTR to increase awareness for pilots while entering a CTR.

In Appendix B, the reader can find a detailed summary of the regulatory references that need to be considered when designing VFR routes for VCA operations.

4.2.3 PinS Flight Procedures Adapted to VCA

PinS procedures have been in place for more than two decades. However, these procedures were originally designed for IFR-capable helicopters, whose performance characteristics differ significantly from those of MVCA.

To execute an approach or take-off from a congested airport, rotorcraft airspace users and VCA, without tailored procedures, would be constrained to use the same approach and departure procedures as fixed-wing aircraft, which can affect runway arrival and departure flows and increase ATCO workload due to significant speed differences. Furthermore, fixed-wing IFP often do not suit rotorcraft due to their shallower approach slopes [57].

ICAO PANS OPS 8168 Vol II Part IV provides the criteria for Helicopter PinS procedures based on a basic GNSS receiver, introduced in 2004 [50]. According to ref. [50], a PinS helicopter-only procedure contains both visual and instrument segments. The PinS departure concept consist of a visual flight phase during which the PIC navigates using visual references to reach the IDF, followed by an instrument flight phase after passing the IDF at or above a specified altitude. The PinS approach concept involves flying under

IFR to a PinS, then either continuing visually or executing an instrument missed approach procedure depending on the availability of visual references. Two types of PinS approach procedures are possible: one based on a published visual flight procedure that can be performed under IFR without VMC, and another that requires VMC.

GNSS, preferably augmented with SBAS, is expected to form the backbone of VCA instrument flight procedures, which will rely on PBN criteria and primarily RNP navigation specifications. Basic GNSS supported with receiver autonomous integrity monitoring enables PinS RNP APCH procedures down to lateral navigation minima, whereas SBAS augmentation provide the integrity and accuracy for lower localizer performance with vertical guidance minima. Future dual-frequency multi-constellation GNSS avionics will further enhance precision navigation for VCA. Currently, no tailored PBN criteria or specifications exist for VCA, therefore helicopters design criteria and navigation specifications are used. Nonetheless, when integrated into existing airspace, it is expected that VCA will comply with the requirements established and be approved for PBN operations in line with ICAO DOC 9613- PBN Manual [58].

Given these assumptions, the following PinS procedure design could be considered for VCA operations.

The initial departure phase may be developed as a "proceed visual", depending on the obstacle environment, ending at an IDF at a minimum crossing height (MCH) not below 90 m (295 ft) above the vertiport. The visual climb follows a visual segment gradient (VSG) of 5.3% (0.8% above the take-off flight path area at 4.5% defined in [21]), so the minimum climb gradient is 5.3%. The visual segment up to the IDF nominally ends at 500 ft above the vertiport, consistent with the vertiport obstacle protection surfaces. The IDF altitude may be lower, though not lower than 300 ft above the vertiport, as long as the minimum crossing altitude (MCA) value at IDF is consistent with the subsequent instrument leg minimum obstacle clearance altitude (MOCA) starting at IDF. From the IDF onward, a PBN SID based on RNP1, RNP0.3, or a mixed configuration may be developed depending on the VCA performance. When operating like a helicopter, RNP0.3 may be used; when operating like a fixed-wing aircraft RNP1 becomes more appropriate. All design criteria for PinS departures are specified in detail in in PANS OPS DOC 8168 Vol. II Part IV, Chapter 1 [50].

Enroute segments should preferably use a PBN RNP aligned with VCA performance. RNP 0.3 may be considered depending on the VCA speed profile. The altitude selection depends on VCA performance but does not impact the design criteria; vertical references must align with the applicable transition altitude set for the airspace in which the operation is planned.

An "RNP APCH" instrument flight procedure (0.3 NM navigation accuracy as defined per [58], applicable to the final approach segment; 1 NM applies to the initial, intermediate, and missed approach phases) leads into a PinS aligned with the vertiport location. The initial approach fix (IAF) should typically not be closer than 6.5 NM to ensure adequate segment length for intermediate and final approach segments. In addition, the RNP APCH procedure should preferably use 3-dimensional design criteria with SBAS. The optimum descent gradient for the final segment is 6.5%, with a recommended maximum of 10%. Gradients up to 13.2% may be used if approach speeds remain below 70 kts. From missed approach point (MAPt)/descent point (DP) to the FATO, a visual segment is provided via a “proceed visually” instruction, depending on the obstacle environment surrounding the vertiport. The MAPt altitude must be at least 250 ft above the FATO, (consistent with a 3D Type A minimum OCH value) and require a minimum visibility value of 800 m

consistent with PINs procedures as defined in EASA Air Operations [16]. The minimum descent gradient during the visual phase must respect the obstacle protection surfaces of the destination FATO and the VCA performance.

The landing decision point equals the MAPt. When the visual segment descent angle reaches the obstacle clearance altitude/height before the latest along track tolerance of the MAPt, a descent point can be defined, though it does not replace the MAPt. MAPt/DP must be no closer than 0.54 NM (for indicated airspeed $\leq$ 70 kt) or 0.85 NM (for indicated airspeed $\leq$ 90 kt) with optimum distances of 0.65NM and 1.08 NM respectively, and a maximum of 1.62 NM (3000 m).

4.2.4 Case Study I: PinS Flight Procedures adapted to VCA

For Case Study I, PinS procedures have been adapted for VCA operations, taking into account Nice Côte d'Azur heliport (LFMN) and Monaco international heliport (LNMC). The procedures developed are based on the specific vertiport location, existing airspace structure, defined by the control area around Nice Airport (LFMN) and Cannes Airport (LFMD) and the intersecting restricted area R106 of Monaco heliport (LNMC), feasibility of the routes based on actual conventional traffic and the performance of the reference IFR MVCA (i.e. tiltrotor configuration). The PinS procedure design for IFR MVCA in tiltrotor configuration from Monaco to Nice is displayed in Figure 23.

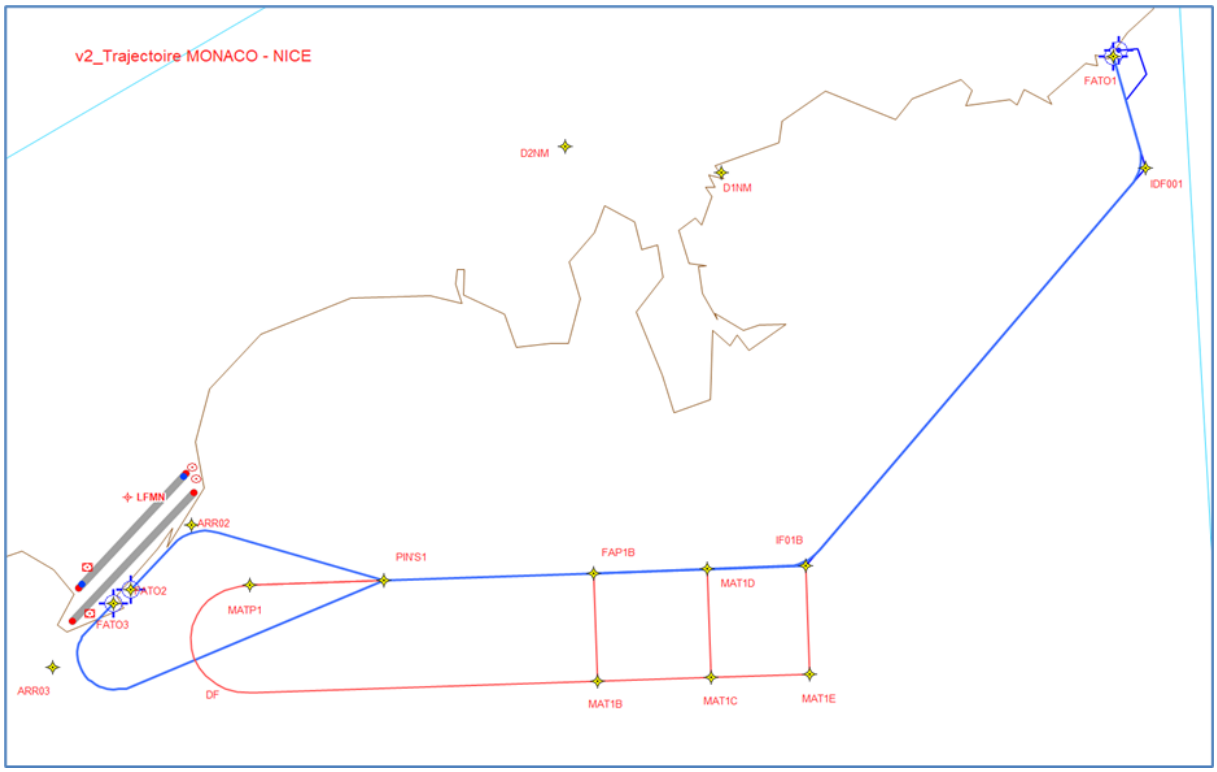


Figure 23: Case Study I: PinS procedure established for IFR MVCA in tiltrotor configuration for R&D purposes, ©ENAC PANS-OPS Office.

The assumption made was that the IFR MVCA could be classified as a Category A aircraft, due to its approach speed <90 kt. Consequently, the new PinS procedures were developed under this assumption. However, the IFR MVCA's performance characteristics do not completely correspond to a Category A aircraft nor to a helicopter, implying that

changes were made to adapt the PinS procedures to the aircraft's performance, such as segment lengths and missed approach.

The reference aircraft considered (IFR Tiltrotor MVCA) descends at a rate of 8%, which is higher than the maximum regulatory value for Cat. A aircraft (5.2%). Therefore, the segments containing descents were shortened accordingly to take into account the increased aircraft manoeuvrability. This resulted in a shortened approach, especially the final approach segment which is highlighted by a steep descent.

Energy reserves of the reference IFR MVCA do not allow for long missed approach segments, especially in a contingency situation. To address this limitation, the traditional missed approach segments were shortened, while taking into account the aircraft manoeuvrability. This was made possible as the reference IFR MVCA has the capability to make 90° turns, which is over the regulatory limit in a published flight procedure. Therefore, the standardised missed approach was adapted to the reference IFR MVCA with a 90° turn to the final approach point (FAP) directly, instead of returning to the IAP, even though this manoeuvre is not strictly compliant with current regulations. This procedure allowed to shorten the missed approach procedure according to the aircraft's needs.

Due to the more limited energy reserves compared to conventional aircraft or helicopter, extended holding patterns present a significant issue, and potential diversion locations or destination alternates must remain reachable only until point of commitment (POC). Taken together, a holding followed by a diversion might not be feasible for all VCA. An immediate decision regarding the next steps is therefore required. From the five options available today, the number of usable options decreases as the electric MVCA approaches its destination. At the POC, the final destination, which could also be a diversion location, must be decided. At that point, the options are generally expected to be reduced from five to three; First, abort the approach and perform a go-around; Second, abort the approach and go into a holding position; Third, go directly into a holding position, however it should be considered that, if possible, holding should be avoided due to battery constraints. This means that only a specific amount of energy is available for contingency situations, and energy management, early communication, and timely information sharing become critical factors in the event of a contingency at a vertiport. The defined reserves allow only a limited number of decisions. An additional factor in this context is the general range capability of the aircraft compared with the flown distance or route length. This can be described as range-route length ratio. The closer this ratio is to 1, the more heavily the operations relies on the pre-defined regulatory required energy reserve, and the fewer alternatives remain available.

In conclusion, the currently planned flight procedures depend on appropriate energy planning during the flight-planning phase. This includes defining a sufficient number of diversion locations and identifying VCA capability in the event of a critical failure performance (CFP) scenario. These procedures may differ depending on the VCA model considered; for example, differences in redundancy, type of failure, battery capacity, or energy consumption may be a factor. It should also be noted that a CFP is not an emergency situation. Any failure condition beyond the defined CFP-failure envelope that is not covered by the pre-planned contingency responses, could lead to an emergency situation. In line with the applicable airworthiness requirements, the probability of such failures must be shown to be below 10^{-9} per flight hour, consistent with the classification of catastrophic failure conditions.

4.2.5 UAM Corridor

While investigating flight procedure design for VCA operations, operating on prescribed VFR tracks or along established IFR routes, both designs make use of the same airspace construct, "UAM corridors". UAM corridors generalise the notion of "prescribed VFR tracks" and IFR routes.

The establishment of dedicated airspace structures such as blocks, segments, flyways, or corridors, may be considered to support the specific operational capabilities of VCA within the European airspace. These structures should be complemented by clearly defined requirements for operating within these airspace constructs. This ensures procedural deconfliction of VCA operations from sUAS operations and other relevant manned traffic.

As, in general, the establishment of two sets of segregated networks of UAM corridors for VFR and IFR in the same airspace connecting the same vertiports might be difficult, we propose that the airspace constructs and resulting corridor network may be designed to be compatible for both VFR and IFR traffic.

As of today, VFR and IFR traffic can share the same ATS routes, although using different cruising flight levels, based on the well-known semicircular rule. Per SERA.5020(b) and SERA.5025(a), IFR flights use whole odd-thousand-foot levels when flying eastbound (magnetic course 000-179) and whole even-thousand-foot levels when flying westbound (magnetic course 180-359), unless superseded by ATC clearance or otherwise indicated by the competent authority in the applicable AIP [41]. Per SERA.5005(g), VFR flights cruising above 900 m (3,000 ft) above ground level (AGL) use odd-thousand-foot-plus-500-foot levels when flying eastbound and even-thousand-floot-plus-500-foot levels when flying westbound [41].

Below 900 m (3,000 ft) AGL, VFR pilots are free to select any cruising altitude compatible with SERA.5005 (f), i.e., at least 300 m (1,000 ft) above the highest obstacle within 600 m (2,000 ft) range over congested areas, and at least 150 m (500 ft) above the ground, water, or highest obstacle within 150 m (500 ft) range elsewhere.

While IFR flights keep following the semicircular rule at or below 900 m (3,000 ft) AGL, SERA.5015(b) establishes general minimum IFR cruising levels as 300 m (1,000 ft) above the highest obstacle within 8 km range, or 600 m (2,000 ft) if over high terrain or mountain areas. These minimum altitudes may have to be increased if minimum en-route altitude, minimum obstacle clearance altitude, minimum reception altitude or minimum vectoring altitude apply.

Bearing in mind that most UAM operations are typically expected to cruise at or below 4,000 ft AGL, assuming relatively flat terrain and obstacles not exceeding 1,000 ft MSL, the above rules would enable the following four IFR cruise levels.

- FL020 (2,000 ft MSL) and FL040 (4,000 ft MSL) for westbound flights
- FL030 (3,000 ft MSL) and FL050 (5,000 ft MSL) for eastbound flights (or FL010 and FL030 if terrain and obstacles do not exceed 500 ft MSL)

And, assuming that the semicircular rule is extended to VFR cruising below 900 m (3,000 ft) AGL, it results to the following four VFR cruise levels:

- FL015 (1,500 ft MSL) and FL035 (3,500 ft MSL) for eastbound flights
- FL025 (2,500 ft MSL) and FL045 (4,500 ft MSL) for westbound flights

However, it should be noted that he usability of lower VFR cruise levels, particularly FL015, depends on the prevailing meteorological conditions. According to SERA.5001, VFR operations at altitudes above 1,000 ft AGL or 3,000 ft AMSL (whichever is higher) require a minimum of 1,000 ft (300 m) vertical separation from clouds [41]. A VCA cruising at FL015 (1,500 ft MSL) in flat terrain would typically operate above this threshold. This means that cloud ceilings below approximately 2,500 ft MSL would make this cruise level unavailable under VFR conditions. This constraint should be considered when planning VCA operations in environments with low ceilings, which are typical of northern and central European airspace.

This provides sufficient options for merging IAM VFR and IFR traffic cruising along the same UAM route, at least for initial operations. This is based on standard vertical separation minima and flight rules, with the only exception being that SERA.5005(g) is extended to VFR flights below 900 m (3,000 ft) AGL.

We believe that defining UAM corridors based on the above mentioned IFR constructs can enable both IAM IFR and VFR traffic of heterogeneous aircraft types to operate within them, thereby supporting the scalability of the airspace design.

Based on the above, UAM corridors may include the following:

- Multiple options of instrument departure procedure (IDP) and instrument approach procedure (IAP), which could be designed for VCA with diverse performance characteristics, limitations and PBN capabilities, as well as for various vertiport configurations.

- An en-route segment connecting the end of the IDP (assumed to be the top of climb (TOC)) with the beginning of the IAP, (i.e. the IAF), which likely coincide with the top of descent (TOD) because a terminal route like the conventional STAR is not considered to be required due to the relatively short flight distances and low flight altitudes. Furthermore, take-off vertiports or diversion locations that are sufficiently close to the destination vertiport/location would not allow for an en-route segment. This could lead to a direct connection between the IDP and the IAP.

Together with VCA operators and based on previous research work, the idea of dedicated airspace structures to procedurally separate VCA operations from drones and other manned aircraft should be further researched, with a specific focus on a thorough safety assessment.

4.3 Vertiport Traffic Zone

EASA's Notice of Proposed Amendment 2022-06, introduces an airspace structure dedicated to the traffic using the airspace in the vicinity of a vertiport [10]. It suggests that, a vertiport information zone (VIZ) could be implemented to coordinate flights and manage the landing pad when necessary. In contrast, the vertiport traffic zone (VTZ), as proposed by the European U-space Edition 4 [59], combines CTR, ATZ and TMA. Building on these two terms (VIZ, VTZ), which are mentioned but not further elaborated, a potential approach for structuring and classifying the airspace around a vertiport is discussed and evaluated. We define the VTZ to be an optional designated area of airspace surrounding the vertiport. The competent authority shall decide, as part of the air risk analysis and airspace risk assessment, whether such airspace structure needs to be established for the analysed vertiport or not.

If established, the VTZ should be designed after the initial VCA routes were designed which includes VCA route design for continuous safe flight and landing (CSFL). This defines the VTZ as an operational airspace volume established to inform, and to manage, if applicable, VCA flights in the final approach and initial departure around the vertiport and to ensure the safety of all airspace users operating within and nearby.

The VTZ can be defined as a geographical or functional volume of airspace (zone). A VTZ can be seen as a geographical volume of airspace (zone) starting from the ground to an upper level, that either follows existing classification of airspace classes, is designated as U-space airspace, and/or is declared as a UAS geographical zone. In the early stages of vertiport operations, the VTZ may represent an airspace that is part of the airspace continuum but acts as a geographical zone for all U-space traffic to reduce the complexity of traffic management. This protects certified VCA operations from risk of in-flight collision between VCA and sUAS that are not intended to land or operate at the vertiport.

The geographical characteristics of the VTZ include:

- the vertiport reference point (VRP) or the airport reference point (ARP) if the vertiport is collocated with the airport [9],
- the definition of an airspace extending upwards from the surface of the earth to a specified upper and lateral limit,
- the definition of the vertiport airside ground and air boundaries which are part of the VTZ,
- VCA routes in all its specifics i.e. normal, contingency, weather dependent and holdings, if any, and
- critical decision points for flight and operating procedures which may vary in space and time based on the VCA performance.

If a VTZ is established, each vertiport may have a specific shape of the VTZ, based on the obstacle and operating environment and the minimum VCA performance requirements, most likely resulting in VTZ shapes other than cylindrical.

The VTZ can be also understood as a functional volume of airspace (zone) which is a better equipped area in terms of CNS, monitoring, weather sensoring, etc. It provides published entry and exit points based on the VCA flight procedure design, dedicated vertiport services and rules where authorisation or clearances may be required to enter, exit or transit, and where minimum VCA performance and equipage is required to operate in this portion of airspace. The functional characteristic of the VTZ is defined as an airspace that provides dedicated vertiport related services to approaching and departing VCA. Once VCA traffic eventually increases over time, the complexity and responsibility these services carry may grow over time and depending on the operational context, resembling AFIS within in a FIZ. Therefore the VTZ includes the provision of vertiport traffic information and vertiport traffic management. Vertiports located in uncontrolled airspace (class G) can have a VTZ in place which is characterised as a volume of airspace in which traffic information service is provided to enhance situational awareness to all airspace users operating at or near the vertiport.

[9] see PTS VPT-DSN.B.110 [3]

As VCA operations transition to controlled airspace (class C,D), the VTZ either will be absorbed by the existing airspace class and its responsible authority, or, if the vertiport is not located in direct oversight to the ATCO, a third party authorised to take on this responsibility must be found. In cases where the vertiport is operating in U-space airspace inside a CTR, air traffic control services have to be provided by an authorised stakeholder, which could be the USSP or a third party. This setup requires interaction with ATM, potentially facilitated through collaborative interface with ATC. Looking ahead, this requires the USSP to be elevated to a controlling entity emerging as a new form and digitalised version of ATC.

In a fully matured and advanced U-space environment, both traffic information and traffic management services would be provided by the USSP or a third party authorised to do so, including "digital clearances", if necessary. It could be envisioned to move from direct "digital clearances" to implicit "digital clearances".

Additionally, the VTZ includes the provision of certified weather services, which are essential for strategic flight preparation and planning, as well as during flight execution (see Section 2.4). Enhanced CNS service provision is also a key component of the VTZ's functional capabilities. The provision of traffic information and/or traffic management is the responsibility of the VTZ manager who ensures the safe management of nominal, contingency and emergency scenarios, including priority management at a vertiport.

The role of the VTZ manager may be assigned to a new stakeholder/actor or to an existing stakeholder/actor. Therefore, this role can be either part of ATC, the stakeholder responsible for the provision of vertiport traffic information and/or traffic management services or a delegated third party (centralised or federated). The correct assignment of the VTZ role is driven by the operating environment and has to be assessed individually for each vertiport and VTZ.

5 Demand and Capacity Balancing

Demand and capacity balancing will strategically evaluate system-wide traffic flows and aerodrome capacities to allow airspace users to determine when, where and how they operate, while mitigating conflicting needs for airspace and aerodrome capacity. This collaborative process will allow for the efficient management of the air traffic flow through the use of information on system-wide air traffic flows, weather and assets." [1]

5.1 Background

The main metric for defining capacity at a vertiport is the number of movements per hour that the infrastructure can enable. Having a clear understanding of the capability of a vertiport to generate capacity at early planning and design stages is essential for a viable business model, especially when operations primarily rely on landing fees. Capacity can be estimated by considering departure and landing pad availability, taxi and turnaround times, vehicle performance, and separation requirements.

When comparing vertiports to other aerodromes, existing best practices and design solutions applied at airports and heliports to maximise capacity offer valuable insights. These focus on maximising runway and FATO utilisation by optimising access and egress points, enabling simultaneous operations where possible, minimising taxi distances, and improving overall ground traffic flow. Such improvements can be achieved, for example, by introducing parallel taxiways and reducing or even eliminating cul-de-sacs on aprons where pushback manoeuvres are carried out. In addition, reducing turnaround times to minimise stand occupancy, as well as employing dynamic and real-time resource allocation, can further increase capacity.

Airports and heliports have traditionally relied on a combination of infrastructure planning, slot allocation, and collaborative decision-making frameworks for the capacity management of civil aviation operations. Established practices such as the worldwide airport slot guidelines (WASG) and the airport collaborative decision making (A-CDM) approach provide relevant mechanisms to balance demand strategically with available infrastructure and ensure predictability of operations especially for those airports that encounter high demand but have constrained capacities. These systems depend on the accuracy of demand forecasting sources, continuous monitoring and surveillance of the availability of ground infrastructure and airspace, and structured procedures to coordinate between the relevant ecosystem stakeholders: ATM, ground handlers, and aerodrome operators.

Similar principles can be applied to the design of vertiports despite its smaller size and number of movements. When a taxiway system is present and VCA are turned around on parking stands, additional FATO access and egress points allow aircraft to vacate the FATO after landing in the most convenient and fastest way possible. This also allows departing aircraft to taxi to the FATO without interference. In the context of IAM, it becomes increasingly evident that the industry requests technology and innovation that demands a new paradigm for capacity management, one that leverages efficiency, resilience, and seamless information flow inside a vertiport network. Unless we have a VCA flight taking-off and landing at the same vertiport, all other VCA operations require a vertiport network, a minimum of two. Therefore, vertiports must be integrated into the IAM network, where data sharing is essential. Adopting collaborative decision-making principles

has shown improved situational awareness, enhanced coordinated decision-making, and optimised performance-based metrics in traditional aviation [60]. This leads to enhanced operational reliability, which is predominantly important for UAM flights that are expected to be less than 30 minutes.

EASA's Notice of Proposed Amendment 2022-06, suggests that "an effective time slot allocation system for managing the traffic and landing pad might be needed. It seems necessary to have more information on the way a vertiport traffic will be managed before determining whether the risk is sufficiently mitigated. There is a clear link between availability of landing pads at vertiports and the management of the circuit/approach, and even the frequency of flights allowed on predetermined routes" [10]. This requires the definition of a vertiport slot, how it is allocated, and the exact meaning of landing pad availability at vertiports as they become safety-critical operational constraints.

According to the Commission Implementing Regulation (EU) 2024/1111, there is an obligation of the VCA-PIC, as part of the "fuel/energy scheme" to select safe landing options during flight preparation and indicate this selection in the operational or ATS flight plan, depending on what is applicable in the operating airspace class [6]. An excerpt is provided in the following.

> ***UAM.OP.MVCA.192 Fuel/energy scheme – selection of vertiports and diversion locations***
> *(a) The PIC shall select and specify in the operational flight plan and, if so required, in the ATS flight plan, for normal operations, including training, and for the purpose of diversion:*
> *(1) at least two safe landing options at the destination, which may be reached from the point of commitment for landing; and*
> *(2) one or more vertiports or diversion locations to ensure safe landing in case a diversion is necessary following a CFP at any moment during the flight.*

In detail, this means that a vertiport and diversion location is selected based on the following criteria:

> ***UAM.OP.MVCA.192 Fuel/energy scheme – selection of vertiports and diversion locations*** *(b) For the purpose of selecting vertiports and diversion locations in accordance with point (a), the PIC shall consider whether:*
> *(1) the actual and forecast weather conditions indicate that at the estimated time of use the conditions at the selected vertiports and diversion locations will be at or above the applicable minima established in accordance with point UAM.OP.MVCA.111;*
> *(2) the certified minimum performance (CMP) of the VCA allows for safe landing at the selected vertiports or diversion locations;*
> *(3) any required additional operational approvals are held.*
> *(c) The PIC shall apply appropriate safety margins to flight planning to take possible deterioration of the meteorological conditions into account at the estimated time of landing compared to the available forecast.*

Instead of referring to a vertiport slot, the requirement stated in UAM.OP.MVCA 192 refers to a "safe landing option". Secondly, the PIC must select and specify, in the operational or ATS flight plan, two (!) safe landing options at destination. An additional requirement, which ties the selection of the safe landing option to the estimated times of use, is stated in the following paragraph UAM.OP.MVCA.193. This is a first indication of how vertiport availability might be defined.

> ***UAM.OP.MVCA.193 Safe landing options at the destination***
> *The PIC shall commit to land at one of the safe landing options in accordance with point UAM.OP.MVCA.192, when the current assessment of the meteorological conditions, traffic, and other operational conditions indicate that a safe landing can be performed at the committed landing site* ***at the estimated time of use****.*

Having a look at the acceptable means of compliance and guidance material to Annex IX (Part-IAM) to Regulation (EU) No 965/2012, one can find an additional requirement to UAM.OP.MVCA.193 [45]:

> ***AMC1 UAM.OP.MVCA.193 Safe landing options at the destination TRAFFIC AND OTHER OPERATIONAL CONDITIONS***
> *(a) The PIC should commit to land at one of the safe landing options:*
> *(1) following an energy system check and prediction indicating that the remaining energy is sufficient to perform a safe landing at the committed landing option; and (2) after checking that the landing option is available.*
> *(b) If the safe landing options are co-located at the destination vertiport,* ***the PIC should ensure that no other aircraft is taking off or landing at any of them at the same time when the landing of the VCA is expected****, unless the landing options are independent and operation at one of them does not affect safe landing at the other one.*

With UAM.OP.MVCA.193, "safe landing options" are now tight to two requirements; First, "estimated time of use" and second, the assurance that no other aircraft is taking-off or landing at any of them at the same time, when dependent. Going back to ref. [6], the first requirement is mentioned in the context of "**adequate** aerodrome, vertiport, diversion locations" which is not used in UAM.OP.MVCA.192 and means:

> *(141) "adequate vertiport" means a vertiport at which the VCA may be operated, taking account of the aircraft dimensions, weight, approach and departure paths, and which is provided with services and facilities necessary for the intended operation and is available at the expected time of use;*

This reference to "adequate vertiport/diversion locations" is also stated in the definition of "safe landing" which is defined as:

> *(104a) "safe landing" means, in the context of the fuel/energy policy or fuel/energy schemes, a landing at an adequate aerodrome or operating site or at an adequate vertiport or diversion location with no less than the final reserve fuel/energy remaining and in compliance with the applicable operational procedures and aerodrome operating minima;*

As a final step, we take a closer look at how an adequate vertiport and adequate diversion location are defined and discover the term "available" in paragraph UAM.OP. MVCA.107":

> ***UAM.OP. MVCA.107 Adequate vertiport and adequate diversion location***
> *(a) The IAM operator shall use adequate vertiports for its normal operations and for diversion from the planned route as necessary.*
> *(b) Notwithstanding point (a), the IAM operator may use one or more adequate diversion locations while en-route to divert from the planned route as necessary.*
> *(c) A vertiport is considered adequate if at the expected time of use it is:*
> *(1) compatible with the dimensions and weight of the VCA;*
> *(2) compatible with the VCA approach and departure paths;*
> *(3) provided with rescue and firefighting services (RFFS) and other services and facilities necessary for the intended operation; and*
> *(4) available.*
> *(d) A diversion location is considered adequate if at the expected time of use:*
> *(1) its characteristics, including dimensions, obstacles, and surface condition, are compatible with the VCA and allow for landing in accordance with an approved landing profile;*
> *(2) it can be reached within the CMP of the VCA taking wind limitations into account;*
> *(3) it has an acceptable level of RFFS protection;*
> *(4) it is pre-surveyed; and*
> *(5) it is available.*

In current aviation terms, availability would refer to consulting the AIP and issued NOTAMs that include, among other elements, information on aerodrome and heliport closure, unavailability, or changes in the aerodrome/heliport operational hours [61]. However, even if all criteria related to the selection of safe landing options are met during the flight preparation phase, the PIC has no means to access the actual availability of the vertiport infrastructure, particularly the landing pad, at the expected time of use. There are currently no explicit processes mandating the vertiport/diversion location operator to share real-time landing pad availability. Given the limited endurance of electric VCA this can pose significant safety risks.

This leads back to the original challenge: the absence of clear specifications regarding a vertiport slot, the slot allocation system, and the definition of vertiport availability itself. Addressing this requires, first, what vertiport information must be provided to the PIC to support its decision-making when selecting safe landing options en-route and at destination during flight preparation. Second, it requires agreement on how this information can be made accessible and reliably transmitted across different airspace classes and operating conditions.

In the following sections, we elaborate how the three concepts, *vertiport slot*, *vertiport availability* and *slot allocation system* can be defined, implemented and leveraged to plan and execute IAM operations in a manner that balances demand and capacity.

5.2 Vertiport Slot

According to the WASG [62], "an airport slot (or 'slot') is a permission given by a coordinator for a planned operation to use the full range of airport infrastructure necessary to arrive or depart at a Level 3 airport on a specific date and time". "Coordinated airports" (not all airports are coordinated), are categorised in the degree of capacity-demand imbalance they experience. This results in Level 1, 2 and 3 classifications, ranging from "demand can be sufficiently met" to "potential risk for congestion" and finally "demand exceeds significantly the capacity".

As IAM is still in its infancy, risk of congestion is unlikely in the early stages. However, for IAM operators to maintain a financially viable business case, they must maximise fleet utilisation, which may lead to a potential risk of congestion at hot-spot vertiports, especially considering additional safety requirements VCA must meet under the CSFL regulation in ref. [6].

For IAM operations, we define a vertiport slot (or "slot") as a time-based operational resource allocation, issued by the operator of the vertiport, that reserves the required vertiport infrastructure for the execution of a specific IAM flight. The "size" and the amount of vertiport slots are derived from a vertiport capacity analysis that is shaped by the vertiport layout configuration (e.g. number of TLOF areas, co-location of FATO and TLOF, hover or ground taxi, operational (in-)dependence), operational hours, charging infrastructure and ground movement availability, staff constraints (e.g. RFFS, security), the level of automation available for ground handling and passenger processing, etc.

Therefore, a vertiport slot defines a time window in which an IAM operation (take-off, landing, taxi, and turnaround processes) may be performed and ensures that the vertiport can safely and efficiently accommodate that flight within its available capacity. Vertiport slot times are based on the scheduled landing (arrival) and take-off (departure) times[10]

[10]For comparison, in conventional airport operations, the airport slot is based on the planned in-block (arrival) and off-block times (departure) [62].

and they specify the assigned landing and departure pads (both regular and diversion) through a unique identifier. The closer the planning horizon approaches the tactical flight phase and decision-making, the more precise the time-window allocated to the vertiport slot gets. Consequently, a vertiport slot represents the fundamental building block of "vertiport availability".

Following best practices in conventional aviation and respecting the requirements for IAM operations, the following requirements on vertiport slots have been collected.

- A vertiport slot is a time-bounded reservation of vertiport resources allocated to a specific IAM operation, enabling a landing, take-off and ground movement (if applicable) at a vertiport under coordinated conditions.
- The vertiport slot applies to vertiport infrastructure only (e.g. FATO, TLOF, stand) and is independent from en-route airspace management.
- Vertiport slots are defined by a specific date and time window, ensuring temporal separation between consecutive operations.
- Vertiport slots are time-dependent; deviations beyond predefined thresholds may trigger slot reassignment, delay or flight plan update.
- Vertiport slots are allocated and managed by the vertiport manager through the Vertiport Management System.
- A TLOF/FATO or stand cannot be allocated to more than one IAM operation at the same time, ensuring safe separation on the ground
- A flight cannot be authorised or activated without a confirmed slot at the origin and destination vertiport.
- Vertiport slots should be allocated to IAM airlines and aircraft operators in a neutral, transparent, and non-discriminatory way.
- The objective is to prevent overlapping use of shared critical infrastructure and guarantees safe scheduling between IAM operations.
- Vertiport slots must be made available in the form of common information regardless of whether the vertiport operation occurs in controlled, uncontrolled or U-space airspace.
- Vertiport slots may be updated or cancelled due to changes of vertiport availability, vertiport status, TLOF/FATO availability, weather conditions, delays or other events causing disruption of the actual traffic flow.
- In U-space,
  - Vertiport slots are a mandatory element of consideration during flight planning and are therefore considered a safety-critical component of the U-plan.
  - The USSP must check and confirm the slot availability before a flight authorisation or activation can be granted. After granting a flight authorisation and activation, slot booking becomes a legally binding confirmation that all required vertiport elements (FATO/TLOF, stands, parking, charging, refuelling, or ground handling services) are available at the requested time of use.

- A confirmed vertiport slot alone does not constitute final landing authorisation and clearance; it is a strategic reservation to ensure the flight will have a landing pad available on arrival, barring unforeseen changes.
- Slot information is disseminated through the extended services of the CISP, which acts as the single source of truth for all static and dynamic data relevant to vertiport availability. Through that, the USSP can access at anytime the relevant data to check slot availability before granting flight authorisation and activation.

– in ATS airspace,

- Vertiport slots must be indicated in the ATS flight plan/or OFP in accordance with the applicable rules of the air for the class(es) of airspace in which the operation will be conducted.
- The VCA operator must verify slot availability before departure. A confirmed slot booking serves as a legally binding assurance that all required vertiport elements (FATO/TLOF, stands, parking, charging, refuelling, or ground handling services) are available at the requested time of use.
- Slot information is accessed bi-laterally either through vertiport-slot allocation systems (e.g. VFR/IFR-slot booking tool for general aviation operating at Zurich Airport [11] [63]) or via telephone coordination. The single source of truth for all static and dynamic data relevant to vertiport operations lies with the originator of this information (i.e. vertiport operator).

5.3 Vertiport Availability

As identified in the previous Section 5.2, the vertiport slot represents the fundamental building block of *Vertiport Availability*. However, several additional characteristics must be considered to obtain a complete view of the real-time operational status of the vertiport and the selected diversion locations. These characteristics directly affect the final allocation of vertiport slots.

An incoming VCA flight intent receives a preliminary vertiport slot reservation based on the theoretical schedule. This schedule is established based on the "hard-constraints" of the vertiport as defined in Sections 5.1 and 5.2, derived from the overall vertiport capacity. Because these slots reflect broader operational uncertainties, they may cover larger time-windows, which may lead to less capacity on a theoretical level. As the planning horizon progresses and approaches the actual departure time, the vertiport slot must be booked and confirmed according to the requirements stated in ref. [6].

Here, we focus specifically on the requirement that "a vertiport/diversion location is considered adequate if at the expected time of use it is available" (i.e. notion of *Vertiport Availability*). We define vertiport availability as confirmed when both *Pad Availability* and *Vertiport Status* are confirmed.

Pad Availability indicates that the FATO infrastructure is physically usable[12] and free for booking. This means that the pad (see Figure 4) is physically usable (i.e. not occupied by another VCA, not undergoing maintenance, not confirmed for contingency operations)

[11] Slot must be booked minimum 30 minutes in advance and confirmed slot-ID must be entered into field 18 of the ATS flight plan.

[12] This should not be confused with *vertiport usability* defined in Section 3.2.3.

and free for booking. Confirmation of pad availability is provided through a two-factor mechanism: system-based confirmation via the VMS or VNMS (when operated by a local vertiport network manager), and visual confirmation by the responsible stakeholder, either through direct oversight or remote-tower technology.

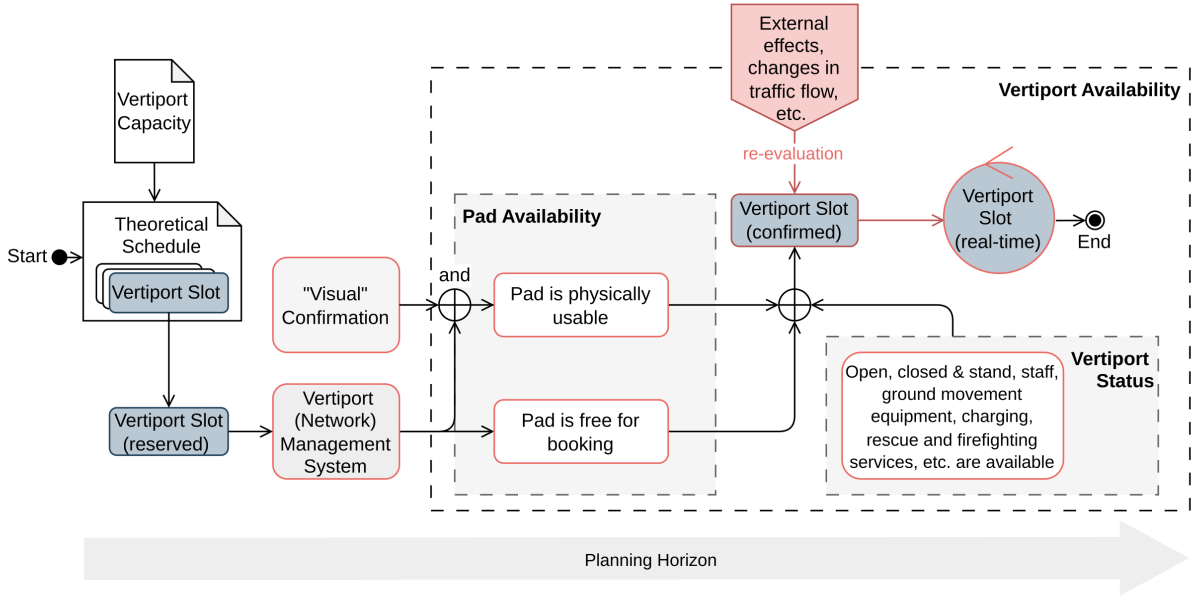


Figure 24: Approach to vertiport availability: Slot progression from reservation to real-time confirmation, combining pad availability and vertiport status. The term "vertiport" can be substituted with "diversion location".

In addition to Pad availability, the *Vertiport Status* is essential for confirming and ultimately booking a vertiport slot. The vertiport must be operational (open/closed), and, where required, stands, staff, ground movement equipment, charging infrastructure, and RFFS capability must be available.

Once both, pad availability and vertiport status are confirmed (= vertiport availability), the vertiport slot is updated from *reserved* to *confirmed*. This confirmed vertiport slot is then allocated to a specific VCA operations and guarantees that the FATO shall not be used by another VCA, except in case of contingencies. We consider this confirmation as a prerequisite for take-off.

Throughout all phases of the flight, the *confirmed* vertiport slot transitions to a real-time slot and remains subject to re-evaluation. External effects such as changing weather conditions or disruptions in the traffic flow may trigger reassessment of the confirmed slot. A summary of the definition of vertiport availability is presented in Figure 24.

5.4 Vertiport Slot Allocation in U-Plan

To ensure vertiport availability is maintained throughout all phases of the flight and that any updates are shared with all relevant stakeholders, a coordinated and continuous information-exchange process is required. This includes the VCA operator, the USSP, ATC, and the vertiport (network) operator. More importantly, vertiport availability must not be treated as a static outcome of the flight planning phase alone. Instead, its real-time status affects pre-flight authorisation/activation, en-route and disruption management,

approach and landing authorisation, and taxi/parking authorisation and all ATS clearances until the flight plan is terminated.

A vertiport (network) management system (VMS/VNMS) must therefore be in place, to manage and monitor vertiport operations and facilitate the reliable, real-time exchange of all required data from flight planning to landing.

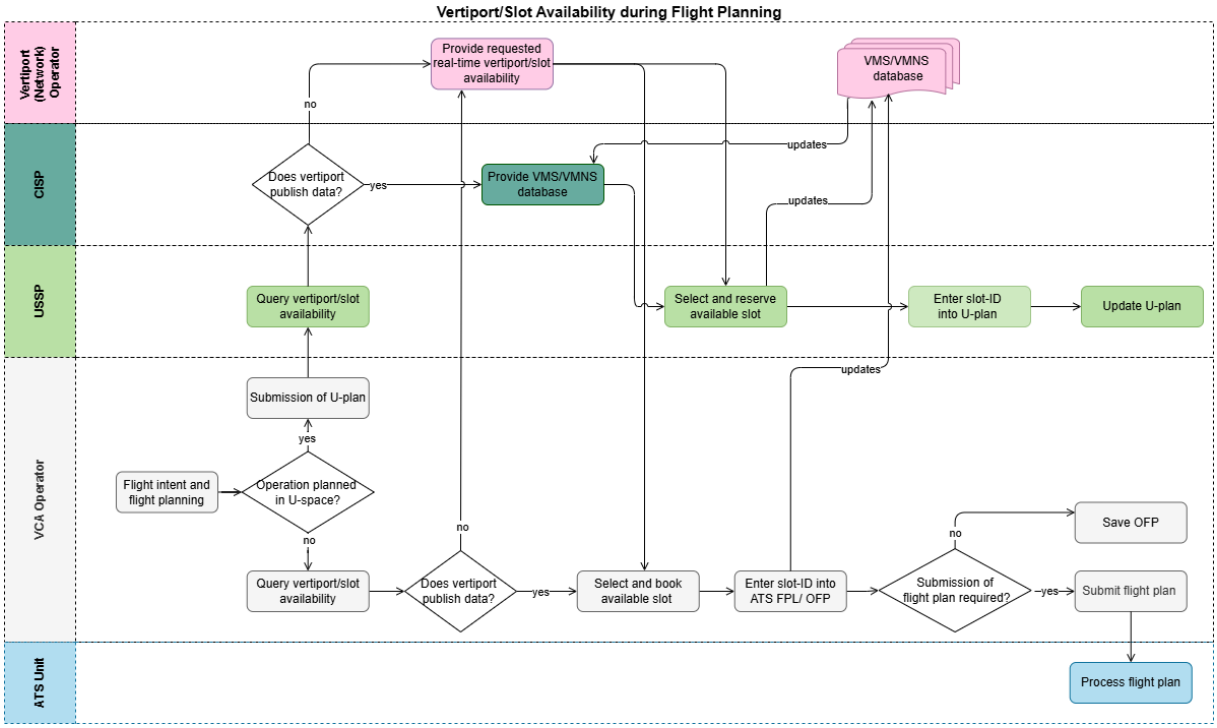


Figure 25: Possible ways of accessing vertiport/slot availability during VCA flight planning in different operating environment.

During flight planning (i.e. Take-off - months/minutes), the VCA operator must query vertiport availability for take-off, destination vertiport and all selected diversion vertiports/locations. Considering a VCA as active U-space user operating inside U-space airspace, this is expected to be facilitated by the USSP. When the VCA operator submits a U-plan, the USSP requests vertiport availability for the required vertiport slots from the vertiport operator. This can occur in two ways.

1. Publication model: The vertiport publishes its availability in real-time (via a database connected to the VMS/VMNS) which the USSP can access directly. This provides access to the entire reserved/booked vertiport schedule.

2. Query/response model: The USSP submits a request to the vertiport operators, who then provides real-time vertiport availability data on demand. This provides access only to the requested time-window of the vertiport schedule.

If the requested vertiports are available at the expected time of use, the vertiport operator (or the VMS/VMNS) reserves it. If not, alternative vertiport slots or diversion locations must be selected. The reserved vertiport slot becomes part of the operator's flight plan (U-plan, ATS flight plan, OFP) and functions as a contractual strategic reservation ensuring that the required ground infrastructure will be available at the estimated time of use.

If the VCA flight is conducted in legacy ATS airspace (outside of U-space airspace), the VCA operator is responsible for querying the vertiport availability directly through bi-lateral coordination mechanisms (e.g. vertiport slot booking tools, telephone).

A summary of how vertiport/slot availability could be queried during VCA flight planning in different operating environments is displayed in Figure 25.

In summary, vertiport slot allocation and keeping the U-plan updated according to real-time vertiport availability relies on coordinated and timely information flows between all operational stakeholder: The vertiport operator provides continuously updated vertiport availability information; the USSP or ATM system facilitates the integration of this information into flight planning, flight authorisation and clearance provision; the VCA operator selects multiple diversion locations in accordance with the regulatory requirement and responds to changes in the U-plan; the ATCO adjusts VCA traffic sequencing in line with real-time conditions. In EUREKA, this collaborative process is captured under the concept of vertiport collaborative traffic management (VCTM), based on A-CDM in conventional aviation, ensuring that decisions like departure release or landing sequence systematically take vertiport (slot) availability into account at every stage. This collaborative framework will be introduced and described in the next section.

6 Traffic Synchronisation

"Traffic synchronisation refers to the tactical establishment and maintenance of a safe, orderly and efficient flow of air traffic" [1]. This involves dynamic, conflict-free 4-D trajectory management as well as optimising traffic sequencing and runway throughput.

6.1 Background

In conventional aviation, a key enabler of traffic synchronisation is the combination of air traffic flow and capacity management (ATFCM) and airport collaborative decision making (A-CDM).

Following the US Airline Deregulation Act in 1978, increased airline competition and traffic volumes led to significant airport congestion and network-wide delays [64]. In response, the FAA introduced a Delay Reduction Program to address these challenges [65]. By the mid-1990s, the FAA adopted a new approach called collaborate decision making, targeting improved information sharing and coordination among operational stakeholders, particularly under capacity constraints due to en-route or airport adverse weather conditions [66]. In Europe, A-CDM evolved with the objectives of improving predictability, capacity and operational efficiency across European airports, aligned with the Single European Sky initiative.

EUROCONTROL defines A-CDM as an approach that "aims to improve the efficiency and resilience of airport operations, by optimising the use of resources and improving the predictability of air traffic. It achieves this by encouraging the airport partners and the Network Manager to work more transparently and collaboratively, exchanging relevant, accurate and timely information" [67]. The A-CDM implementation manual identifies the A-CDM platform as the central enabler of this information exchange [67]. Traditionally, airports develop their own airport operational plan (AOP) based on their local airport operational database, leading to an inherently airport-centric model [68].

While A-CDM focuses on optimising the flow of traffic at a specific airport, ATFCM aims to balance traffic demand with available airspace and aerodrome capacity. When capacity cannot be further increased, demand is adapted accordingly.[69]

ATFCM services are provided to the airspace operators and ATC by the Flow Management Positions and EURONCONTROL's Network Manager and are structured into four phases [69]:

- Strategic flow management: begins seven or more days before operations and includes long-term planning and coordination through collaborative processes.
- Pre-tactical flow management: covers the six days prior to the day of operations, and compares the expected demand of the day of operations with the predicted available capacity and adjusts the strategic plan.
- Tactical flow management: on the day of operations, real-time events are managed and those that affect the ATFCM daily plan are adapted accordingly.
- Post operational analysis: After the tactical phase of operations the operational performance is assessed, outcomes are measured and reports generated.

In the context of U-space, considering VCA flights operating in U-space airspace, the U-space regulation defines the CIS as ”a service consisting in the dissemination of static and dynamic data to enable the provision of U-space services for the management of traffic of unmanned aircraft” [25]. It is the only U-space stakeholder that functions "network-wide", however, it is "only" a database providing information and acting as a single-source of truth. Consequently, relying solely on the CIS as defined in the U-space regulation is insufficient to achieve the level of operational coordination required for IAM, which is why we focus on three complementary conceptual elements.

The following sections introduce three conceptual elements, VCTM, vertiport collaborative decision making (V-CDM), and L-VNM, developed to enable IAM traffic synchronisation across vertiports. These concepts build on the U-space framework and explore how a digital infrastructure may enhance overall traffic synchronisation. Although this work focusses on VCA operations in U-space, conventional IFR and VFR rotorcraft, general aviation and helicopter emergency and medical service (HEMS) flights could equally benefit from improved, digital, information sharing.

6.2 Vertiport Collaborative Traffic Management

VCTM introduces a new cooperative framework within U-space that connects digitally all key stakeholders, CIS, ATCO, VCA operator, USSP and vertiports, to share time-sensitive and critical information related to the take-off, destination, and potential diversion vertiports and locations (see Figure 26). The objective is to enable safe and efficient VCA operations, by continuously monitoring the operational status of the vertiport (airside and landside) and reducing operational uncertainties across all phases of the VCA flight. In this framework, the CIS acts as the single source of truth for hosting and distributing vertiport availability information. Overall, VCTM enables information sharing from origin to destination by utilising the digital architecture and service provision of U-space. This includes:

- Identification and tracking: Registration, network identification, tracking, vertical conversion service
- Mission management: Flight authorisation service, U-plan preparation/optimisation, U-plan processing, vertiport availability.
- Interface with ATC: Procedural interface with ATC.
- Airspace management: drone aeronautical information management, common information, geo-awareness, geofence information exchange.
- Conflict Management: Strategic conflict detection and resolution.
- Monitoring: Conformance monitoring, traffic information, legal recording, digital logbook.

The key enabler of VCTM is the digital vertiport management system, which tracks the real-time status of all vertiport resources: pads (TLOF/FATO), gates, stands, charging facilities, turnaround progress, and schedules. Operated by the vertiport manager/operator, the VMS is responsible for publishing vertiport availability data[13]. Depending on the level

[13]Please refer to Section 5.3 to revisit the definition of *vertiport availability*.

of implementation, the VMS may include vertiport resource management, scheduling, and sequencing algorithms that optimise pad and taxiway usage and minimise delays. This system supports the "effective time slot allocation system" envisioned by the regulator in [10], as the VMS prevents conflicting pad allocations unless they are operated fully independently.

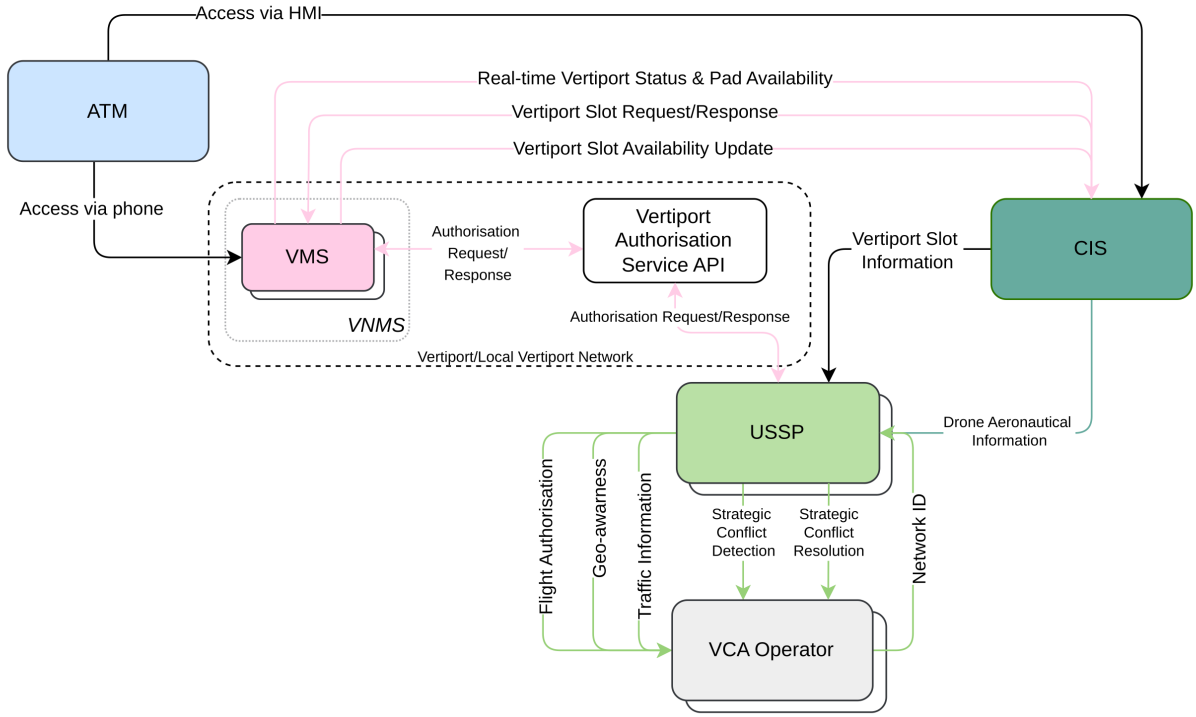


Figure 26: Initial VCTM system architecture for IAM operations in U-space. Key information and authorisation flows between ATM, Vertiport, USSP, CISP, and IAM operator.

Within the VCTM framework, the USSP functions as the digital broker of information and authorisations. A vertiport's VMS is connected to one or more USSPs, either directly or through CISP, to ensure network-wide and consistent data dissemination. The CIS acts as a shared data layer that provides all USSPs operating in one U-space airspace with common information including aeronautical data, U-space constraints, and vertiport availability. When a VCA operator submits a U-plan, the USSP can automatically query real-time vertiport availability and reserve an appropriate vertiport slot. Similarly, if a vertiport suddenly closes or a slot becomes unavailable, the VMS pushes updates to the USSP through the CIS, triggering alerts or re-planning for affected VCA flights.

ATCOs interact with the CIS system through integrated displays and procedural and collaborative interfaces as proposed in the U-space ConOps Edition 4 [59]. In practice, this allows ATCOs in towers or approach control centres to view U-plans, access relevant constraints such as vertiport slot allocation, and track VCA positions. For example, when a VCA is inbound to a vertiport within controlled airspace, the ATCO's system can display the assigned landing pad and scheduled time, including any delays and last-minute changes from the USSP. If a pad becomes temporarily unavailable, the controller receives an alert via this interface and can act accordingly.

Digital clearance requests may also be integrated in the VCTM framework. For

instance, the USSP could send a digital request to the tower: “Request landing clearance at Vertiport X at 10:30 for Flight Y,” and the tower could approve or deny it electronically, coordinating with the vertiport operator when necessary. The overall goal of VCTM is seamless data fusion between U-space, ATM systems and vertiports so that both human controllers and automated services share a common and accurate picture of vertiport usage and availability.

In summary, the VCTM framework enables the sharing of vertiport availability information through connected digital services: VMS feeds pad status and slot data to U-space (USSP/CISP), which then interfaces with VCA operators and ATC. This ensures that every stakeholder has timely and consistent information whether a vertiport can accommodate a VCA at its planned arrival time. Such integration is essential for meeting the regulatory requirement of “safe landing” options while maintaining operational efficiency.

Initial real-time human-in-the-loop simulation studies and a flight trial have demonstrated the feasibility of this collaborative framework and validated the data exchange between vertiports and U-space. As maturity will increase, validating the concept as part of comprehensive live trials (potentially leveraging U3-U4 U-space services) and formalising stakeholder responsibilities in regulation will be key next steps to ensure that vertiport availability becomes a systematically integrated element of flight authorisation and, ultimately, clearance processes.

6.3 V-CDM

Vertiport collaborative decision making (V-CDM) is an approach based on A-CDM principles that targets effective decision-making among operational stakeholders and better predictability of operations through increased collaboration, accurate, timely information exchange, and continuous monitoring of the VCA flight progress. V-CDM, therefore, represents a central component of the overall VCTM framework. Based on the principles of A-CDM, we propose the following initial requirements for a V-CDM framework tailored to the needs of IAM operations.

- Digital-only information exchange: Unlike traditional airports, heliports, and helipads, vertiports must rely heavily on automated systems and digital interfaces.
- V-CDM must prioritise real-time data sharing via APIs, cloud-based platforms, and U-space services to ensure seamless and timely coordination.
- With shorter turnaround times and potentially higher movement rates, V-CDM must incorporate predictive analytics and automated scheduling tools to manage vehicle flow efficiently.
- Given the novelty and complexity of IAM operations, V-CDM must embed resilience strategies, such as automated contingency protocols and real-time reallocation of vertiport resources, to handle disruptions effectively.

While the core A-CDM principles, transparency, predictability, and collaboration, remain relevant, several adaptions will be necessary for V-CDM to function effectively in the vertiport environment. With increasing automation and autonomy, decision-making will rely more on system intelligence than human coordination which will result in a shift from human-centric to system-centric decision making.

While the traditional A-CDM approach comprises 16 main milestones for monitoring flight in a real-time and sequential manner, developing a V-CDM approach will require adjustment of these milestones to the particular characteristics of VCA operations such as short turnaround times and flight durations.

To this end, a set of 13 milestones specifically designed for VCA operations within U-space is proposed, as depicted in Figure 27. These milestones are structured across three sequential operational phases: inbound, turnaround, and outbound. The inbound phase covers the U-plan creation and activation (1) which starts the initial operational check (such as U-plan discrepancy, vertiport availability, etc.) followed by the actual take-off time (ATOT) (2) (resembling departure of outstation), and, final approach (3), and actual landing time (ALDT) (4) with an operational taxi-in phase applicable only if the landing pad is not co-located with the stand. The turnaround phase captures actual in-block time (AIBT) (5), actual ground handling time (6), and the automatic final update of target off-block time (TOBT) (7), followed by the boarding process, actual taxi authorisation request time (ATART) (8), and actual taxi authorisation approval time (ATAAT) (9). Finally, the outbound phase encompasses actual off-block time (AOBT) (10), including and operational taxi-out where applicable, actual departure authorisation request time (ADART) (11), actual departure authorisation approval time (ADAAT) (12), and the depature ATOT.

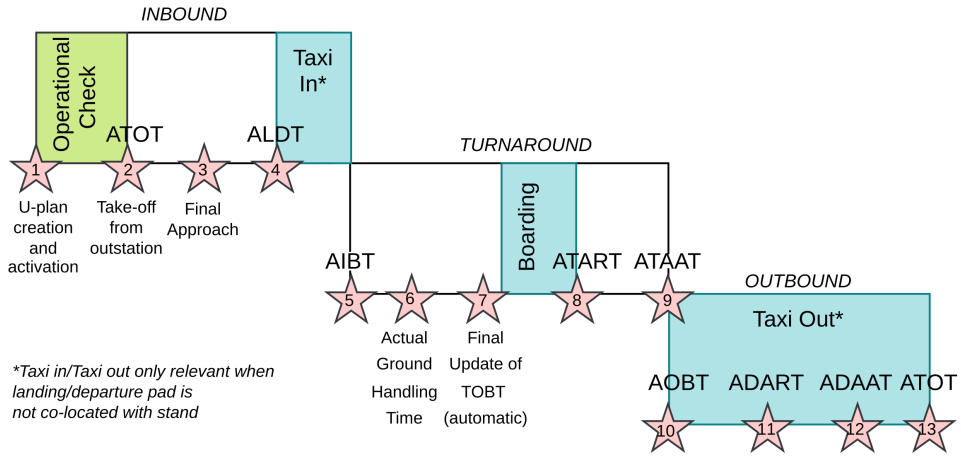


Figure 27: Initial V-CDM milestones for VCA-Vertiport operations: inbound, turnaround, and outbound phases.

Building on the collaborative decision-making principles described above, the operational focus must evolve from managing a single vertiport to coordinating a local network of vertiports. In this extended context, capacity management becomes not only a local challenge but a network-level one, triggering the discussion about a dedicated role to maintain a consolidated view of demand, vertiport availability and operational constraints across the local vertiport network.

6.4 L-VNM Role and Tasks in Achieving Collaborative Decision-Making

The L-VNM can be understood as a network-level extension of collaborative decision-making, applicable when responsibilities are distributed across a local vertiport network

managed by one operator. Supported by the VNMS, the L-VNM provides a consolidated view of demand, vertiport availability and operational constraints across the vertiport network, with demand–capacity balancing, slot and stand allocation, and comparison between planned and real-time conditions form the core of its role. This also reflects a different operating and business model, since the concept assumes a closed network in which, in the first implementation phase, one operator manages at least two vertiports.

Within this framework, Demand–Capacity Balancing (DCB) studies are used to assess routing options, flow distribution and network capacity, while operational information such as vertiport availability, slot status and relevant constraints is shared through the CISP, aligned with the VCTM framework. In this way, flight authorisation and operational coordination can reflect not only airspace constraints, but also the actual status and declared capacity of vertiport resources across the network.

This interpretation is supported by the Rome Case Study III, where the concept was first examined through a fast-time simulation and expert-judgement workshop conducted in Rome, Italy, and then further explored through real-time simulation and live-trial activities in the Pianabella Test Vertiport and Regulatory Sandbox at Rome Fiumicino. The expert-judgement phase involved ATCOs, network management experts, U-space experts and operational experts, who associated the L-VNM with slot and stand allocation, capacity balancing across the network, comparison between planned and real-time conditions, and oversight of the operational information layer and of the status of each vertiport in the network. Building on these insights, later stages considered capacity, interoperability, human performance, operational feasibility and cost-efficiency perspective. The resulting validation findings support the view that the L-VNM/VNMS concept can be integrated with the USSP and the CISP as part of a coordinated operational ecosystem. However, further research and validation is necessary to understand better the potential safety benefit of translating the responsibility from the VCA operator to the a central stakeholder especially acting upon disruptions in the network traffic flow.

In summary, Section 6 builds on the GATMOC concept of traffic synchronisation as the tactical mechanism and maintenance of a safe, orderly and efficient flow of air traffic. Starting from conventional ATFCM and A-CDM as reference frameworks and U-space as currently regulated, this section demonstrates that those principles are insufficient for IAM when applied without any adaptation. The common information services in ATM or U-space alone cannot deliver the coordination depth that vertiport operations require. Three complementary concepts are therefore introduced: VCTM connects all stakeholders through a shared digital data layer rooted in the VMS and U-space; V-CDM adapts airport collaborative decision-making to the high-automation and short turnaround and flight time requirements of VCA; and the L-VNM extends these principles to the network level to provide a consolidated demand-capacity view across multiple vertiports. Together, these three concepts represent a baseline how to enable a safe and orderly VCA traffic flow at and between vertiports. The following Section 7 examines what happens when this synchronisation breaks down by addressing conflict detection, resolution, and contingency management for VCA operations.

7 Conflict Management

Conflict management will consist of three layers: strategic conflict management through airspace organization and management, demand and capacity balancing, and traffic synchronization; separation provision; and collision avoidance." [1]

7.1 Background

Conventional aviation relies on the well-established set of standardised flight rules, VFR and IFR, which have evolved over decades to operational needs and technological advances. These rules form the backbone of safe air operations and provide the predictability required for pilots to operate in shared airspace. Basic collision avoidance principles, such as both aircraft turning right when approaching head-on and giving way to the right on converging flight paths, ensure clear and universally deconfliction actions.

These principles are defined in ICAO Annex 2, "Rules of the Air" [48]. Under VFR, pilots navigate primarily by visual reference to the ground and are responsible for maintaining separation from other aircraft. In contrast, IFR pilots rely on instrument-based navigation and adherence to a defined flight plan. Together, VFR and IFR ensure safe traffic flow in a wide range of operational environments.

Airspace structure and the associated provision of ATS further support conflict management. As defined in Appendix 4 of ICAO Annex 11, airspace classes A-G determine which type of flights are permitted (IFR only, IFR, VFR), between which aircraft separation is provided (all aircraft, IFR from VFR, IFR from IFR, VFR from IFR, none), the services provided (ATC service, traffic information, traffic avoidance advice, air traffic advisory service, flight information service), speed limitations (none, 250 kt below 10,000 ft AMSL), radio communication requirements (no, continuous two-way), and whether the flight is subject to ATC clearance [47]. ICAO Annex 2 distinguishes between controlled and uncontrolled airspace, defining where ATC actively provides separation between controlled aircraft versus where the pilot is the separator.

However, emerging IAM use cases introduce novel aircraft designs (sUAS, UAS, UVCA, MVCA), advanced CNS solutions, and increased automation and autonomy. These developments have initiated discussion, sometimes controversial, as to whether a new category of flight rules is needed beyond traditional VFR/IFR. Up to nine concepts (probably even more) have been proposed, most of which assume extensive digital connectivity, collaborative information exchange, and automated separation functions (see Table 13).

Except for the FAA's exemption-based approach (2003), these proposal consistently envision highly digitalised and cooperative operations.

Conventional aviation applies three layers of conflict management: strategic conflict management, separation provision and collision avoidance. Early VCA operations are expected to begin under VFR, however, VFR clearance is mandated in airspace class B, C and D. In class D airspace, ATC is responsible only for IFR-IFR separation.

To support safe and scalable IAM operations, we therefore adapt these three layers of conflict management with the objective to enable a scalable path towards high-density, remotely piloted VCA operations in the future.

Because VCA operations rely on dedicated and procedurally deconflicted routes (see Section 4.2) VCA flight intent must be clearly expressed in either an operational plan or a flight plan, depending on the applicable rules of the airspace. Understanding how "flight plan" applies in controlled, uncontrolled and U-space airspace is thus essential.

Table 13: Non-exhaustive summary of novel flight rule concepts.

Year	Originator	Focus	Reference
2003	FAA	VFR operations crossing LAX through class B airspace without need of ATC clearance	[70]
2011	NASA	Leveraging technological advancements enabling self-separation techniques	[71]
2018	Airbus	Supporting UAS through free routing and UAS traffic management by a central authority	[72]
2018	EUROCONTROL	Accommodating UAS operations in VLL and above flight level 600.	[73]
2022	NASA	Progression of autonomous flight rules (AFR)	[74]
2022	FAA	Expanding the idea of cooperative operating practices and digital connectivity	[75]
2023	RTCA	Introduction of digital communication air2air, air2ground, ground2ground	[76]
2024	JARUS	Enabling UAS operations, eventually superseding VFR and IFR	[77]
2024	DLR	U-space flight rules	[78]

SERA.4001 requires that information related to an intended flight provided to ATS must be in the form of a flight plan [41].

> ***SERA.4001 Submission of a flight plan***
> *Regulation (EU) 2016/1185*
> *(a) Information relative to an intended flight or portion of a flight, to be provided to air traffic services units, shall be in the form of a flight plan. The term* ***'flight plan'*** *is used to mean variously, full information on all items comprised in the flight plan description, covering the whole route of a flight, or limited information required, inter alia, when the purpose is to obtain a clearance for a minor portion of a flight such as to cross an airway, to take-off from, or to land at a controlled aerodrome.*

Importantly, "submission of a flight plan" does not automatically imply a 'filed flight plan', as clarified in GM1 SERA.4001 [41]. Under VFR, filing a flight plan is generally not required.

> ***GM1 SERA.4001 Submission of a flight plan***
> *ED Decision 2013/013/R*
> *GENERAL*
> *(a) A flight plan may cover only part of a flight, as necessary, to describe that portion of the flight or those manoeuvres which are subject to air traffic control.*
> *(b) The term* ***'submit a flight plan'*** *refers to the action by the pilot or the operator to provide ATS with flight plan information. The term* ***'filed flight plan'*** *refers to the flight plan as received and accepted by ATS whereas* ***'transmit a flight plan'*** *refers to the action by a pilot to submit the flight plan, or submit abbreviated flight plan by radiotelephony to the ATS unit concerned.*

However, for VCA operations with limited diversion options, very restricted energy reserves and overall constrained vertiport capacities, the absence of a formal filing can introduce additional safety risks. For that reason, EU (IR) 2024/1111 requires the submission of an ATS flight plan (important: not equivalent to "filing a flight plan") [6].

EU (IR) 2024/1111
Manned VTOL-capable aircraft (MVCA)
UAM.OP.MVCA.177 Submission of an air traffic services (ATS) flight plan
(a) The IAM operator shall submit an ATS flight plan as required by the applicable rules of the air for the class(es) of airspace in which the operation will be conducted.
(b) If the submission of an ATS flight plan is not required by the applicable rules of the air for the class(es) of airspace in which the operation will be conducted, the IAM operator shall ensure that adequate information is deposited with the appropriate ATS unit to permit alerting services to be activated if necessary.

Piloted MVCA require preparation of an operational flight plan (OFP[14]).

EU (IR) 2024/1111
VTOL-CAPABLE AIRCRAFT IN MANNED CONFIGURATION (MVCA)
UAM.OP.MVCA.175 Flight preparation
(a) An operational flight plan (OFP) shall be completed for each intended flight, taking into account the airspace in which the flight is to be conducted and the applicable rules of the air, aircraft performance, operating limitations, and relevant expected conditions along the route to be flown and at the vertiport or diversion location to be used.
(b) The flight shall not be commenced unless the pilot-in-command is satisfied that: [. . .]
(11) an air traffic service (ATS) flight plan has been approved and flight clearance has been granted in accordance with the applicable rules of the air and the class(es) of airspace in which the operation will be conducted.

According to ref. [6], use of ATS is required for MVCA under the following conditions:

EU (IR) 2024/1111
UAM.OP.MVCA.100 Use of air traffic services (ATS)
The IAM operator shall ensure that:
(a) ATS appropriate to the airspace in which the operation is conducted and to the applicable rules of the air are used, whenever available;
(b) in-flight operational instructions involving a change to the ATS flight plan are coordinated with the appropriate ATS unit before transmission to the VCA;
(c) search and rescue service arrangements can be maintained whenever the use of ATS in the airspace in which the operation is conducted is not mandated for VFR flights by day;
(d) for operations in airspace designated by the competent authority as U-space airspace and not provided with air traffic control (ATC) services by an air navigation service provider (ANSP), the VCA continuously makes itself electronically conspicuous to U-space service providers.

VCA-specific constraints, especially related to CSFL and restricted energy reserves, affect what must be known and declared before take-off. Diversion vertiports/locations must be identified by the VCA operator during flight planning and depend on the certified aircraft performance, D-value, fuel/energy supply system, obstacle limitation surface, CNS equipage, wind constraints, and other operational factors [3].

Given the operational constraints of IAM, we recommend that filing a flight plan becomes mandatory for IAM operations regardless the operating environment and airspace type. As VCA operations eventually transition towards full U-space integration, flight intent must be structured in a way so that both ATS units and the USSPs can process it. Current UAS flight authorisation data will require adaptation to meet the requirements stated in ref. [6], an operational challenge addressed in the next section.

[14]"An operational flight plan (OFP) is used by the pilots during flight to monitor the progress of the flight and make sure that the aircraft will reach the destination on time and with sufficient fuel on board. OFPs can also be used as a formal record of the flight for audit or reconstruction purposes. A well-designed, and properly completed, OFP can be a highly useful tool, enhancing situational awareness".[79]

7.2 Flight Plan for VCA Operations

Under U-space, no standardised format yet exists for submitting a UAS flight authorisation request. EUROCAE WG 105 Subgroup 3 and the U-space coordination cell "Flight Plan" working group are currently analysing how such a format should be defined for sUAS operations. At the same time, the legacy flight planning and filing process for IFR operations has undergone a major change: as of January 2026, IFR operators must submit filed flight plan exchanged via FF-ICE services (eFPL) using the flight and flow information for a collaborative environment (FF-ICE) Release 1 services when operating in the European Union, Norway and Switzerland [80]. This means that EUROCONTROL's Network Manager as well as the ANSPs of the participating countries are transitioning to process FF-ICE flight plans following flight information exchange model (FIXM) instead of the FPL2012 data format and structure. The objective is to reduce the reliance on voice radio communications, improve collaborative planning, and enable flexible, dynamic 4D-trajectory management in all flight phases [81, 82].

As of now, it remains unclear how a future U-plan (flight plan in U-space) and potentially eFPL for VCAs should look like, or whether revision of the eFPL will become necessary.

With the full integration of certified VCA operations into U-space, the mandatory information transmitted as part of the flight authorisation and activation request should evolve to include VCA-specific data (see Table 14).

Table 14: VCA-related information transmitted for flight authorisation and activation, eventually defining the U-plan and eFPL content.

Attribute	Description
Authorisation/U-plan identifier[1]	Unique identifier of the authorisation request/U-plan Identification of the originator and the publisher of the data exchange: SAC and SIC.
State of the authorisation/U-plan	accepted, rejected, activated, withdrawn, ended, cancelled; as well as creation and last update times
Contact information	Contact details of the operator and the PIC that performs the flight (registration number, full name, telephone, email)
Aircraft information	Registration and serial number, performance specifications, and general characteristics of the VCA such as maximum take-off mass, maximum speed, manufacturer, model, propulsion, endurance including electric reserve
Operation details	Category of operation[2]: Type 1 = IFR cargo UAS; Type 2 = UVCA passenger- and/or cargo-carrying; Type 3 = MVCA Mode of operation: VFR, IFR, DFR (digital flight rules, if eventually adopted)
Vertiport information[3]	take-off vertiport and TLOF; expected time of use/slot destination vertiport and TLOF, expected time of use/slot diversion vertiport/location TLOF, expected time of use/slot
Take-off and landing procedures	Selected procedures according to operational limitations and weather constraints
Route	4-D trajectory including waypoints relative to the intended take-off locations, maximum cruise altitude
Operation volumes	Airspace geometry for the operation, including minimum and maximum altitudes, and time windows for the start and end of each operation volume.
Contingency information	Contingency procedures, plans, etc.

[1] This means that, prior to operation, bilateral agreements must be in place between the USSP and VCA operator.
[2] Following categories introduced in EASA ToR RMT.0230 [23].
[3] This means that, prior to operation, bilateral agreements must be in place between the vertiport operator and VCA operator.

This information defines the basis of how a U-plan can be generated following ICAO 2012/FF-ICE/FIXM standard, supporting flight-intent sharing via the U-space UAS flight authorisation service, ensuring alignment with current requirements introduced for VCA operations in ref. [6] and with legacy IFR flight plan processes.

Through the UAS flight authorisation service, the VCA operator shares the flight intent, further referred to as U-plan, with the USSP. In U-space airspace, it is assumed that the USSP is responsible for processing, managing and updating the U-plan and ensuring that the information is shared with other relevant stakeholders such as the CISP.

The time between flight authorisation request/ U-plan submission and U-plan activation

request may vary between weeks, days, hours, or seconds. According to the U-space ConOps Edition 4 [59], a U-plan can be in the states: *draft*, *approved, active*, or *end*. Building on these definitions, we propose a dedicated lifecycle for VCA U-plans as presented in Figure 28.

The proposed states are divided into two categories: U-plan states shared with the the CISP (rejected, accepted, cancelled, withdrawn, activated, ended) and internal USSP states shared with the VCA operator (pending activation authorisation,taxi/take-off/landing authorisation, and termination request).

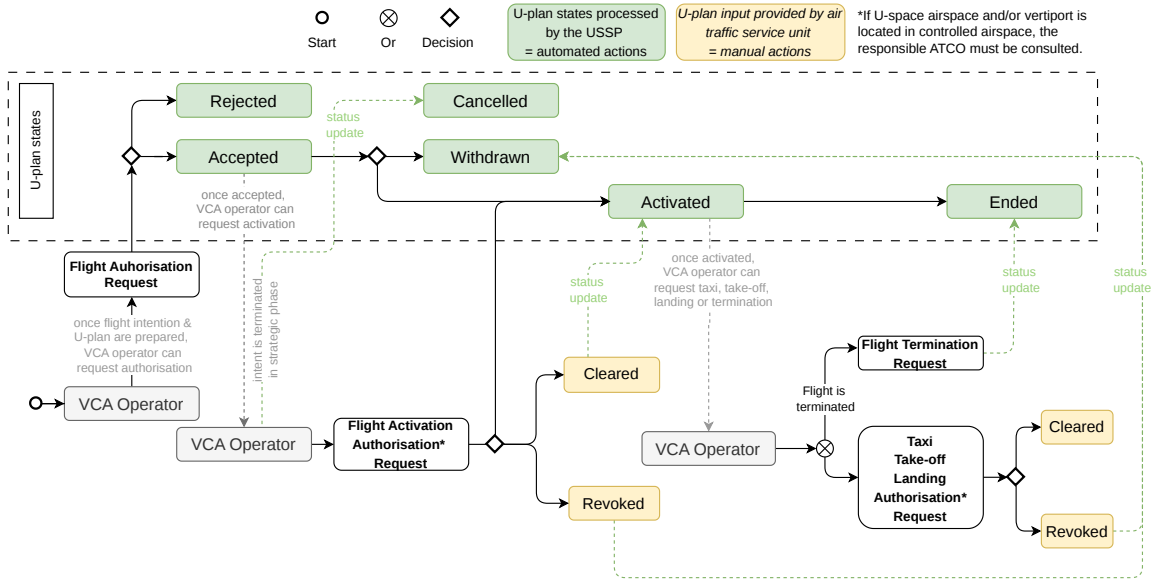


Figure 28: U-plan state lifecycle for VCA operations, distinguishing U-plan states shared with the CISP and internal actions taken by the VCA and the ATS unit in charge, if vertiport and/or U-space airspace are located in controlled airspace. Note: As of now, the USSP is not a certified ATS provider, hence, not empowered to provide clearances. This could change in the future.

- **Strategic Phase - U-plan submission and activation:** The VCA operator initiates the lifecycle by submitting a flight authorisation request to the USSP that transmits the U-plan. The U-plan is either *accepted* or *rejected* by the USSP based on the operational constraints of the airspace and the requested vertiports, coordinated through the VMS/VNMS. An *accepted* U-plan is shared with the CISP for dissemination to other USSPs and vertiports, including allocation of previously coordinated vertiport slots. A *cancelled* state is reached when the VCA operator manually cancels the flight intent primarily during the strategic phase. Once accepted, the VCA operator may request activation of the U-plan.

- **Pre-tactical phase - Activation and dynamic updates:** Following an activation request, the USSP automatically processes the *pending activation authorisation* and either clears or revokes it. If cleared, the U-plan status is updated to *activated* and the CISP is notified accordingly. If revoked, the U-plan does not progress to the active state. Should dynamic changes, such as airspace re-configuration or vertiport availability, affect a previously accepted U-plan, the USSP may *withdraw* it, reassess

all affected U-plans under its responsibility and forward updated statuses to the VCA operator and the CISP. If the vertiport and/or the U-space airspace is located in controlled airspace, the responsible ATCO must be consulted before activating the flight request.

– **Tactical phase - Operational authorisations and termination:** Once *activated*, the VCA operator requests taxi, take-off, and landing authorisation from the vertiport operator or the respective responsible entity in place. If granted, the U-plan status remains *activated*. If denied, only the internal USSP state is updated to *revoked* while the U-plan itself remains *activated*. Upon completion of the flight, or before take-off for whatever reason, the pilot in command or the operation control centre can manually trigger flight termination. This changes the U-plan to the status to *ended*. Throughout the tactical phase, the USSP sends the updated state to the CISP, which updates the VMS/VNMS. Any further updates on the U-plan, such as a contingency or emergency declaration or change of the expected time of arrival, are transmitted by the USSP, and CISP to the the VMS/VMNS.

Compared to current ATM practice, the VCA flight plan lifecycle is more dynamic and simple. In today's operations, an airline-originated flight plan is processed by several units including the integrated initial flight plan processing system and enhanced tactical flow management system of EUROCONTROLS's Network Manager before reaching the ATS units providing ATC services. The flight plan is then subject to clearances that span across all flight phases and cover start-up, taxi, take-off, en-route, to crossing, climb, descent, approach and landing.

VCA flights, in contrast, are much shorter in flight time and distance. Further research and flight trials are necessary to determine the appropriate level of complexity and to ensure safe, efficient and real-time processing and updating of U-plans.

7.3 Contingency and Disruption Management

Contingency and disruption management is a critical enabler for achieving safe and resilient VCA operations when the operational state is no longer under normal conditions. "For Category Enhanced aircraft [...] the aircraft must be able to perform a continued safe flight and landing after any single failure or combination of failures that are not classified as catastrophic" [83]. Disruptions such as vehicle-level failures, vertiport unavailability, service-level degradations, and adverse environmental conditions, have potential to propagate across both pre-flight and in-flight phases affecting not only directly the impacted flight but also surrounding traffic, vertiport operations, and overall traffic flow. Therefore, an integrated system-wide framework that supports coordinated decision-making across different operations was researched to address such situations. The main objective of this approach is to help relevant stakeholders in reducing exposure to abnormal and faulted conditions and enabling an efficient recovery towards normal conditions. As future IAM ecosystems evolve and operational demands increase, contingency and disruption management activities are expected to rely on higher levels of autonomy to support timely and scalable responses.

7.3.1 Categories of Operational Conditions

Operational conditions explain the state of VCA operations and aim to provide a common reference for distinguishing between various operational situations. It is important to

establish a clear and shared terminology since terms such as nominal, non-nominal, off-nominal, and disrupted are often interpreted differently across ATM research activities and operational concepts.

To support a shared and consistent understanding, EUREKA adopts a structured definition of operational conditions aligned with the perspective followed by EUROCONTROL safety experts. Under this definition, operational conditions are classified as normal, abnormal, and faulted conditions. This approach serves as a practical starting point to support consistent terminology and remains open for further discussion and refinement.

- **Normal conditions:** Conditions of the operational environment that functional systems are expected to encounter in day-to-day operations, under which the full functionality and performance must always be maintained. This also includes unusual but anticipated events that occur rarely yet remain within the limits imposed by the standards, such as long latencies in controller pilot data link communications.
- **Abnormal conditions:** External changes in the operational environment that functional systems may exceptionally encounter such as severe weather, infrastructure unavailability, or temporary service disruptions. Under these conditions, the system may be allowed to operate in a degraded state provided that it can easily be recovered when the abnormal condition passes and the risk during the period of the degraded state is shown to be tolerable.
- **Faulted conditions:** Conditions generated by the occurrence of failures or errors of functional system elements such as technical failures and human errors, which potentially lead to an operational hazard or a degraded mode. These conditions are characterised by one or a combination of functional system elements that fail to work as specified.

In this context, abnormal and faulted conditions require contingency and disruption management solutions as the target safety level is already eroded and the exposure needs to be reduced, while normal conditions represent the intended operational state to be returned.

7.3.2 Potential Use Cases

Contingency and disruption use cases can be investigated based on where they originate and how their effects propagate. Such operational conditions may arise at the vehicle level, infrastructure level, service level, or due to external impacts. These situations may occur during pre-flight or in-flight phases depending on the operational context. Defined use cases can have different implications by affecting a single flight or influencing surrounding traffic flows, vertiport capacity, or network-level operations.

The effects of a contingency are not always limited to the flights that are directly affected. Observed contingencies or relevant activities to resolve them may lead to indirect impacts on other flights through potential conflicts or vertiport operations through capacity constraints. For instance, a diversion initiated for a flight due to a contingency may cause potential conflicts for surrounding traffic which require in-flight and pre-flight adjustments along with contingency management activities. Similarly, vertiport unavailability may result in temporary capacity shortages that need such coordination between resolution actions. Such examples highlight contingency and disruption management activities often require coordinated and integrated consideration through various operational elements rather than focused solutions at individual flight level.

7.3.3 System-Level Decision Support Approach

Addressing contingency situations that have an impact beyond individual flights requires system-level consideration. Since local contingencies or related mitigating activities may propagate to affect surrounding traffic flows, vertiport capacity, and service availability, isolated contingency handling may not suffice to maintain operational safety and stability. Therefore, a structured decision support approach is necessary to assess system-wide conditions, consider interactions between operational elements, and support coordinated contingency and disruption management.

In this regard, a future operational service concept, contingency decision support (CDS), is proposed as a future operational service concept, grounded in EUREKA validation activities, with further development and certification required before deployment grounded. The dedicated and integrated decision supportlayer for contingency and disruption management is based on the approach proposed in [84]. CDS establishes a structured approach for assessing abnormal and faulted conditions by consolidating operational information from flights, vertiports, and related services. The CDS service provides advisories that support alignment between operational elements during contingency situations.

The CDS service is structured around three distinct but interconnected states namely the Contingency State, Tactical State, and Strategic State. The general structure of the CDS is depicted in Figure 29. These states support contingency and disruption management across both pre-flight and in-flight phases through a progressive activation logic driven by the operational impacts of contingencies. The Contingency State focuses on immediate evaluation of abnormal or faulted conditions and their direct implications. The Tactical State is activated when contingency situations or the actions taken to address them introduce interactions affecting flights that are in the in-flight phase. The Strategic State is engaged when these interactions extend to flights that are in the pre-flight phase. Through this layered structure, CDS generates advisory outputs that support coordination across operational elements when contingency effects extend beyond the initially affected flight.

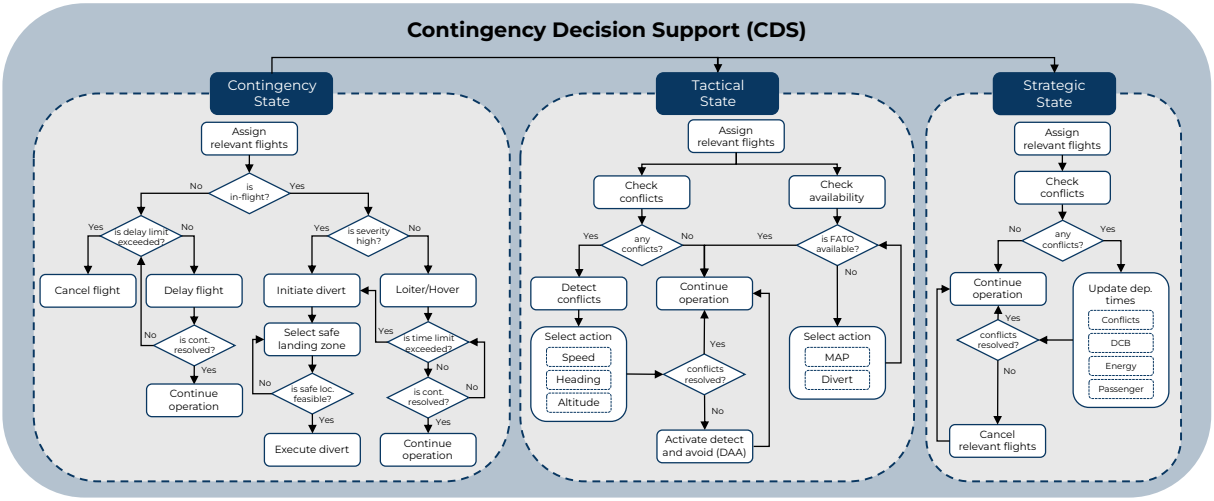


Figure 29: General framework for the introduced Contingency Decision Support service.

After identifying an abnormal or a faulted condition, CDS is initiated with the Contingency State to interpret the operational implications and generate immediate flight-level advisories. Such conditions are evaluated based on flight phase and severity of the condition which change the nature and urgency of the suggestions. This interpretation also helps

framing the operational intent of the responses, for instance distinguishing between actions such as land as soon as practical and land as soon as possible depending on the assessed risk level. For pre-flight contingencies, CDS provides decisions such as delaying or cancelling a departure to avoid unsafe or infeasible operations. For in-flight contingencies, CDS suggests airborne mitigation options such as loitering if applicable, or executing a diversion when continued safe flight and landing is no longer acceptable. In particular, the Contingency State of CDS provides diversion-related advisories by verifying and recommending feasible diversion locations based on proximity, manoeuvrability, operational constraints, and environmental conditions.

Once the Contingency State of CDS provides the relevant advisories, the Tactical State is triggered if the contingency or the associated advisory affects other flights that are already in the air. At this stage, the objective becomes maintaining a safe and stable traffic environment by analysing how the affected aircraft and surrounding traffic influence each other. Thus, the Tactical State suggests in-flight adjustments to preserve separation and ensure safe operations. These suggestions vary depending on the specifics of operational conditions. When traffic-level interactions such as potential conflicts are detected, intent-based adjustments including speed, heading, or altitude changes are suggested. When the interaction is driven by infrastructure availability, procedural advisories such as missed approach or diversion recommendations are issued based on Tables 18, 20, and 22.

Following the Tactical State suggestions, CDS proceeds to the Strategic State where the evolving traffic is assessed to determine whether adjustments are needed to scheduled flights on the ground. The objective of this state is to maintain traffic synchronisation by ensuring that upcoming flights remain compatible with the updated operational conditions. Therefore, the Strategic State provides pre-flight updates to avoid potential conflicts and consider demand–capacity balancing along with the other operational requirements. These updates consist of departure delays, and flight cancellations when a suitable delay cannot be found within the passenger delay flexibility limit.

These three CDS states describe how decision-making is supported from the moment an abnormal or a faulted condition is identified to the point where planned operations may need adjustments. By linking actions from the most urgent situations to less time-critical ones, the framework provides consistent and autonomous advisories for handling contingency and disruption management across different operational phases and mitigating their ripple effects.

7.3.4 Case Study I: CDS

To understand how the CDS service performs in practice, a number of validation activities were carried out under EUREKA. These activities were designed to observe how CDS advisories support decision-making under representative abnormal and faulted conditions in a realistic operational environment. Therefore, several case studies were examined to assess potential benefits of the introduced service in contingency and disruption management.

The diversion advisories are compared between controlled airspace and U-space. In controlled airspace, these advisories are analysed based on actual ATCO suggestions observed in real-time human-in-the-loop simulations and modelled ATCO responses in fast-time simulations as shown in Figure 30. The CDS advisories generated in U-space are examined through fast-time simulations, as illustrated in Figure 31. A difference between controlled airspace and U-space is observed in the elapsed time from contingency identification to the mitigation action which is diversion in this case. Reaction duration in controlled airspace clusters around fifty seconds, whereas in U-space they remain within a

few seconds. That difference is mainly related to the communication structure and decision process in each environment. The difference in response duration can be important for contingencies that require immediate action, where delayed mitigation may escalate the abnormal or faulted condition. In controlled airspace, the process begins with the PIC informing ATCO about the abnormal or faulted condition. The ATCO then proposes diversion options to the PIC, which are verified in coordination with the OCC before the final decision is executed. In U-space, the diversion advisory is generated through digital coordination between the USSP and OCC supported by the CDS Contingency State, which evaluates the feasibility of all the diversion locations considering proximity, environmental constraints, and vehicle dynamics. Therefore, several intermediate communication steps are passed and the response time becomes significantly shorter.

Apart from that, observations from the real-time simulations in controlled airspace showed that ATCO suggestions often included returning to the departure vertiport as well. During the debriefing sessions, this preference was explained by the availability of operational resources at the departure vertiport which was under ATCO control. However, these suggestions did not consider aircraft manoeuvrability, energy limitations, or other operational feasibility constraints. In the fast-time simulations, ATCO responses were modelled based on proximity to the diversion locations which was also the outcome observed in real-time simulations. In contrast, the CDS service selects diversion locations by considering multiple operational factors which reduces the need for additional verification.

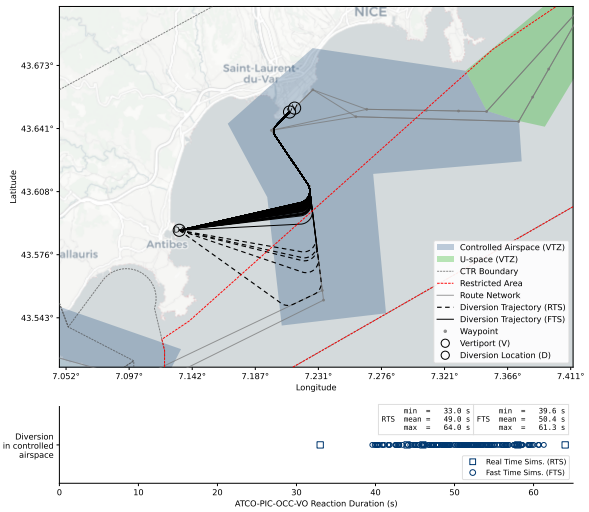


Figure 30: Case Study I: Simulated diversion trajectories and associated response duration in controlled airspace without CDS.

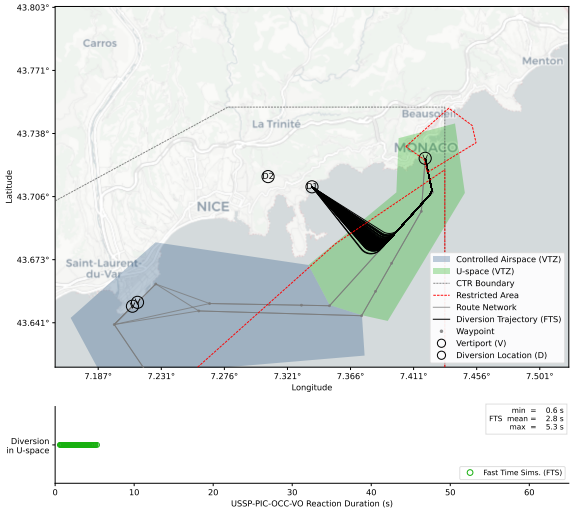


Figure 31: Case Study I: Simulated diversion trajectories and associated response duration in U-space airspace with CDS.

CDS capabilities were further examined for in-flight advisories under vertiport FATO unavailability scenarios. Relevant FATOs were made unavailable for a certain duration during the approach phase to evaluate how and when mitigation actions are initiated. Figure 32 presents the actual ATCO suggestions observed in real-time simulations in controlled airspace while Figure 33 depicts the CDS advisories provided through fast-time simulations in U-space. The results show a difference between controlled airspace and U-space in terms of the time needed to initiate a mitigation action when the FATO unavailability is identified. The mitigation action may involve a missed approach, contingency landing, or diversion depending on the aircraft position relative to the approach procedure and estimated time of arrival considering each possible action. In controlled

airspace, initiating a mitigation action took around forty seconds after the FATO became unavailable. In U-space, the response was initiated within a few seconds. That difference occurs due to communication steps considering each environment which can be crucial during the final approach phase since the missed approach is not a practical action after the PinS. In controlled airspace, communication starts with the ATCO identifying the FATO unavailability through the HMI and informing the PIC. Then the PIC requests a missed approach after coordination with the OCC (if in place). Finally, the ATCO evaluates the situation and confirms the action. In U-space, advisories generated by the CDS are coordinated by the USSP with the OCC and PIC through digital communication. Once the FATO is unavailable, the CDS passes the Contingency State since none of the flights are directly under an abnormal or a faulted condition, and the CDS Tactical State provides advisories based on the current operational conditions. Thus, the CDS enables autonomous decision-making by allowing mitigation actions to be determined and initiated efficiently.

During the real-time simulations in controlled airspace, in one of the simulations the ATCO waited until very close to the PinS before approving the PIC's missed approach request. This created a situation where the aircraft had very limited time to initiate the missed approach before passing the PinS. On the other hand, in the fast-time simulations, the contingency landing action is observed in 3 of the 180 runs when the FATO unavailability case occurs after the aircraft has already passed the PinS, since the FATO unavailability start time and duration were randomly triggered. In these simulations, CDS demonstrated the ability to autonomously select the appropriate mitigation action while considering the relevant operational aspects without requiring additional verification.

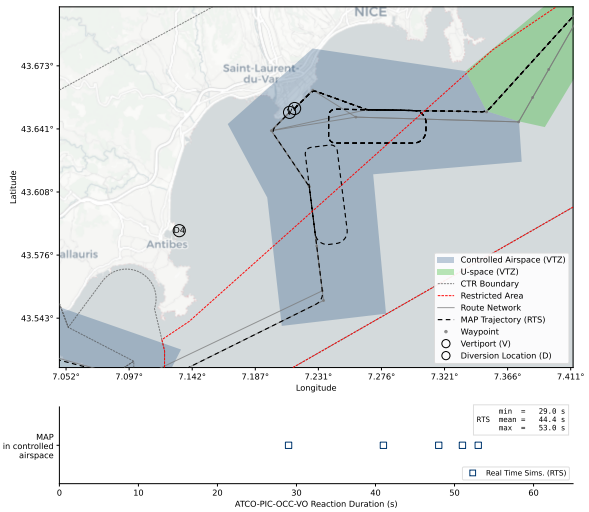


Figure 32: Case Study I: Simulated missed approach procedures and associated response duration in controlled Airspace without CDS.

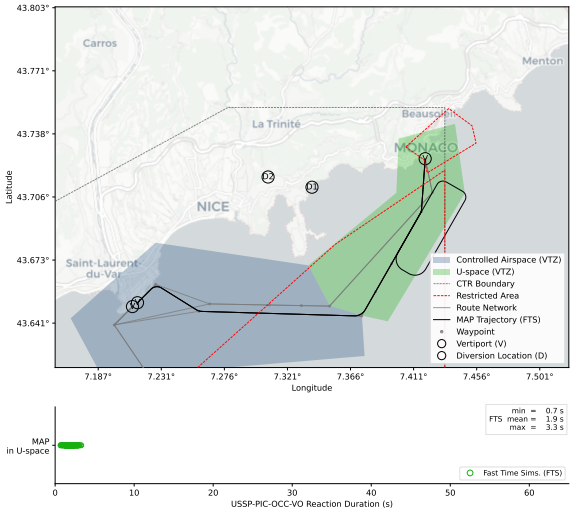


Figure 33: Case Study I: Simulated missed approach procedures and associated response duration in U-space Airspace with CDS.

Overall, the results show how the CDS service can support contingency and disruption management by providing advisories based on operational conditions. CDS enables autonomous decision support that can help identifying and initiating mitigation actions more efficiently through its modular state structure. The validation activities conducted for CDS under EUREKA focused on specific use cases such as diversion advisories and in-flight actions under vertiport unavailability. Other capabilities of the CDS framework

such as additional tactical functions or strategic updates to planned operations, were outside the scope of the validation activities.

7.3.5 Future Use and Integration

The CDS service is structured as a U-space service provided by the USSP to support operators during abnormal or faulted conditions, as tested in the validation activities. The envisioned service aims to analyse the operational information along with environmental and performance constraints and provide advisory guidance when mitigation actions are needed. Although the CDS service is designed mainly for the U-space airspace, similar advisory capabilities could also support ATCOs in controlled airspace by assisting to identify suitable mitigation actions.

For accurate advisories, the CDS service requires several inputs such as traffic state information, vertiport availability and capacity, and environmental conditions. The CDS service generates suggestions through Contingency, Tactical, and Strategic states when needed, based on the received information. Depending on the observed conditions, these suggestions may include diversion recommendations, in-flight adjustments, or pre-flight updates. The outputs of the service should be provided in a simplified format suitable for time-critical situations indicating the affected flight, recommended action, and relevant action details. Then, these outputs should be shared through digital coordination between the USSP and relevant OCC and aircraft systems.

Future work should explore the full capabilities of the CDS service under more demanding operational conditions. This includes examining how the service performs in denser traffic situations and more complex operational scenarios which also allows testing CDS functions beyond the cases presented here, for example supporting tactical coordination or strategic updates to planned operations. One important step would be to test the service in real-time simulations with operational systems and human operators involved. Another step would be to assess the service through flight trials where CDS provides decision support in real-time during operations, to advance the maturity of the service.

8 ATM and U-space Service Delivery Management

"ATM service delivery management will operate seamlessly from gate to gate for all phases of flight and across all service providers. The ATM service delivery management component will address the balance and consolidation of the decisions of the various other processes/services, as well as the time horizon at which, and the conditions under which, these decisions are made. Flight trajectories, intent and agreements will be important components to delivering a balance of decisions."[1]

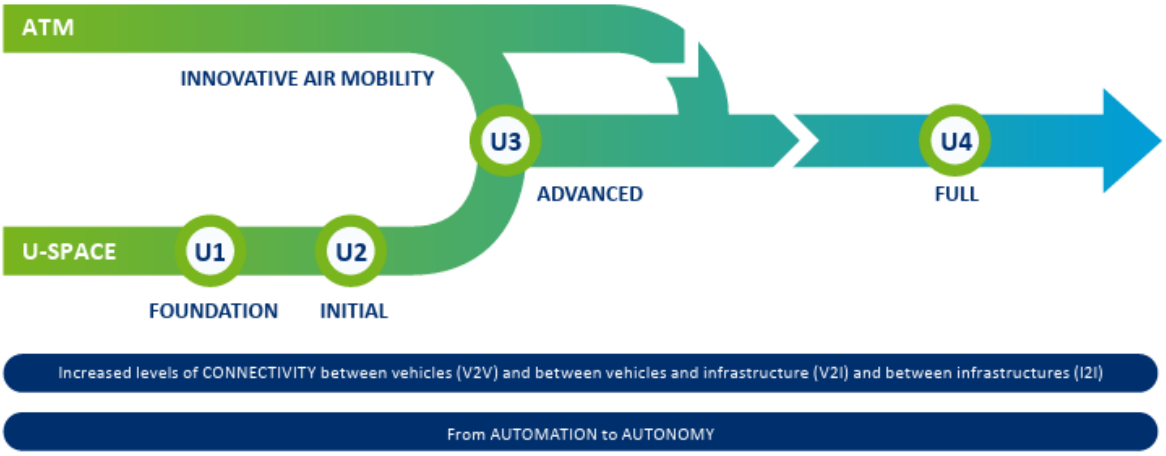


Figure 34: U-space 2.0 in the context of the overall ATM evolution as targeted in the ATM Masterplan 2025 [5], ©SESAR 3 Joint Undertaking.

8.1 Background

As IAM continues to develop, the integration of VCA into complex airspace structures requires new approaches to flight authorisation and operational control. Unlike traditional aviation, IAM targets to heavily rely on automated, digital systems to manage safety, efficiency, and scalability in operating environments that may eventually see high-density operations. Within this emerging operational landscape, the traditional concept of ATC clearance, and the way it is provided, is challenged to meet the specific needs of VCA and vertiport operations. At the same time, we must ensure safe and seamless coordination among a variety of stakeholders.

According to ICAO Annex 11 [47] and Doc 4444 PANS-ATM [85], an *Air Traffic Control clearance*, or simply *clearance*, is an authorisation for an aircraft to operate under specific conditions issued by an ATC unit. Such clearances are provided only to controlled flights. A pilot must obtain a clearance from the relevant ATC unit before entering controlled airspace, and when exiting it as the clearance generally extends only to the boundary of the controlled airspace. For flights with intermediate stops, the initial clearance usually covers the first leg unless coordination between ATC units allows a single clearance for multiple segments. The requirement for a clearance depends on both the airspace class and flight rules. As discussed in section 7.1, for IFR flights, ATC clearance is mandatory in airspace classes A, B, C, D, and E while, if a flight operates under VFR, a clearance is required in classes B, C, and D. VFR flights are prohibited in class A airspace and are not

subject to ATC control in class E. In general, clearances are issued for the sole purpose of expediting and separating air traffic. They are based on known traffic conditions that affect operational safety, including airborne traffic, manoeuvring area activity, and any non-permanent obstructions. Clearance delivery typically follows a stepwise sequence, start-up, pushback, taxi out, line-up, take-off, landing and taxi-in, and must be issued early enough so that the aircraft operator can comply with it. What is important, is that ATC clearances provide authority within the limits of known traffic; they neither permit violations of safety regulations nor relieve the PIC of any responsibility for regulatory compliance. ATC units must therefore issue only those clearances necessary to prevent collisions and to maintain an orderly traffic flow.

Moreover, clearances are directly linked to operational risk factors such as fuel and energy management. As specified in IR (EU) 2024/1111 [6], if a clearance amendment threatens to breach final fuel or energy reserve, the pilot must declare “MINIMUM FUEL”, and escalate to a "MAYDAY [...] FUEL" declaration when projected reserves fall below the planned/mandatory final reserve.

> ***UAM.OP.VCA.195 Fuel/energy scheme – in-flight fuel/energy management***
> *(a) The IAM operator shall establish policies and procedures ensuring that in-flight fuel/energy checks and fuel/energy management are performed.*
> *(b) The PIC shall monitor the amount of usable fuel/energy remaining in the VCA to ensure that it is protected and not less than the fuel/energy required to proceed to the selected destination vertiport, diversion location or VEMS operating site where a safe landing can be performed.*
> *(c) When a change to the clearance to proceed to a specific vertiport, diversion location or VEMS operating site at which the PIC has committed to land may result in landing with less than the planned final reserve fuel/energy, they shall advise air traffic control (ATC) of a “minimum fuel / energy” state by declaring “MINIMUM FUEL”.*
> *(d) The PIC shall declare a situation of “fuel/energy emergency” by broadcasting “MAYDAY MAYDAY MAYDAY FUEL” when the usable fuel/energy that is calculated to be available upon landing at the nearest vertiport, diversion location or VEMS operating site where a safe landing can be performed is less than the planned final reserve fuel/energy.*

Applying these established concepts to IAM operations introduces specific challenges. As highlighted in the Appendix A, Regulation (EU) 2024/1111 [6] seeks to adapt traditional clearance procedures to VCA operations, yet does not address the specific operational complexity when operating in U-space airspace. Amendments to SERA, Annex of IR (EU) No 923/2012 [**?**], such as SERA.8015 and SERA.8020 extend ATC clearance principles to *operating sites* and introduce provisions for weather-related clearance and adherence to revised routes.

> ***SERA.8015 Air traffic control clearances**, point (b) (4) is replaced by the following:*
> *‘(4) Potential reclearance in flight. If, prior to departure, it is anticipated that, depending on fuel/energy endurance and subject to reclearance in flight, a decision may be taken to proceed to a revised destination aerodrome, the appropriate air traffic control units shall be so notified by the insertion in the flight plan of information concerning the revised route (where known) and the revised destination.’;*
> ***SERA.8020 Adherence to flight plan**, point (d)(1) and (2) are replaced by the following:*
> *‘(d) Weather deterioration below the VMC. When it becomes evident that flight in VMC in accordance with its current flight plan will not be practicable, a VFR flight operated as a controlled flight shall:*
> *(1) request an amended clearance enabling the aircraft to continue in VMC to destination or to an alternative aerodrome or operating site, or to leave the airspace within which an ATC clearance is required; or*

(2) if no clearance in accordance with point (1) can be obtained, continue to operate in VMC and notify the appropriate ATC unit of the action being taken either to leave the airspace concerned or to land at the nearest suitable aerodrome or operating site;

For IAM operations, these amendments are particularly relevant. Similarly, for airside ground VCA procedures. According to the IR (EU) 2024/1111 [6] (see excerpt below), ground movement and taxi requirements for VCA at vertiports or operating sites mandate VCA operator to define procedures and provide qualified ground personnel. This reinforces the need for clear coordination and bilateral agreements.

UAM.OP.VCA.125 Taxiing and ground movement
(a) The IAM operator shall establish standard and contingency procedures for the taxiing of VCA (in the air and on the ground) and for the movement of VCA on the ground in order to ensure the safe operation of the VCA at the vertiport, diversion location or VEMS operating site. In particular, the IAM operator shall consider the risk of collision between a taxiing VCA or a VCA being moved and another aircraft or other objects, as well as the risk of injuries to ground personnel. The IAM operator's procedures shall be coordinated with the operator of the vertiport, the diversion location or the operating site, as applicable.
(b) The VCA shall be taxied on the movement area of a vertiport, diversion location or VEMS operating site:
(1) by an appropriately qualified pilot at the controls of the VCA; or (2) in the case of ground taxiing without passengers for a purpose other than taking off, by a person at the controls of the VCA, designated by the IAM operator, after having received appropriate training and instructions.
(c) The IAM operator shall ensure that the ground movement of a VCA on the movement area of a vertiport, diversion location or VEMS operating site is carried out or supervised by personnel that have received appropriate training and instructions.

Furthermore, as discussed in Section 7.1, for MVCA operations, operators are required to use ATS services where available, submit and obtain approval for ATS flight plans where required, and obtain clearance in accordance with the applicable rules of the air and the class(es) of airspace in which the operation will be conducted. All instructions that alter the ATS flight plan must be coordinated with the relevant ATC unit. When crossing U-space airspace, the MVCA must also remain electronically conspicuous to U-space service providers.

In NASA's High-Density Vertiport ConOps [86], clearance-like functions are embedded within the vertiport automation system (VAS) and are distributed among multiple actors. For example, the VAS Manager issues take-off and landing permissions in real-time, based on surface trajectory planning, vertiport capacity, and sequencing. Meanwhile, the Provider of Services to UAM (PSU) (analogous to USSPs), manages tactical deconfliction and interfaces with ATC for boundary crossings. Having now three stakeholders potentially issuing clearances to VCA (i.e. ATC and clearance-like authorisations such as USSP, vertiport operator), it reinforces the need for a coherent, digitally supported clearance framework, combining elements of traditional ATM, U-space services and emerging vertiport-network operations, and that supports tactical handover between controlling authorities.

The shift towards digital and increasingly automated processes is therefore highly relevant for IAM operations. In Europe, digital clearances are governed by the Datalink Service Implementation Rule (DLS-IR), which mandates controller pilot data link communications above Flight Level 285 and establishes the technical and procedural foundation for digital data and clearance exchange [87]. Rooted in ref. [85], it describes "a two-way data-link system by which controllers can transmit non urgent 'strategic messages to an aircraft as an alternative to voice communications." [88]. Under this framework, data link initiation capability, ATC communications management service, ATC clearances service

and ATC microphone check service are mandated, whereas, departure clearance as well as downstream clearance service are not.

In the following section, we introduce our proposed approach for defining, structuring and sequencing authorisations for VCA operations. Building on both traditional ATC principles and digital U-space service architecture, we outline a process specifically tailored to IAM, one that supports tactical coordination between all responsible stakeholders.

8.2 Roles and Responsibilities

8.2.1 Role of the Airport Operator

In the context of IAM operations that are integrated within existing aerodrome infrastructure, the airport operator remains a key stakeholder responsible for ensuring the continuity of safe and efficient operations. The airport operator collaborates with IAM stakeholders to enable coexistence within shared operational environments. Depending on the local setup, the airport operator may coordinate directly with the vertiport operator or establish specific procedures to integrate vertiport operations with conventional airport operations. For example, a small regional airport may choose to use existing infrastructures or develop a vertiport within the airport perimeters.

IAM flights and vertiport operations introduce new complexities when sharing airside or landside infrastructure with traditional airport functions. Such integration affects the airport operation in several ways. On the airside, coordination is required to manage access to runways, taxiways, and apron areas that may be co-utilised by VCA while ensuring adequate distances and separation to avoid interference (e.g. wake vortex turbulence or jet blast). The airport operator must harmonise flight and ground procedures to prevent conflicts between IAM and conventional traffic (see Section 3.2). On the landside, shared terminals, security zones, and passenger flows require collaborative planning to maintain service quality, regulatory compliance and a seamless passenger experience. This landside operation is challenged by the time-saving principle IAM operations advertise.

The airport operator works alongside the vertiport operator[15], the L-VNM, and air traffic control to align procedures for ground handling, passenger transfer, and aircraft servicing. The integration of digital platforms such as CIS and meteorological systems into existing airport IT architecture becomes essential for maintaining situational awareness across all stakeholders.

From a strategic perspective, the co-location of vertiport infrastructure within airport premises may influence spatial planning, investment decisions, and safety protocols. IAM presents an opportunity to broaden the range of services offered to passengers and introduce a new sustainable transport option for urban and regional mobility. The airport operator must therefore assess how new operational flows impact airport throughput, capacity planning, and emergency response capabilities.

In the EUREKA operational concept, the airport operator functions as a bridge between traditional aviation and new, U-space-enabled operations. The airport operator's ongoing role in infrastructure stewardship, procedural alignment, and stakeholder coordination is essential to successfully integrating IAM services into the broader aviation ecosystem.

[15] In some cases this can be the same legal entity.

8.2.2 Role of the Vertiport Operator

The vertiport operator role emerged with the development of vertiports as dedicated facilities for VCA operations. Since these facilities have similar operational aspects as airports and heliports, it is necessary to define a role that is responsible for their safe and efficient operation on the ground. Considering that, the vertiport operator role follows the same baseline as in current aviation where airports and heliports rely on an identified operator to manage the facility, maintain its operational readiness, and coordinate its local use. Therefore, the vertiport operator can be accepted as the extension of this established role to a new operational setting based on IAM requirements and the specific needs of VTOL operations.

The purpose of the vertiport operator is to manage the vertiport as an operational facility on a day-to-day basis. This includes supporting the regular flow of arrivals and departures, coordinating the use of key ground resources, and ensuring that relevant status and availability information is shared with the appropriate stakeholders. The role is not limited to infrastructure monitoring. It also supports the continuity and predictability of vertiport operations. Based on that, the vertiport operator acts as the main local coordinating entity for the facility.

Within EUREKA, the vertiport operator is defined as a ground operations stakeholder responsible for the local management of vertiport activities and resources. These responsibilities cover managing parking position allocation, organising ground movements within the vertiport, ensuring the real-time availability of the FATO, coordinating arrival and departure slots, supporting on-site emergency response, and sharing current vertiport status, availability, and capacity information with relevant stakeholders. All these functionalities are provided through VMS which is detailed in Section 3.5.

The vertiport operator may also have additional responsibilities beyond the ones explored in EUREKA, depending on the operational concept and the regulatory setting. These may include setting local operating requirements for VTOL operations, sharing operational status and constraints on a continuous basis, and providing local aeronautical information such as obstacle, terrain, approach and departure, and weather information. The role may also cover ground handling, passenger handling, and turnaround services such as boarding, charging, or refuelling where needed. In some cases, it may further include safety management, compliance monitoring, staff training, security, and coordination with external stakeholders such as USSPs. These aspects were not part of the current EUREKA scope, but they show that the role of the vertiport operator may grow as vertiport operations further develop. In future concepts, this could also lead to a more active local operational role, including some clearance-like or movement approval functions linked to the current condition and use of the vertiport. However, this would depend on the adopted regulatory approach and how responsibilities are shared with other aviation stakeholders.

In summary, the vertiport operator role is similar in many ways to the traditional airport or heliport operator role. In both cases, there is a clearly identified role responsible for the use of the facility and supporting its local operation. The main difference is that vertiport operations are expected to rely more on digital systems, faster information exchange, and more dynamic use of local resources. This is particularly relevant in settings where traffic density, turnaround optimisation are expected to increase. As a result, the vertiport operator follows a familiar model, but in a more connected and data-driven operational environment.

8.2.3 Role of the Local Vertiport Network Manager

The L-VNM is introduced as a network-level function to coordinate operations across a group of interconnected vertiports. Traffic flows, resource availability, and operational constraints at one vertiport may affect conditions at another vertiport. The L-VNM addresses this by maintaining a general view of the network and supporting the coordinated management of flow, capacity, availability, and operational constraints.

The L-VNM supports the planning and coordination activities that are needed to manage the vertiport network. Its responsibilities include monitoring available capacity, managing open slots and reservations, supporting stand allocation, and keeping track of resource status. It also considers planned constraints such as maintenance activities and other conditions that may affect operations. Lastly, the L-VNM exchanges relevant vertiport status and availability information with other relevant stakeholders.

These functions are enabled by the VNMS which provides the necessary digital tools for a coordinated network management. These digital tools cover tasks such as resource monitoring, slot and capacity management, operational information display, weather input, and data exchange with other systems and finally allow a connected display through the considered vertiport network. Functionalities of the VNMS are detailed in Section 3.6.

In EUREKA, the L-VNM/VNMS concept was explored through strategic modelling and expert assessment for the Case Study III. Then, it was examined in a more representative setting through real-time human-in-the-loop simulations and flight trials in the Pianabella Regulatory Sandbox at Rome Fiumicino. These activities showed that the L-VNM approach can be integrated into a relevant operational environment. The results also indicated that the VNMS supported operator tasks well, with low workload and good situational awareness. In the validation activities, the use of SWIM Yellow Profile between the CIS and the L-VNM also supported the feasibility of standards-based information exchange.

Based on these outcomes, the L-VNM can serve as a network-level function for vertiports supported by dedicated digital services and linked to the wider operational ecosystem. The concept appears useful for improving coordination across interconnected vertiports and for making better use of shared infrastructure and resources. Yet, further work is still needed especially on scalability under denser traffic, more dynamic resource allocation, and the handling and coordination of disruptions and recovery actions across the network.

8.2.4 Role of the ATCO

In the considered operational concept for the IAM in controlled airspace, ATC continues to play a central role in ensuring safe traffic management for the operational environment. The ATCO remains responsible for providing air traffic control services, monitoring flights according to the approved trajectory in the ATS flight plan and procedures, providing sequencing between controlled flights, and communicating with the PIC through voice communication when required. The introduction of VCA operations into the controlled airspace does not change these core ATCO responsibilities, but yet it does introduce additional considerations for safely accommodating such operations.

Depending on the VCA traffic density, the number of additional aircraft movements increase ATCO workload. A real-time human-in-the-loop study conducted by DLR with 10 ATCOs, integrating VCA operations into Hamburg Airport, showed that adding 15 VCA per hour to an existing traffic volume of 44 movements per hour resulted in 44% increase in workload and 18% reduced situational awareness [89]. As a result, ATCOs may require

new training to become familiar with the operational characteristics of VCAs, the specific procedures associated with VCAs and vertiport operations, and the required coordination mechanisms. In addition, the operational environment demands coordination with new stakeholders and systems such as the VMS, USSP, and VCA PIC and OCC by constantly exchanging information such as vertiport availability, airspace boundary crossing, and contingency situations. Therefore, ATCOs must have access to the relevant operational information and tools that will enhance their situational awareness and support effective traffic management.

To support these operational needs, the ATCO requires an update to their HMI as depicted in Figure 35. The ATCO monitors and manages the VCA flights within controlled airspace and the VTZ (if in place). This covers monitoring VCA flights from departure to arrival according to their ATS flight plan, issuing clearances, monitor vertiport status and availability, and transfer control, all under normal, abnormal, or faulted conditions. The enhanced ATCO HMI consolidates relevant operational information for both VCA and conventional traffic into a single display, enabling ATCOs to maintain improved situational awareness and efficiently manage mixed traffic operations.

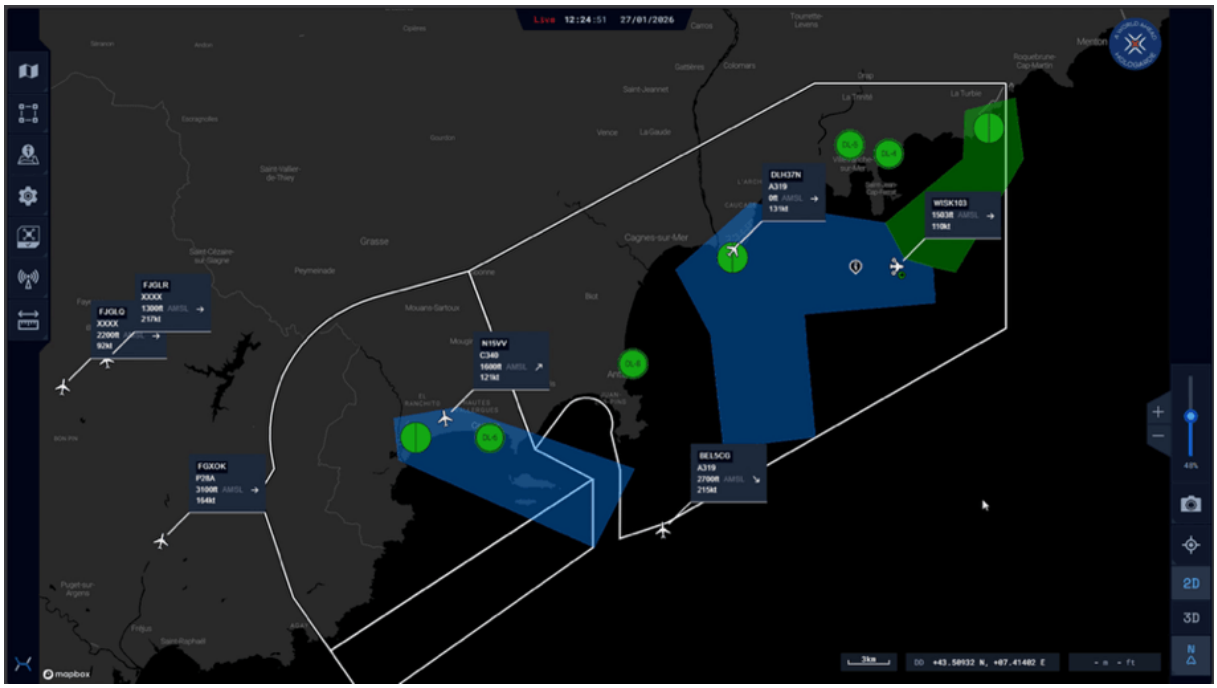


Figure 35: HMI of the ATCO in command working position developed for R&D purposes, ©Hologarde.

For Case Study I, the operational information considered for VCA flights, includes aircraft position, speed (kts), velocity vector, altitude (ft), and the associated take-off and destination vertiports. In addition, the ATCO HMI displays relevant information about the operating environment, such as VTZ boundaries and FATO locations.

Other operational aspects are visualised in the ATCO HMI as well, such as FATO availability, contingency indication under abnormal or faulted conditions, and the handover status when exiting/entering between controlled airspace. The FATO availability information which is detailed in Section 5.3, is received from the VMS in real-time. When the FATO becomes unavailable, its icon on the display turns red to alert the ATCO. If an abnormal or faulted condition is detected on a VCA, with information received from the

OCC in real-time, the ATCO HMI displays the contingency status on both, the aircraft label and its icon so that the ATCO can quickly identify and respond to the situation. Finally, the interface contains specific visual indicators related to the handover process which is described in detail in Section 8.4.

8.2.5 Role of the USSP

U-space operations rely on dedicated service providers known as USSP, which provide traffic management through digital services and information exchange. The USSP is responsible for providing the operational services needed for flights conducted in U-space. As defined by EASA, a USSP is an organisation that is certified by the relevant competent authority in accordance with Regulation (EU) 2021/664 to provide U-space services in a U-space airspace designated by the Member States [90]. Once certified, the USSP may provide these services to open, specific and certified operations (UAS and VCA operators) and coordinate with other USSPs and aviation stakeholders in line with the conditions and limitations included in the certificate.

U-space was originally developed to support lightweight drone operations, however, the introduction of VCA operations requires the USSP to support a broader and more demanding operational environment. As a result, the USSP is responsible for several operational activities from the planning phase to the execution phase of a flight. To deliver these capabilities, the USSP must be able to provide the mandatory U-space services defined by EASA, namely network identification, geo-awareness, traffic information, and UAS flight authorisation. For VCA operations to be integrated safely in U-space the two optional U-space services according to [25]); weather information and conformance monitoring, should be considered mandatory as well. These responsibilities include processing and managing flight authorisation requests, maintaining and updating the associated flight authorisation, and providing relevant operational information to operators during flight execution. Through these activities, the USSP contributes to the safe coordination of traffic inside U-space airspace while ensuring compliance with the operational constraints defined by the competent authority.

During the pre-flight phase, the USSP processes flight authorisation requests submitted by the VCA operator. First, the USSP verifies the request is complete and the required operational information has been correctly provided. The planned operation is checked against the applicable conditions within the U-space airspace, including verifying compliance with airspace restrictions, temporary limitations, and other operational constraints that may be active at the time of submission. Based on this assessment, the USSP may accept the request, reject it, or propose an alternative authorisation. Once the authorisation is issued, the flight must adhere to the defined operational conditions and deviation thresholds. Prior to take-off, the USSP confirms the activation of the flight without unjustified delay once all necessary conditions are met. Most importantly, the USSP accesses the VMS/VMNS through the CIS to validate vertiport availability at expected time of use and confirm flight activation.

During the in-flight phase, the USSP continues to support the operator by providing operational information relevant to the flight. A key service is the provision of traffic information which allows operators to be aware of other known surrounding traffic. This information may include position, time of the report, speed, heading or direction, and flight status of nearby aircraft. The geo-awareness service further provides operators with real-time information on applicable operational conditions, geographical zones, airspace constraints, and temporary restrictions that may affect the flight. The USSP may also

supply VCA and vertiport operators with now-cast and forecast weather data. As part of ongoing operational monitoring, the USSP may introduce updates to an existing flight authorisation when new operational information becomes available. These services collectively support operators in maintaining situational awareness of the operational environment throughout the flight.

Looking ahead, we expect that the UAS flight authorisation will converge to a formalised U-plan structure that aligns with the FF-ICE flight plan framework which the aviation industry began adopting this year. This evolution would support interoperability between U-space and conventional ATM systems, especially when VCA "cross borders".

Apart from the described U-space services, the USSP is obligated to coordinate and exchange information with other stakeholders. This coordination of activities and information and data exchange must follow the relevant regulations and comply with common secure interoperable open communication protocols and with defined data quality, latency, and protection requirements. In addition, all information relevant to the safe provision of U-space services must also be coordinated with other USSPs.

8.2.6 Role of the CIS

The CIS provides the necessary information for the functioning of U-space. As defined by EASA, the CIS is provided by a certified organisation responsible for collecting, verifying, and distributing this information, with certification carried out in accordance with Regulation (EU) 2021/664 [90]. Within each designated U-space, the CIS acts as a single authoritative source of operational information so that all stakeholders rely on a common and consistent data set when providing their services.

The common information distributed through the CIS primarily describes the operational environment in U-space. This includes the horizontal and vertical limits of the U-space airspace, applicable operational requirements, and the list of certified USSPs operating within that airspace. The CIS also provides information about adjacent U-space airspaces, relevant geographical zones, and any static or dynamic airspace restrictions defined by the authorities. This data can be shared from a single source (single CISP) or embedded in the USSP. In accordance with Regulation (EU) 2021/664, Art. 5(1) [90], the CIS ensures that U-space services operate on a basis of consistent operational information shared to all stakeholders.

Within EUREKA, the information distributed through the CIS is extended to include additional elements necessary to support the management of IAM operations. These extensions cover vertiport availability, taking into account operational inputs provided by USSPs and vertiport operators. In addition, the CIS provides access to real-time vertiport schedules and vertiport contact information. Through this enhanced data set, the CIS strengthens the coordination of operations across the various stakeholders active in the U-space airspace.

Although the CIS applies only to the U-space environment, the concept of common information exchange should not be limited to that, since IAM operations may also take place in mixed operational environments. In EUREKA, a similar approach is applied in controlled airspace through the digital exchange platform (DEXP) which enables information exchange between relevant stakeholders including ATCOs, vertiport operators, VCA operators, and USSPs. Through information exchange mechanisms such as the CIS and DEXP, operational data can be shared in a consistent and collaborative manner across the operational environment. These approaches also align with the broader System

Wide Information Management (SWIM) framework, which provides the foundation for information exchange across modern ATM systems [91].

8.3 Clearances and Authorisations for VCA Flights

As introduced in Section 8.1, ATC clearance and UAS flight authorisation will need revision once VCA flights are transitioning between these two operating environments.

Minutes before take-off (T-minutes), the activation of the flight authorisation (in U-space) or ATC clearance request ("start up clearance" in controlled airspace), must verify that the previously booked vertiport slot remains available. Because VCA operations may range from services scheduled months in advance, to fully ad-hoc on demand missions, the planning lead time, and therefore the certainty of vertiport availability, can vary considerably. To address this, we therefore introduce a *vertiport clearance/authorisation request* mechanism: the USSP, as part of processing the flight authorisation queries the destination vertiport availability at the expected time of use. The VMS/VMNS responds with approval or adjustments (for example, if delays require a new slot and take-off time). This is analogous to how an airport tower or coordinator ensures a runway slot before an aircraft departs.

For ATC managing VFR VCA flights, vertiport availability must be secured too.[16] Theoretically, this means that the tower controller at an airport vertiport will not clear an VCA for take-off unless the destination pad is confirmed available at the expected time of use. As of now, this information is transmitted between the VCA operator and vertiport operator. The ATCO has only access to the vertiport information through the submitted flight plan, hence the responsibility lies with the VCA operator to make sure that the vertiport slot is actually available. The ATCO has no means to check the actual vertiport availability in real-time.

In U-space airspace, information sharing and access are much easier. Regardless of the U-space airspace category (Y or Z), the USSP's flight authorisation itself is contingent on a confirmed landing slot, thereby withholding authorisation if no destination vertiport availability can be assured. This collaborative pre-flight step ensures that every flight that takes off has a high degree of certainty that a landing pad will be available upon arrival. All this also applies to any selected diversion vertiports and locations.

Once airborne (T>=0, landing (L)<60 minutes), maintaining vertiport availability requires dynamic updates. Vertiport operators continuously update the status if conditions change, for instance, if a pad becomes unexpectedly unavailable or a priority flight (VEMS flight, contingency or emergency flight) is disrupting the scheduled sequence. In such cases, the USSP immediately alerts the VCA operator and suggests a reroute to a designated alternate vertiport or holding, as per the VCA operator's pre-planned diversion options indicated in the flight plan. The PIC always retains the authority to divert to the alternate "safe landing" site if the primary destination landing pad's availability can no longer be assured.

If the flight is conducted under ATC, the ATCO must be integrated into this information loop through shared situational awareness tools or as part of the network management. To allow for safe operations regardless of the operating environment, vertiport availability must be shared among the relevant stakeholders (see Section 6.2). Therefore, U-space services

[16] For the time being, only VFR VCA flight are concerned by constraints defined in Regulation 2024/1111 [6]. However, as this restriction is mainly rooted in the limited electric VCA endurance, it can be expected, that this will eventually apply to IFR VCA flight as well.

and systems must relay pertinent updates to ATC interfaces to establish a collaborative environment. This ensures ATC coordination (especially in terminal airspace) to account for the latest vertiport availability changes. The overall operational concept demands that traffic flow adjustments (speed control, holding, or sequence changes) can be initiated by either the USSP or ATC to safely manage the traffic flow at a vertiport and inside a vertiport network.

As the VCA approaches its destination vertiport (L<-minutes), a final confirmation of landing pad availability is performed. The VCA operator (PIC, OCC) must verify the landing slot availability with the VMS (via data link or voice, depending on the operational constraints). If the landing pad is available (see definition in Section 5.3), the final landing authorisation or clearance can be given.

In a fully digital U-space environment, this clearance becomes a tactical authorisation sent by the VMS/VNMS directly or through the USSP to the pilot's interface when the all constraints are met.

In a controlled airspace scenario (e.g. vertiport at an existing airport or under a tower's oversight), the ATCO (e.g. tower controller) will issue the actual landing clearance to the PIC, but only when having direct oversight that the landing pad is available. Essentially, we expect that the tower would treat the landing pad like an additional runway/helipad, ensuring via voice communication or integrated digital systems that no other VCA is on the pad or on short final, before clearing the next arrival. This final approach coordination guarantees that "safe landing" criteria are met: the arriving VCA lands with no risk of conflict and with required ground services standing by.

However, despite this initial evaluation and referring to the regulatory guidance summarised in Section 8.1, a clear and universally (European) accepted allocation of roles, responsibilities in the "authorisation-clearance-context" for VCA at vertiports remains an ongoing gap. This becomes particularly evident when considering the diversity of vertiport operational environments; aerodrome landside, aerodrome airside, aerodrome surroundings, controlled airspace, uncontrolled airspace, U-space airspace, and inside city centres and urban environment. As a result, situations may arise in which clearance and authorisation authorities may shift to who is best-positioned and able to make decisions (see Section 1.1). Table 15 summarises the key areas of uncertainty identified when working on the three EUREKA case studies.

Table 15: ATC clearance vs. U-space authorisation: Unresolved topics.

Not clarified yet	**ATS airspace**	**U-space airspace**
Authority "Who" ?	ATC issues clearances	Multiple actors may be certified to hold clearance-like functions and responsibilities (USSPs, vertiport operator, etc.). Due to the federated notion of U-space, multiple different USSPs can operate in one airspace airspace. The lack of a single point of responsibility risks conflicting instructions and raises accountability and liability issues in case of incidents.
Terminology "Clearances vs. Authorisation"	ATC clearances are tactical and safety-critical and issued by a certified ATC unit.	Authorisations are strategic (pre-flight) and issued by a certified USSP. It is unclear if a "U-space authorisation" is legally equivalent to an ATC clearance and if it holds the same weight for compliance and liability.
ATM and U-space interoperability	There is no procedural or collaborative interface established between ATM and U-space that supports transfer of control and responsibility of VCA flights entering and existing U-space as full U-space user.	
Timing "When?"	Stepwise clearance	Once the flight request and activation is authorised, the U-space flight is authorised for the entire flight. It is unclear if a stepwise or full flight authorisation or clearance is favoured. Stepwise clearance can increase safety, but at the same time, it risks slowing down VCA flights («30 minutes cruise time) if not fully digitised and automated. Clearing missions upfront does not accommodate unforeseen circumstances no matter how well and accurate the strategic phase was planned.
Ground operations	Vertiport ground and taxi clearances are mentioned but require direct visual oversight of the tower controller. If the vertiport is not located at an airport but in controlled airspace, remote tower technology must be in place to provide ATS.	Authorisations concerning ground movement are not part of the U-space regulatory framework [25] and ConOps [59]
Integration of energy management	The VCA regulation [6] directly links clearances with fuel and energy state. Prioritisation processes might need adaptation	Standardised prioritisation processes are lacking.

8.4 Case Study I: ATC-USSP "Handover"

To examine how the defined coordination procedures for the transfer of an aircraft responsibility between ATS units and USSP (referred to as "handover") could work in practice when transitioning from controlled airspace to U-space, real-time human-in-the-loop simulations were conducted. In this scenario, the ATCO was acting as the VTZ manager, i.e. the ATCO was responsible for the arriving and departing VCA traffic at the vertiport. The handover procedure is initiated with the ATC system automatically sending an Estimate (EST) message to the USSP through the Digital Exchange Platform (DEXP) as the flight continues. The EST message consists of a four-dimensional reference point and the estimated time the aircraft is expected to reach the transfer point. In the ATCO HMI displayed in Figure 36, the white arrow attached to the VCA icon represents the transmission of this handover EST, meaning the transfer is in progress. At the operational level, the ATCO informs via voice communication the PIC that the flight is about to leave controlled airspace while the USSP activates the required U-space services for the flight at the defined transfer point. Once the U-space services are activated, the USSP notifies the OCC directly. At the same time, the USSP sends an Acknowledgement (ACK) message back to the ATC system (the ATCO) confirming the aircraft has been accepted into the U-space environment. In the ATCO HMI, the white arrow turns green when the ACK message is received. At this stage, voice communication between the ATCO and the PIC is terminated indicating that the handover is completed, however, the PIC does not leave the frequency until the airspace boundary is reached. Two main steps of the handover process, EST and ACK, are illustrated in Figure 36.



Figure 36: Handover from controlled airspace to U-space.

The suggested handover procedure was evaluated through five simulation runs involving five ATCOs. In the designed procedure, the ACK message is expected to be transmitted at least 2 minutes before the aircraft reaches the U-space boundary. Additionally testing of timing thresholds at 1 minute and 1.5 minutes was not deemed sufficient. Two minutes timing was identified as providing a sufficient margin to ensure safe separation from potential U-space traffic before the aircraft enters that airspace, as well as sufficient reaction time for the ATCO. However, in the first two simulation runs, the ACK message was sent later than expected, when the aircraft was approximately 1 NM from the U-space boundary. While this did not result in any safety violations in the simulated scenarios due

to low traffic densities, it was noted that such a late ACK could become critical in situations involving higher traffic density in U-space, as it would not allow for sufficient reaction time. Therefore, in the remaining simulation runs, the ACK message was finally sent when the aircraft was around 2 to 2.5 NM from the boundary, aligning with the intended timing of the handover procedure. The transfer distance should be investigated further in the future based on the separation requirements that will apply between manned and unmanned aircraft, and VCA and conventional aviation. Since traffic conditions beyond the boundary may vary, the handover should take place early enough, to allow for all the necessary information to be gathered to ensure the aircraft can be safely integrated into the receiving airspace. These conditions should be defined in future letters of agreement.

Following each simulation, the participating ATCOs also provided feedback on the handover procedure via questionnaires and debriefing sessions. One of the main concerns raised by several ATCOs was the lack of visibility of the traffic operating in the adjacent airspace. As the controllers do not have direct information about traffic in the adjacent airspace, discomfort might be expressed with transferring an aircraft without first confirming the absence of nearby traffic. In conventional operations, controllers ensure that the receiving sector can safely accept the aircraft before completing a handover. The handover procedures between human-driven and system-driven airspace managers were designed with the objective to maintain the same level of safety. For this reason, each (potential) managing authority (ATC and USSP) shall have access to a shared database containing real-time information to ensure situational awareness amongst all relevant stakeholders. This should include the FATO usability, the aggregated real-time traffic in both airspaces, the VCA's potential contingency status, and the handover status between ATC and USSP. This will enable both responsible entities to clearly identify and communicate when responsibility for a given flight has been successfully transferred. A key point that emerged during the simulations was the need for confirmation that the aircraft had successfully connected to the USSP. Several controllers requested that the PIC inform them verbally once the connection to the USSP had been established, as they considered this information as confirmation that the handover of responsibility, already received through ACK, had been completed. Although this confirmation step was not explicitly included in the designed procedures, several controllers incorporated it into the handover communication during the simulations.

A similar procedural approach could also be applied to study handovers from U-space to controlled airspace which may be examined in future studies, as well as potential handovers resulting from contingency situations.

9 Conclusion

The findings presented in this paper address four operational challenges outlined in the introduction; where to place a vertiport, how to operate a vertiport, how to manage VCA at a vertiport, and how to operate and manage VCA inside a vertiport network. Across these domains, our results show that to successfully progress with IAM, both ATM and U-space must acknowledge their respective benefits and shortcomings. IAM requires a collaborative operating environment in which the responsibilities for air traffic service, management and control provision are clearly and unambiguously defined.

Regarding vertiport location and vertiport operation, the current European VCA and vertiport regulatory framework (ref. [6]) imposes stricter planning requirements on the PIC (e.g. identification of take-off, destination and diversion vertiports/locations and assurance of their availability at the expected time of use). As of now, neither existing heliports nor ATM and U-space provide this information reliably and on an area-wide basis. This directly affects the design of VCA operating procedures and the ability to safely and efficiently operate and manage VCA at a vertiport and within a vertiport network.

Furthermore, implementing U-space as proposed in the current regulation (see ref. [25]), treats VCA operations as if they were conducted in segregated airspace. At the same time, ATM lacks the digital maturity and short-term and ad-hoc planning horizons needed to support highly automated aircraft operations, which are forced to fall back on traditional operating methods such as voice communication. Consequently, the four operational challenges cannot be addressed effectively within the existing ATM operational concept that would allow scalability.

In response, we propose a shift towards a data-centric, vertiport-network focused and service-based operating model that treats vertiports as nodes of the airspace system with explicit interfaces to the USSP and CISP and (where needed) ATM systems and PICs. A core enabler is the system architecture for information sharing around vertiport availability: The VMS is a “single source of truth” for pad/slot/stand status, overall operational constraints and vertiport availability, publishing real-time information to the entire ecosystem, while the local VNMS acts as a digital orchestrator that monitors and manages vertiport network resources. Through USSP–CISP connectivity, flight intent can be checked against live vertiport capacity, slots can be reserved, booked, confirmed, and disruptions such as sudden closure can propagate as digital and machine-readable updates that trigger alerts and re-planning across stakeholders.

Our studied concepts, together with the operational challenges faced in IAM, underline why we need to rethink air traffic management and service provision, and how both systems, ATM and U-space, can converge to digital air traffic services. The subsequent outlook introduces next steps, and potential required changes to pave the way for digital air traffic services and clearances and to achieve the convergence of ATM and U-space in the long run.

10 Outlook

The evolution of IAM depends on a coherent, interoperable, and digitally mature integration between legacy ATM and U-space. As we highlighted in previous sections, several foundational elements and assumptions, embedded in today's aviation ecosystem must be revisited.

This section outlines the key areas in which ATM and U-space must evolve to support scalable IAM operations. It highlights the need to harmonise altitude references, reference local weather, adapt U-space services and airspace structures, reconsider future flight rules, and identify regulatory steps required to enable IAM flight testing and long-term convergence between both systems, ATM and U-space.

10.1 How U-space Needs to Evolve

The findings presented here confirm that the current U-space framework and operational concept, which is designed primarily for low-kinetic-energy UAS operating in VLL airspace, is insufficient to support scalable IAM operations involving certified, passenger and cargo-carrying VCA, which may typically fly up to 3000 ft AGL or higher and routinely interact with controlled airspace (see further reference in [92]). These gaps are evident in unclear responsibilities relating to flight authorisation and clearances, conflict management, and traffic synchronisation, particularly when ATM and U-space jurisdictions overlap or are adjacent. At the same time, however, certified operations are part of and mentioned in the U-space regulation [25].

We therefore identify the following required changes:

- U-space airspace volume: U-space airspace should be extendable to at least 3000 ft AGL. Context: Regulation EU (IR) 2019/947 sets maximum altitude of 120 m AGL for the open category, while (IR) 2021/664 does not specify a maximum altitude for U-space airspace.

- Conformance monitoring: U-space service "Conformance Monitoring" should become a mandatory service provided by a certified entity.

- Weather information service: The U-space Weather Information Service should be established as a mandatory, certified service, providing operationally relevant weather advisories to VCA operators.

- Weather-related restrictions: While EU (IR) 2021/664 [25] allows USSP to reject a flight authorisation due to weather constraints, the VCA operator retains responsibility for airworthiness and operating limits in certified category operations. Therefore, the USSP can only provide advisory weather input to the VCA operator through flight authorisation and activation. However, the vertiport operator or competent authority can impose additional limitations that can restrict the VCA operation. (Current regulation (2021/664) provides only limited clarity!)

- Vertiport integration: Vertiports should be integrated into U-space using a network centric approach rather than a vertiport-centric one, balancing commercial confidentiality and safety requirements.

  - *Vertiport availability* should not be an exclusive U-space service. It should be provided as common information, regardless of whether operations occur in controlled, uncontrolled, or U-space airspace.
  - Confirmation of the vertiport slot should be required before flight activation.
  - Real-time pad and vertiport availability for all vertiports and designated diversion locations in the network should be provided as common information.
- U-space services should be accessible outside U-space airspace, if desired, to enable operations such as take-off outside U-space followed by entry into designated U-space.
- Filing a flight plan should be considered mandatory for IAM operations regardless of the operating environment. In particular, as VCA operations eventually transition towards full U-space integration, the flight intent needs to be structured in a way that can be processed not only by ATS units but also by the USSP
- The U-plan format should be standardised to enable the sharing of flight intent through the Flight Authorisation Service in U-space, in alignment with current and emerging standards introduced in existing ATM systems such as FIXM (FF-ICE).
- The USSP should be responsible for processing, managing and updating U-plans.
- Prior to operation, bilateral agreements should be in place between the vertiport operator, VCA operator and the USSP.
- Mandatory information transmitted as part of the flight authorisation service should be extended to include:
  - Modes of operation: VFR, IFR, any form of futuredigital flight rules (DFR) (if eventually in place)
  - Category of the operation: aligned to EASA categories (see [23]):
    - Type 1: IFR Cargo UAS
    - Type 2: unmanned VCA cargo- and/or passenger-carrying
    - Type 3: manned VCA
  - The operational intent is built on the 4-D waypoint sequence relative to the intended take-off locations plus additional information describing the flyable flight path, e.g. using path terminators
  - Take-off vertiport + expected time of use
  - Destination vertiport + expected time of use
  - Selected take-off and landing procedures
  - Endurance information, including electric reserve (unit to be standardised, e.g. minutes)
  - Contingency information, including diversion locations + expected time of use
- USSP advisory information should evolve, where appropriate, into mandatory operational instructions, particularly in Z U-space airspace.

- The establishment of dedicated airspace structures such as blocks, segments, flyways, or corridors, may be considered to support their specific operational functions within the designated airspace. These structures should be complemented by clearly defined requirements for operating within these airspace constructs. This ensures procedural deconfliction of VCA operations from sUAS operations and other relevant manned traffic.

- Best practices should be collected and developed for designing VCA VFR flight procedures, given that only instrument flight procedures are currently widely designed and used.

10.2 How We May Reimagine the Existing Flight Rules Paradigm

First, we might consider integrating VFR operations into U-space by providing U-space services as advisory services to manned aviation. Doing so would not only support MVCA operations but also enhance overall safety by improving situational awareness and enabling strategic deconfliction across the entire lower-altitude layer, where general aviation, state aircraft, law enforcement, HEMS and VEMS also operate.

The initial step would be to enhance VFR to fully leverage the benefits of U-space. This could lead to a concept such as U-space visual flight rules (UVFR), applied to VFR-like operations within U-space airspace. Technically, those operations would no longer fit within the conventional VFR because additional requirements such as e-conspicuity may become mandatory. UVFR would thus represent a specialisation of conventional VFR, still including an onboard PIC and remaining limited to VMC. An evolution of conventional VFR is expected to gradually incorporate enhancements, such as DAA, increasing airborne automation (e.g., autopilot/flight management system) and improved interoperability with U-space services, including traffic information, strategic conflict detection and resolutions, and weather information.

Once sufficient experience has been gained in exploring the convergence of VFR and U-space, attention could turn to IFR operations. U-space instrument flight rules (UIFR) would apply to IFR-like operations within U-space airspace, which again, technically, would no longer fit legacy IFR. Under the current U-space regulatory framework, legacy aircraft operating under IFR in U-space airspace are not subject to any equipage requirements or restrictions on having an onboard PIC. However, existing ATC must be able to perform dynamic airspace reconfiguration, temporarily reclaiming ATS airspace that had been delegated to U-space. Additionally, given the relatively low speeds and altitudes of IAM IFR flights and their potential presence in uncontrolled airspace, there may be environments where conventional IFR traffic surveillance means (PSR, SSR, ADS-B, etc.) are no longer effective. This could imply that conventional IFR aircraft may also need alternative e-conspicuity solutions. Certain advanced UIFR operations, conducted with an onboard PIC meeting the required capabilities (data connectivity, automation/autonomy capabilities, etc.) could help validate the solutions needed to enable pilotless IAM operations in later stages. Initial low density UIFR operations could rely on strategic deconfliction provided by U-space services, with ATC providing separation or traffic advisories consistent with conventional IFR, depending the airspace class.

All this preparatory work could ultimately lead to DFR, applicable to all types of aircraft, including MVCA, remotely-piloted, automated or autonomous aircraft, such as drones, UVCA, high-altitude operations, and enable the evolution of airspace classes that currently do not provide air traffic services.

Achieving this vision will require extensive research, development, testing and global collaboration led by ICAO, to safely reimagine the existing flight rules paradigm.

10.3 How We May Challenge VFR and IFR Flight Procedure Design

To enable more en-route capacity in the future as UAM traffic densities increase, additional measures should be further researched and tested. This may include:

- Dedicate two of the four introduced available cruise levels in Section 4.2.5 of each set of flight rules for high-speed UAM aircraft, and the other two for low-speed aircraft, e.g. the ones at higher altitudes for the 'hybrid multi-copter/aeroplane' type and the ones at lower altitudes for the 'multi-copter' type, though discriminating by doable altitude and speed range rather than by type of VCA for flexibility.
- Resort to higher cruise levels (above 3,000 ft AGL), if airspace availability and VCA performances permit.
- Enable lateral overtaking manoeuvrers to solve in-trail conflicts (per current rules of the air for VFR or specifically designed manoeuvrers for IFR), if navigation accuracy proves to achieve containing them within the lateral route containment (NavSpec) while maintaining required cross-track separation, and/or enable route offsetting, if airspace availability combined with cross-track separation permit (see projects like [53, 55]).
- Enable vertical overtaking manoeuvrers to solve in-trail conflicts, if ATC applies (IFR) and workload permits, otherwise if advanced U-space tactical deconfliction services prove enough maturity to handle these manoeuvrers (for IFR and VFR).
- Reduce cross-track separation, if navigation accuracy permits, thereby enabling more parallel tracks.
- Reduce vertical separation, akin to the Reduced Vertical Separation Minima initiative in conventional aviation, if altitude accuracy and wake vortex limitations permit, thereby enabling additional flight levels.
- Allow crewed IFR flights to use VFR cruise levels while in VMC. This would imply a further departure from legacy flight rules, which might be articulated through replacing vertical separation between VFR and IFR flights by horizontal separation (along-track and/or cross-track), or through advanced U-space tactical deconfliction services, or a combination of the mentioned solutions.
- Reduce along-track separation, as higher trajectory predictability is achieved and advanced U-space tactical deconfliction services become more capable.

Regarding the departure and approach segments, diverse conventional IFPs such as RNP0.3 would support low-level routes and PinS departure, RNP APCH would support PinS Approach and RNPx would support narrower corridors where x<0.3 NM. Visual departure/approach for VFR would be designed overlapping corresponding IFPs. While conventional IFPs do have a visual segment adjacent to the FATO, which requires a PIC onboard, in the future, such a limitation must be overcome, thereby enabling full

precision instrument departure and approach down to the FATO (i.e., lifting-off from and touching-down at the FATO instrumentally, respectively).

Additional research and validation effort should be spent to further reiterate, evaluate and evolve the regulatory framework that guides VCA flight procedure design. This includes:

- MOC VTOL.2115 Take-off performance [83], and PTS-VPT-DSN.D.405 General [3], and PTS-VPT-DSN.D.430 Obstacle limitation requirements [3] create an intersection at 465 ft while it should bring the VTOL-capable aircraft to 152 m (500 ft) above FATO elevation. This creates a mismatch between the take-off procedure and OLS requirements. Therefore, we suggest a change to 535 ft above FATO elevation.

- ICAO Doc 8168 PANS-OPS Vol III [51] are not containing any instrument flight procedure design criteria and current PinS are not designed for VCA performance profiles. Therefore we suggest to develop dedicated VCA IFP design criteria and more specific navigation specifications are needed.

- Automatic take-off and landing is eventually considered to be a key capability for operating at urban airports which may be untowered or not offer sufficient visibility in the event that a control authority were to be physically located at the airport, thus substituting the use of PinS procedures. This would increase the predictability and safety in all-weather conditions as VCA operations are intended to operate. The guidance on ATOL operations provided by EUROCAE ED-252 – OSED for RPAS automatic take-off and landing is focused on fixed-wing RPAS [93]. Although much of such guidance is anticipated to remain valid for the segments where VCA operate in fixed-wing configuration, further guidance material covering the VTOL phases and the transitions between fixed-wing and VTOL modes needs to be developed.

- ICAO Doc 4444 [85] defines a current 5 NM en-route separation or 3 NM separation when sufficient radar coverage is provided. This requirement does not take into consideration that VCA under IFR are flying the entire time with minimally RNP 0.3 navigation accuracy. Furthermore, surveillance technologies exist which may perform real-time conformance monitoring either by ATS or a USSP. These two items together should enable 4 x RNP separation distances for "UAM corridors", thus permitting a more efficient and safe use of airspace which is vital for the economically feasible design of VCA travel routes.

- Previous SESAR solutions have established the viability of Simultaneous Non-Interfering Operations for Rotorcraft at heliports collocated at Airports [57, 94, 95]. It is considered equally essential to study the applicability of these procedures to VCA operations in a standardised process such that frequent, regular operations may be performed at airport vertiports which is where precisely the primary business case for VCA in passenger transport is expected to occur.

10.4 We Must Rethink the Importance of Weather Systems and Altitude Referencing

As VCA operators will be flying within, across, and outside U-space airspace, a harmonised approach to weather information systems is essential. Currently, conventional aviation relies on pressure-based altitude referencing (e.g., QNH, QFE, and standard pressure

settings), while U-space operations, particularly those involving drones, often use GNSS-derived altitude or even relative height above ground level. This divergence introduces risks in vertical separation, flight planning, and situational awareness. For instance, a drone operating under GPS height may not be vertically deconflicted from a crewed aircraft using pressure altitude unless both systems are reconciled. Even with GNSS, that provides geometric altimetry, the reference for zero height needs to be established and agreed; it can be the WGS-84 ellipsoid, the geoid (mean sea level) or the elevation of the home point. Similarly, weather minima and flight rules based on pressure altitude may not be directly applicable to GPS-based operations.

Therefore, we identify the following harmonisation needs:

- Weather Data Harmonisation: Ensure that meteorological services used in legacy aviation (e.g., METAR/TAF, QNH-based wind profiles) are interoperable with U-space weather services, which may rely on local, GNSS-referenced data.
- Altitude Reference Alignment: Develop conversion protocols and shared standards between pressure altitude and GNSS altitude to support safe mixed operations.
- Regulatory Synchronisation: Align definitions and thresholds for VMC/IMC, flight levels, and vertical separation across ATS airspace, U-space airspace, and drones operating outside of U-space airspace.
- Operational Interfaces: Equip vertiport systems and flight planning tools with dual-referencing capabilities to accommodate both legacy ATM and U-space altitude models.
- Weather Data Sources: Open regulatory frameworks to allow the use of non-authoritative meteorological sources, both public and private sector, alongside certified national weather providers. This flexibility is essential not only to enhance safety through redundancy and local precision, but also to address economic constraints that may limit the availability or scalability of authoritative data services.

Author Contributions: Conceptualization, K.S; methodology, K.S; software, all; validation, all; formal analysis, all; investigation, all; data curation, all; writing—original draft preparation, all; writing—review and editing, K.S., A.T.A.; visualization, K.S, A.T.A, J.N.B, V.G, S.M, A.M., B.I., M.H., E.M. A.M., M.K.; supervision, K.S.; whitepaper administration, K.S. All authors have read and agreed to the published version of the manuscript.

Funding: This project has received funding from the SESAR3 Joint Undertaking under the European Union's Horizon EUROPE research and innovation programme under grant agreement No 101114799.

Data Availability Statement: The entire collection of research data can be accessed after the completion of the EUREKA project under https://cordis.europa.eu/project/id/101114799.

Acknowledgments

The authors would like to acknowledge the valuable contributions of external subject matter experts Naomi Gray and Pablo Haro, whose guidance and feedback shaped both this manuscript and the project. The authors also thank Volocopter and Lilium for their role in advancing the digitalisation and electrification of aircraft operations and challenging the established ATM paradigm. During the preparation of this manuscript, the authors used Microsoft 365 Copilot and Claude Code (Anthropic) to support language refinement and improve overall structure of the manuscript. The authors have reviewed and edited all outputs and take full responsibility for the content of this publication.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this paper:

A-CDM airport collaborative decision making

AAM advanced air mobility

AAMSG advanced air mobility study group

ACK acknowledgement

ADAAT actual departure authorisation approval time

ADART actual departure authorisation request time

ADS-B automatic dependent surveillance – broadcast

AGL above ground level

AIBT actual in-block time

AIP aeronautical information publication

ALDT actual landing time

AMC acceptable means of compliance

ANSP air navigation service provider

AOBT actual off-block time

AOP airport operational plan

API application programming interface

ATAAT actual taxi authorisation approval time

ATART actual taxi authorisation request time

ATC air traffic control

ATCO air traffic controller

ATFCM air traffic flow and capacity management

ATM air traffic management

ATOT actual take-off time

ATS air traffic services

ATZ aerodrome traffic zone

CDS contingency decision support

CFP critical failure performance

CIS common information service

CISP common information service provider

CMP certified minimum performance

CNS communication navigation and surveillance

col collision

CSFL continuous safe flight and landing

CTR control zone

DAA detect and avoid

DCB demand and capacity balance

DEXP digital exchange platform

DFR digital flight rules

DP descent point

DVCA VTOL-capable aircraft in unmanned configuration that carry cargo

EASA European Union Aviation Safety Agency

eFPL filed flight plan exchanged via FF-ICE services

EGNOS European Geostationary Navigation Overlay Service

EST estimate

EUSPA European Union Agency for the Space Programme

eVTOL electric vertical take-off and landing

FAA Federal Aviation Administration

FAP final approach point

FATO final approach and take-off area

FF-ICE flight and flow information for a collaborative environment

FIXM flight information exchange model

FL flight level

ft feet

FTS fast-time simulation

GM guidance material

GNSS global navigation satellite system

HEMS helicopter emergency and medical service

HMI human-machine interface

IAF initial approach fix

IAM innovative air mobility

IAP instrument approach procedure

IAS innovative aerial services or indicated airspeed

ICAO International Civil Aviation Organisation

IDF initial departure fix

IDP instrument departure procedure

IFR instrument flight rules

IMC instrument meteorological conditions

L landing

L-VNM local vertiport network manager

LOS loss of separation

m metre

MAPt missed approach point

MCA minimum crossing altitude

MCH minimum crossing height

METAR Meteorological Aerodrome Report

MOCA minimum obstacle clearance altitude

MVCA VTOL-capable aircraft in manned configuration

NASA National Aeronautics and Space Administration

NOTAM notice to air missions

OCC operational control centre

OFP operational flight plan

OIS obstacle identification surface

OLS obstacle limitation surface

P probability

PBN performance-based navigation

PIC pilot in command

PinS point-in-space

POC point of commitment

PSR primary surveillance radar

RFFS rescue and firefighting services

RNP required navigation performance

RTS real-time simulation

s second

SaaS software as a service

SBAS satellite based augmentation system

SERA standardised European rules of the air

SID standard instrument departure

SSR secondary surveillance radar

STA scheduled time of arrival

STAR standard terminal arrival

STOT scheduled take-off time

sUAS small unmanned aircraft systems

SWIM system-wide information management

T take-off

TAF Terminal Area Forecast

TLOF touch-down and lift-off area

TLS target level of safety

TMA terminal control area

TOBT target off-block time

TOC top of climb

TOD top of descent

UAM urban air mobility

UAS unmanned aircraft system

UIFR U-space instrument flight rules

USSP U-space service provider

UVCA VTOL-capable aircraft in unmanned configuration that carry passengers

UVFR U-space visual flight rules

V-CDM vertiport collaborative decision making

VAS vertiport automation system

VCA vertical take-off and landing capable aircraft

VCTM vertiport collaborative traffic management

VEMS VCA emergency and medical service

VFR visual flight rules

VHF very high frequency

VIZ vertiport information zone

VLL very low level

VMC visual meteorological conditions

VMS vertiport management system

VNMS vertiport network management system

VSG visual segment gradient

VTZ vertiport traffic zone

WASG worldwide airport slot guidelines

WIS weather information service

A Excerpt of IAM Regulatory References

To help the reader navigate the European regulatory environment for VCA and vertiports, this Appendix provides a summary (non-exhaustive) of the most relevant references.

Document	Summary	Ref.
EASA RMT 0230	The regulatory task RMT.0230, launched by EASA in 2022, responded to the urgent need for a safe and harmonised civil UAS operations framework in Europe. Before RMT.0230 was initiated, most of these operations were relying on national authorisations delivered locally by each Member State. The aim of this task is to create a European regulatory framework that harmonises and balances innovation and safety for UAS, in order to avoid fragmentation in Europe. While initially starting with operations in the "open" and "specific" categories, the current focus of RMT.0230 on the "certified" category operations. It is a starting point for integrating high-risk UAS and VCA into the European aviation system. RMT.0230 includes different deliverables, defined as "tasks" and listed from task A to task G. Task C targets Unmanned Aircraft System operations in the "certified" category and UAM and subdivides operations into three different types: cargo UAS under IFR at conventional aerodromes (Type #1 operations), unmanned VTOL in U-space for passenger or cargo transport (Type #2 operations), and manned VTOL operations in urban environments (Type #3 operations). For the first time, EASA recognises the emergence of IAM, introducing this term as part of the Opinion. Previously it was referred to as UAM, and including VCA, previously referred to as VTOL.	[23]

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Table 16: IAM Regulatory References.

Document	Summary	Ref.
EASA 2024/1111	The Commission Implementing Regulation (EU) 2024/1111 is applicable since 1 May 2025 and represents a significant step towards the structured integration of VCA into the European aviation system. This regulation evaluates three established key European regulations and includes changes to them addressing different aspects of IAM to ensure its proper integration. The first amendment to Regulation (EU) No 1178/2011 allows holders of commercial pilot licenses to add a VCA type rating to their licence, including instrument flight operations where required, and provides the basis for defining type ratings and specific training requirements for VCA crews, including recurrent training and operational checks. The second amendment concerns the Implementing Regulation (EU) No 923/2012 (SERA) which was necessary to ensure the safe introduction and coexistence of VCA with conventional aviation and to mitigate the risk of mid-air collisions. Notably, the term "energy" was introduced regarding "fuel/energy" management to cover electric propulsion, as well as requirements to manage the coordination with ATM. The last amendment is to Regulation (EU) No 965/2012 which formally includes the term "VCA" as new aircraft category into European regulation for the first time. In addition to the amendment, EASA 2024/1111 included Annex IX to Regulation (EU) No 965/2012 – Innovative Air Mobility Operations (Part-IAM) with generic requirements such as crew and PIC responsibilities, carriage of goods and passengers, power supply, meteorological conditions, altitude minima, submission of flight plan, definition of diversion location, obstacle accountability or instruments and equipment, but only for operations in VFR by day. This creation of a dedicated annex marks the most substantive innovation within the package, as it recognises VCA as a distinct operational category with specific requirements.	[6, 45]

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Table 16: IAM Regulatory References.

Document	Summary	Ref.
EASA PTS-VPT-DSN	EASA published the "Prototype Technical Design Specifications for Vertiports" (PTS-VPT-DSN) in March 2022 as the first attempt to provide guidance for the safe design of vertiports to accommodate VCA operations. This guidance was developed under the RMT.0230, concretely in Subtask (G) and even though it is a non-binding rule, it sets a technical baseline for local authorities, urban planners and future VCA operators on the design of vertiports. The vertiport prototype specification was developed with the support of the Member States experts, future vertiport operators and VCA manufacturers and specifically targets congested vertiports in urban environment for the first time. This document is an anticipated glance of the planned Certification Specifications for vertiports (CS-VPT-DSN) which will cover a proper Regulation of vertiports under (EU) 2019/1139. Similarly to the IR (EU) 2024/1111, PTS-VPT-DSN follows the approach of adapting the existing regulations for aerodromes and heliports design principles to the specificities of VCA operations. One of the key aspects covered is the definition of the obstacle-free volume in a funnel-shaped configuration that shall enable vertical operations in dense urban contexts. This presents the first step to the integration of VCA into urban environments. It also sets out detailed physical design elements such as FATO/TLOF dimensions, safety areas, taxiways, stand configurations, visual aids, signalling systems, and structural strength requirements.	[3]
EASA 2021/664, 665, 666 (U-space)	The U-space regulatory framework consists of three regulations. IR (EU) 2021/664 establishes the U-space framework and what U-space services are mandatory and non-mandatory for UAS operations in designated U-space airspace. To IR (EU) 2021/664 EASA developed acceptable means of compliance and guidance material. IR (EU) 2021/665 and IR (EU) 2021/666 are complementing the U-space framework by defining requirements for providers of air traffic management/air navigation services and other air traffic management network functions in the U-space airspace designated in controlled airspace as well as requirements for manned aviation operating in U-space airspace	[25, 96, 97]
ICAO Manual on RPAS (Doc 10019)	This manual summarises key considerations for introducing remotely piloted aircraft systems (RPAS) into non-segregated airspace and aerodromes, including airworthiness, operations, licensing, air traffic management, command and control, detect and avoid, safety, legal, and security issues.	[98]
ICAO Annex 6, Part IV	Provides SARPs for RPAS covering operator certification, flight operations and limitations, communication/navigation equipment, remote crew qualifications, and maintenance and operational manuals. ICAO Annex 6, Part IV also categorises UAS operations according to the level of risk involved: Open Category (Low Risk), Specific Category (Moderate Risk) and Certified Category (High Risk). The SARPs within Part IV to Annex 6 contain the requirements to regulate international operations in the Certified category.	[4]

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Table 16: IAM Regulatory References.

Document	Summary	Ref.
ICAO Annex 14, Volume II (Heliports)	Defines the physical and operational characteristics which have to be provided at heliports and is currently the foundational reference for vertiport design and PTS-VPT-DSN [3]	[21]
ICAO Heliport Manual (Doc 9261)	Provides guidance for heliport design and operations under ICAO Annex 14. While vertiports are not exactly heliports, in many cases guidance from heliports is used as a template or starting point for vertiport operations.	[99]
ICAO AAMSG and Vertical Flight Infrastructure Working Group	ICAO's Secretariat set up the AAMSG to advise the secretariat about AAM. The aim of the activity is to enable the secretariat to identify elements of current ICAO doctrine (Annexes, Documents, Circulars) that prevent AAM, and hence recommend work to be done by ICAO panels to address these blocking points. The group is currently working on the vision of AAM. A mature draft was produced at the end of 2025, and is being circulated among ICAO expert groups for comment with the aim of producing the final AAM Vision by the end of 2026. The AAMSG aims to deliver a final gap analysis and recommendations for work by mid 2027. In parallel, ICAO's Vertical Flight Infrastructure Working Group is developing tailored global guidance that recognises the unique operational characteristics of VTOL aircraft and the urban contexts in which they are expected to operate. By establishing a distinct VTOL flight infrastructure framework, aligned with ICAO's vertical infrastructure working group guidance, aviation authorities avoid adapting legacy heliport standards to a fundamentally different operational paradigm.	not public
EUROCAE ED-299	Guidance for Vertiport Operators and Operations	not public
EUROCAE ED-278	Concept of Operations for VTOL Aircraft – Volume 1: General Considerations	not public
EUROCAE ED-278A	Updated Concept of Operations for VTOL Aircraft – Volume 1: General	not public
EUROCAE ED-293	Concept of Operations for VTOL Aircraft – Volume 2: Commercial Passenger Air Taxi Transport	not public
ENAC	ENAC – Primo Regolamento Nazionale per la Mobilità Aerea Innovativa	[100]

Note: Detailed flight and operating procedures for VCA (for example, *vertiport usability*, *vertiport availability*, flight crew procedures, contingency in case of performance failures) are more mature in EU implementing regulations than in ICAO material. Also, ICAO documents are often templates or model regulations, leaving States to decide the details.

B VCA Flight Procedure Design Requirements

To help the reader navigate the regulatory environment for VCA flight procedure design, this Appendix provides a summary of the most relevant references.

Table 17: Approach flight procedure requirements by VCA mode.

Parameter	Requirement	Reference / Baseline
VFR Multicopter		
IP	≤1 NM from vertiport, ≈1300–500 ft AGL	EASA PTS-VPT-DSN §3.3.1
Approach Slope	≈18°or vertical descent	EUROCONTROL Helicopter VFR Ops Manual
Speed Profile	60–100 km/h to hover descent at <20 km/h	SC-VTOL-01 multicopter profiles
Final Segment	Hover descent from ≈1100–150 ft AGL	EASA PTS-VPT-DSN §3.4.2
Visual Reference	Perimeter/alignment lights	EASA PTS-VPT-DSN §3.2.5
LDP	≈130–50 ft AGL	SC-VTOL-01 §2.5.3.3
PoC (Approach)	Same as LDP	Enhanced Category compliance
VFR hybrid multicopter/aeroplane		
IP	1.5–3 NM from vertiport at 1000–1500 ft AGL	EASA PTS-VPT-DSN §3.3.1
Approach Slope	Nominal 4–7°; max 12.5:1 in final 100 m	EASA PTS-VPT-DSN §3.4.2
Speed Profile	Transition from 150–200 km/h to rotor mode (<60 km/h), then vertical descent	SC-VTOL-01 §2.5.3.3
Final Segment	Steep/vertical descent from ≈1300–500 ft AGL	EASA PTS-VPT-DSN §3.4.3
Visual Reference	Vertiport beacon or alignment lighting	EASA PTS-VPT-DSN §3.2.4
LDP	≈1150 ft AGL and 200 m from pad	SC-VTOL-01 §2.5.3.3
PoC (Approach)	Same as LDP	SC-VTOL-01; ICAO Doc 8168 Vol II
IFR Hybrid Multicopter/Aeroplane		
IAF	≥5 NM from vertiport, ≈12000 ft AGL; RNP APCH with SBAS; segment lengths procedure-dependent; waivers possible	ICAO Doc 8168 Vol II §III-2-2-1
Approach Slope	5.0–7.1°from FAF to MAPt	
FAP to MAPt	RNP 0.3 GNSS approach (ideally 0.1–0.15). NAIS: MAPt/DP ≥0.54 NM (indicated airspeed 70 kt) or ≥0.85 NM (indicated airspeed 90 kt).	EASA AMC PBN Helicopter PinS
MAPt	≤500 m lateral and ≤300 ft vertical; recommended 250 ft lateral and 25 ft vertical	ICAO Doc 8168 Vol II §III-2-6-2
Visual Segment	Visual descent to pad; onboard systems recommended for accuracy	EASA PBN AMC; ICAO PANS-OPS Vol II
LDP	At MAPt	SC-VTOL-01 §2.5.3.3
PoC (Approach)	Same as LDP	EASA AMC and PinS guidance

Table 18: Contingency approach flight procedure requirements by VCA mode.

Requirement	Reference / Baseline
VFR Multicopter	
Hover capability permits tactical go-arounds before LDP (≈30–50 ft AGL)	SC-VTOL-01 §2.5.3.3
Must still define two alternate pads in vicinity	EU 2024/1111 UAM.OP.MVCA.192
VFR Hybrid Multicopter/Aeroplane	
Must identify a missed approach path usable before reaching the LDP	SC-VTOL-01 §2.5.3.3
Beyond LDP, visual contact must be established; otherwise, initiate missed approach	
Two alternate safe landing options must be defined past PoC	EU 2024/1111 UAM.OP.MVCA.192
IFR Hybrid Multicopter/Aeroplane	
MAPt equals LDP and PoC per ICAO PinS design. This terminology will need to be modified for remotely piloted aircraft.	ICAO Doc 8168 Vol II §III-2-6
The decision to proceed visually or execute the missed approach must occur at or before the MAPt.	ICAO Doc 8168 PANS-OPS Volume II §III-3-4-6
Must initiate missed approach at MAPt if visual contact is not established.	
Two alternate safe landing options must be defined past PoC, including contingency FATO concept at vertiport.	EU 2024/1111 UAM.OP.MVCA.192

Across all operation types, the contingency procedures must be supported by flight planning tools and operational approval procedures per Part-CAT, EU 965/2012, and EU 2024/1111. The PIC is the last allowable regulatory point to perform a diversion before full commitment to land.

In Regulation EU 2024/1111 UAM.OP.MVCA.192, the requirement to define "two safe landing options at the destination" refers to identifying, during flight planning, two reachable contingency pads or sites that can be used in case of diversion before the PoC. Once the aircraft passes the PoC, the regulatory expectation is that it will commit to land at the planned vertiport, but it must still be able to do so even in a degraded mode (e.g. with one engine inoperative). These alternate sites are not for landing after PoC but serve to ensure redundancy up to the PoC.

Table 19: Departure flight procedure requirements by VCA mode.

Parameter	Requirement	Reference / Baseline
VFR Multicopter		
Vertical Climb	≈1150–400 ft AGL	EASA PTS-VPT-DSN §3.4.1
Speed Profile	60–80 km/h	SC-VTOL-01 multicopter performance
Turn Point	≤0.2 NM, obstacle-free	EASA PTS-VPT-DSN §3.5.1
PoC (Departure)	Optional ≈120 ft AGL	SC-VTOL-01 §2.5.2.4
VFR Hybrid Multicopter/Aeroplane		
Initial Climb	Vertical to 300–500 ft AGL	EASA PTS-VPT-DSN §3.4.1
Transition	Forward flight after clearance	SC-VTOL-01 §2.5.2.4
Turn Point	≈10.25 NM from pad	EUROCONTROL VFR Route Design
Speed Profile	0 to 150–180 km/h	SC-VTOL-01 tiltrotor profiles
PoC (Departure)	≈1100 ft AGL	SC-VTOL-01 §2.5.2.4
IFR Hybrid Multicopter/Aeroplane		
Initial Climb	Visual climb to TF (≈1300–500 ft AGL) The PINs departure procedures consist of a visual segment up to an IDF. The visual climb is based on a VSG of 5.3% (0.8% above the Annex 14 take-off flight path area at 4.5%), so the minimum climb gradient is 5.3%. The visual segment up to the IDF may be reached also at a lower altitude than 500Ft AGL, as long as the MCA value at IDF is consistent with the subsequent instrument leg MOCA starting at IDF.	ICAO PANS-OPS Vol II PinS SID
Climb Profile	Min 760 ft/NM to 500 ft, then 400 ft/NM onward	-
RNP Path Join	≈11000 ft AGL, once above MOCA	ICAO Doc 8168 Vol II §III-2-7-1
PoC	≈100 ft AGL	SC-VTOL-01 §2.5.2.4

Table 20: Contingency departure flight procedure requirements by VCA mode.

Requirement	Reference / Baseline
VFR Multicopter	
Abort via vertical return to vertiport if prior to PoC (≈20 ft AGL)	EASA PTS-VPT-DSN corridor model
Emergency hover/land permitted if redundancy supports safe descent	SC-VTOL-01 and multicopter performance
VFR Hybrid Multicopter/Aeroplane	
Before PoC, vertical return to vertiport possible	-
Past PoC, climb-out path must allow safe diversion to alternate site	SC-VTOL-01 §2.5.2.4
IFR Hybrid Multicopter/Aeroplane	
Visual departure segment must include abort altitude and alternate climb-out path	ICAO PANS-OPS Volume II PinS SID criteria
Diversion required if contingency arises before RNAV fix join	-

Table 21: Enroute flight procedure requirements by VCA mode.

Parameter	Requirement	Reference / Baseline
VFR Multicopter		
Altitude	150-500 ft AGL	EASA PTS-VPT-DSN corridor model
Speed	80-120 km/h	SC-VTOL-01 and multicopter performance
Routing	Urban low-level routes	EUROCONTROL UAM Corridor Design
VFR Hybrid Multicopter/Aeroplane		
Altitude	1000-1500 ft AGL	EUROCONTROL VFR Helicopter Guidelines
Speed	150-250 km/h	SC-VTOL-01 performance data
Routing	Predefined VFR corridors	EUROCONTROL VFR Routing Manual
IFR Hybrid Multicopter/Aeroplane		
Altitude	1,000 ft AGL and 4,500 ft AGL, if above MOCA. The vertical reference shall be consistent with the transition altitude set for the airspace involved. Routes should be based on RNP specifications; considering the speed range involved the choice of RNP 0.3 criteria could be assessed.	EUROCONTROL RNP SID Charts & ICAO Doc 8168 Vol II
Speed	150-220 km/h	SC-VTOL-01 Tiltrotor Enhanced Category Profiles
Routing	RNAV or DCTs	EASA AMC IFR VTOL Routing

Table 22: Contingency enroute flight procedure requirements by VCA mode.

Requirement	Reference / Baseline
VFR Multicopter	
Follow predefined emergency corridor or divert via direct hover descent to emergency area.	-
Contingency planning must cover at least one fail-safe hover point every 3-5 minutes.	EUROCONTROL UAM Conceptual Design Notes
VFR Hybrid Multicopter/Aeroplane	
Must maintain sufficient endurance to divert to a published emergency site.	AMC to SC-VTOL and EU 2024/1111 UAM.OP.MVCA.192
Flight planning must accommodate CSFL requirements.	-
IFR Hybrid Multicopter/Aeroplane	
Managed under IFR alternate routing via ATC or published rerouting.	-
Must maintain diversion fuel and published alternate aerodrome or vertiport.	SC-VTOL-01 §2.5.4

References

[1] ICAO, *Global Air Traffic Management Operational Concept (Doc 9854)*, 1st ed. Montréal, Quebec, Canada: ICAO, 2005.

[2] K. Schweiger and L. Preis, "Urban Air Mobility: Systematic Review of Scientific Publications and Regulations for Vertiport Design and Operations," *Drones*, vol. 6, no. 7, p. 179, Jul. 2022. [Online]. Available: https://doi.org/10.3390/drones6070179

[3] EASA, "Vertiports Prototype Technical Specifications for the Design of VFR Vertiports for Operation with Manned VTOL-CapableAircraft Certified in the Enhanced Category (PTS-VPT-DSN)," https://www.easa.europa.eu/downloads/136259/en, Mar. 2022, (accessed on 10 June 2026).

[4] ICAO, *Annex 6 - Operation of Aircraft - Part IV - Remotely Piloted Aircraft Systems*, 1st ed. ICAO, 2024.

[5] SESAR Joint Undertaking, "European ATM master plan: making Europe the most efficient and environmentally friendly sky to fly in the world : 2025 edition." https://data.europa.eu/doi/10.2829/9855255, 2024, (accessed on 18 December 2025).

[6] European Commission, "Commission Implementing Regulation (EU) 2024/1111," https://eur-lex.europa.eu/eli/reg_impl/2024/1111/oj, May 2024, (accessed on 23 July 2025).

[7] ICAO, "Global Air Navigation Plan Strategy– The conceptual roadmap," https://www4.icao.int/demo/GANP/GANP_EN.pdf, (accessed on 14 October 2025).

[8] EASA, "Innovative Air Mobility (IAM): Basics Explained," https://www.easa.europa.eu/en/domains/drones-air-mobility/drones-air-mobility-landscape/basics-explained, 2023, (accessed on 15 June 2025).

[9] EASA, "Urban Air Mobility (UAM): What is UAM?" https://www.easa.europa.eu/en/what-is-uam, 2023, (accessed on 15 June 2026).

[10] EASA, "NPA 2022-06 - Introduction of a regulatory framework for the operation of drones — Enabling innovative air mobility with manned VTOL-capable aircraft, the IAW of UAS subject to certification, and the CAW of those UAS operated in the 'specific' category," https://www.easa.europa.eu/en/downloads/136705/en, Jun. 2022, (accessed on 16 June 2025).

[11] FAA, "Advanced Air Mobility Implementation Plan," https://www.faa.gov/sites/faa.gov/files/AAM-I28-Implementation-Plan.pdf, 2023, (accessed on 15 June 2026).

[12] FAA, "Urban Air Mobility Concept of Operations (ConOps) 2.0," https://www.faa.gov/sites/faa.gov/files/Urban

[13] ICAO, "Advanced Air Mobility Study Group (AAM SG)," https://www.icao.int/UA/advanced-air-mobility-study-group-aam-sg, n.d., (accessed on 15 June 2026).

[14] European Commission, "Commission Regulation (EU) No 1178/2011," https://eur-lex.europa.eu/eli/reg/2011/1178/oj, 2011, (accessed on 15 June 2026).

[15] European Commission, "Commission Implementing Regulation (EU) No 923/2012," https://eur-lex.europa.eu/eli/reg_impl/2012/923/oj, 2012, (accessed on 15 June 2026).

[16] European Commission, "Commission Regulation (EU) No 965/2012," https://eur-lex.europa.eu/eli/reg/2012/965/oj/eng, 2012, (accessed on 15 June 2026).

[17] European Commission, "Commission Implementing Regulation (EU) 2017/373," https://eur-lex.europa.eu/eli/reg_impl/2017/373/oj/eng, 2017, (accessed on 16 June 2026).

[18] EASA, "EASA Steps Up Regulatory Framework for Innovative Air Mobility," https://www.easa.europa.eu/en/newsroom-and-events/news/easa-steps-regulatory-framework-innovative-air-mobility, Jul. 2025, (accessed on 15 June 2026).

[19] EASA, "EASA opinion no 03-2023," https://www.easa.europa.eu/en/document-library/opinions/opinion-no-032023, Aug. 2023, (accessed on 15 June 2026).

[20] EASA, "Special Condition Vertical Take-Off and Landing (VTOL) Aircraft," https://www.easa.europa.eu/sites/default/files/dfu/SC-VTOL-01.pdf, Jul. 2019, (accessed on 20 September 2021).

[21] ICAO, *ANNEX 14 – Aerodromes Volume II Heliports*, 5th ed. Montréal, Quebec, Canada: ICAO, 2020.

[22] FAA, "Helicopter Instructor's Handbook (FAA-H-8083-4)," FAA, Tech. Rep., 2012, (accessed on 8 October 2025). [Online]. Available: https://www.faa.gov/sites/faa.gov/files/regulations_policies/handbooks_manuals/aviation/FAA-H-8083-4.pdf

[23] EASA, "ToR RMT.0230 - Introduction of a regulatory framework for the operation of unmanned aircraft systems and for urban air mobility in the European Union aviation system - Issue 4," https://www.easa.europa.eu/en/downloads/137376/en, Dec. 2022, (accessed on 13 February 2026).

[24] FAA, "Engineering Brief No. 105A, Vertiport Design, Supplemental Guidance to Advisory Circular 150/5390-2D, Heliport Design," https://www.faa.gov/airports/engineering/engineering_briefs/eb_105a_vertiports, Dec. 2024, (accessed on 25 June 2025).

[25] EASA, "Easy Access Rules for U-space (IR + AMC/GM)," https://www.easa.europa.eu/en/downloads/139563/en, May 2024, (accessed on 16 March 2026).

[26] Eve Air Mobility, "Global Market Outlook 2025 - The 20-year Urban Air Mobility View," https://www.eveairmobility.com/storage/2025/07/Eve_MarketOutlook_2025.pdf, (accessed on 26 February 2026).

[27] EASA, "Study on the societal acceptance of Urban Air Mobility in Europe," EASA, Tech. Rep., Mar. 2021, (accessed on 26 February 2026). [Online]. Available: https://www.easa.europa.eu/en/downloads/127760/en

[28] EASA, "NPA 2024-01 Introduction of a regulatory framework for the operation of drones — Enabling innovative air mobility with manned VTOL-capable aircraft," https://www.easa.europa.eu/en/document-library/notices-of-proposed-amendment/npa-2024-01, Feb. 2024, (accessed on 26 February 2026).

[29] S. Kim, O. Park, and H. Shin, "A design of vfr approach and departure procedures of uam at vertiports adjacent to the airport," 2024, (accessed on 17 June 2026).

[30] Grand View Research, "Logistics Market (2024 - 2030)," Tech. Rep. GVR-4-68040-323-8, 2023, (accessed on 16 March 2026). [Online]. Available: https://www.grandviewresearch.com/industry-analysis/logistics-market-report#

[31] ImAFUSA Consortium, "Impact and capacity Assessment Framework for U-space Societal Acceptance (ImAFUSA)," https://cordis.europa.eu/project/id/101114776, (accessed on 26 February 2026).

[32] R. W. Howard, "Breaking through the 106 barrier," *The Aeronautical Journal*, vol. 96, no. 957, pp. 260–270, 1992. [Online]. Available: https://doi.org/10.1017/S0001924000050405

[33] Boeing, "Statistical summary of commercial jet airplane accidents: Worldwide operations 1959–2024," Boeing Commercial Airplanes, Tech. Rep., 2025. [Online]. Available: https://www.boeing.com/resources/boeingdotcom/company/about_bca/pdf/statsum.pdf

[34] P. G. Reich, "Analysis of Long-Range Air Traffic Systems: Separation Standards—I," *Journal of Navigation*, vol. 19, no. 1, p. 88–98, 1966. [Online]. Available: https://doi.org/10.1017/S037346330004056X

[35] P. Haro, C. Aguilera, and G. Lucchi, "Required Navigation Performances for Drone Flight Operations," in *ENC 2023*. MDPI, Oct. 2023, p. 51. [Online]. Available: https://doi.org/10.3390/ENC2023-15459

[36] P. D. Vascik, "Systems Analysis of Urban Air Mobility Operational Scaling," Ph.D. dissertation, Massachusetts Institute of Technology, 2020.

[37] EASA, "Easy Access Rules for Small Rotorcraft (CS-27) (Amendment 10)," https://www.easa.europa.eu/en/downloads/137635/en, Feb. 2023, (accessed on 7 March 2026).

[38] EASA, "Easy Access Rules for Large Aeroplanes (CS-25)," https://www.easa.europa.eu/en/document-library/easy-access-rules/easy-access-rules-large-aeroplanes-cs-25, Jan. 2023, (accessed on 8 May 2025).

[39] G. van Es, "NGW–Near-Ground Wind Gust Detection," EASA, NLR, Research Project EASA.2011/08, Oct. 2012, (accessed on 16 March 2026). [Online]. Available: https://www.easa.europa.eu/en/downloads/17505/en

[40] ICAO, *Procedures for Air Navigation Services (PANS) - Aircraft Operations - Volume I Flight Procedures (Doc 8168)*, 6th ed. Montréal, Quebec, Canada: ICAO, 2018.

[41] EASA, "Easy Access Rules for Standardised European Rules of the Air (SERA)," https://www.easa.europa.eu/en/document-library/easy-access-rules/online-publications/easy-access-rules-standardised-european, Dec. 2024, (accessed on 9 February 2026).

[42] EASA, *Easy Access Rules for Air Operations (Regulation (EU) No 965/2012)*, https://www.easa.europa.eu/en/document-library/easy-access-rules/easy-access-rules-air-operations-regulation-eu-no-9652012, (accessed on 15 March 2026).

[43] FAA, *Instrument Procedures Handbook*, U.S. Department of Transportation, Federal Aviation Administration, (accessed on 15 March 2026). [Online]. Available: https://www.faa.gov/sites/faa.gov/files/regulations_policies/handbooks_manuals/aviation/instrument_procedures_handbook/FAA-H-8083-16B.pdf

[44] EASA, *Second Publication of Means of Compliance with the Special Condition VTOL*, (accessed on 15 March 2026). [Online]. Available: https://www.easa.europa.eu/sites/default/files/dfu/moc-2_sc-vtol_-_issue_3_-_22_dec_2022.pdf

[45] EASA, "Acceptable Means of Compliance and Guidance Material to Annex IX (Part-IAM) to Regulation (EU) No 965/2012," https://www.easa.europa.eu/en/downloads/142230/en, Jul. 2025, (accessed on 8 August 2025).

[46] EUROCONTROL, "Airspace Volumes & Sectorisation (Module 13 - Activity 9)," https://www2023.icao.int/MID/Documents/2014/PBN

[47] ICAO, *ANNEX 11- Air Traffic Services*, 15th ed. Montréal, Quebec, Canada: ICAO, 2018.

[48] ICAO, *ANNEX 2 - Rules of the Air*, 10th ed. Montréal, Quebec, Canada: ICAO, 2005.

[49] EUROCONTROL, "European Route Network Improvement Plan (ERNIP) - Part 1," https://www.eurocontrol.int/publication/european-route-network-improvement-plan-ernip-part-1, EUROCONTROL, Tech. Rep. ERNIP PART 1, Jul. 2025, (accessed on 6 October 2025).

[50] ICAO, *Procedures for Air Navigation Services (PANS) - Aircraft Operations - Volume II Construction of Visual & Instrument Flight Procedures (Doc 8168)*, 7th ed. Montréal, Quebec, Canada: ICAO, 2020.

[51] ICAO, *Procedures for Air Navigation Services (PANS) - Aircraft Operations - Volume III - Aircraft Operating Procedures (Doc 8168-3)*, 1st ed. Montréal, Quebec, Canada: ICAO, 2018.

[52] EUROCONTROL, *Helicopter Point in Space Operations in controlled and Uncontrolled airspace - Generic Safety Case*, 1st ed. EUROCONTROL, 2019.

[53] P. Gutierrez, "SAMVA eVTOL Flights at EGNOS-enabled Vertiport," https://insidegnss.com/samva-evtol-flights-at-egnos-enabled-vertiport/, Aug. 2024, (accessed on 1 May 2026).

[54] GAUSSIAN Consortium, "GAUSSIAN," https://gaussianproject.eu/en/, (accessed on 1 May 2026).

[55] EUSPA, "VITOLMINS - 'Visual and Instrument Take-Off and Landing Maneuvers with EGNSS and Copernicus'," https://www.euspa.europa.eu/opportunities/horizon-europe/project-portfolio/vitolmins-visual-and-instrument-take-and-landing, Nov. 2024, (accessed on 1 May 2026).

[56] EUROCONTROL, *EUROCONTROL MANUAL FOR AIRSPACE PLANNING -Common Guidelines*, 2nd ed., ser. ASM.ET1.ST03.4000.EAPM.02.02. EUROCONTROL, 2003. [Online]. Available: https://www2023.icao.int/safety/pbn/Documentation/EUROCONTROL/Eurocontrol%20Manual%20for%20Airspace%20Planning.pdf

[57] M. Mendoza, M. Ellejmi, J. Kopec, M. Sokolowski, and A. Wall, "SESAR Solution 02-08 SPR-INTEROP/OSED for V3 - Part I," EARTH Project, Tech. Rep. D6.1.20, Nov. 2019, (accessed on 6 March 2026). [Online]. Available: https://www.sesarju.eu/sites/default/files/documents/solution/SESAR%202020%20PJ02-08%20D6_1_20%20V3%20SPR%20INTEROP%20OSED%20Part%20I%20-%2000.02.00%20(1).pdf

[58] ICAO, *Performance Based Navigation (PBN) Manual (Doc 9613)*, 5th ed. ICAO, 2023.

[59] EUROCONTROL, "U-space Concept of Operations Edition 4," https://www.sesarju.eu/sites/default/files/documents/reports/U-space

[60] EUROCONTROL, "A-CDM Impact Assessment," Final Report, Mar. 2016, (accessed on 1 May 2026). [Online]. Available: https://www.eurocontrol.int/sites/default/files/2019-04/a-cdm-impact-assessment-2016.pdf

[61] ICAO, *Aeronautical Information Services*, 16th ed. Montréal, Quebec, Canada: ICAO, 2018.

[62] ACI, IATA, WWASCG, "Worldwide Airport Slot Guidelines (WASG) Edition 4," https://www.iata.org/contentassets/4ede2aabfcc14a55919e468054d714fe/wasg-edition-4-english-version.pdf, Aug. 2025, (accessed on 17 February 2026).

[63] Flughafen Zuerich AG, "Individual travel - general and business aviation," https://www.flughafen-zuerich.ch/en/business/airlines-and-handling/flight-operations/general-aviation, (accessed on 18 February 2026).

[64] National Air and Space Museum, "Airline Deregulation: When Everything Changed," https://airandspace.si.edu/stories/editorial/airline-deregulation-when-everything-changed, Dec. 2021, (accessed on 23 February 2026).

[65] FAA, "CDM International Online Workshop," https://tfmlearning.faa.gov/tfm-training/atfm-basics/index.html, (accessed on 23 February 2026).

[66] S. Vail, A. Churchill, J. Karlsson, T. McInerney, J. Domitrovich, T. Phillips, Airport Cooperative Research Program, Transportation Research Board, and National Academies of Sciences, Engineering, and Medicine, *Guidebook for Advancing Collaborative Decision Making (CDM) at Airports*. Washington, D.C.: Transportation Research Board, Jun. 2015.

[67] EUROCONTROL, "Airport Collaborative Decision-Making (A-CDM) Implementation Manual," https://www.eurocontrol.int/publication/airport-collaborative-decision-making-cdm-implementation-manual, Mar. 2017, (accessed on 23 February 2026).

[68] IATA, "A-CDM toolkit," Jun. 2025, (accessed on 23 February 2026). [Online]. Available: https://www.iata.org/contentassets/1be2bec28b3d45f9ae7780d6ebea7be9/iata-a-cdm-toolkit-june-2025_20250624.pdf

[69] S. Pierre, "ATFCM OPERATIONS MANUAL Network Manager," https://www.eurocontrol.int/publication/atfcm-users-manual, Nov. 2025, (accessed on 14 March 2026).

[70] FAA, "Special Air Traffic Rules in the Vicinity of Los Angeles International Airport," https://www.federalregister.gov/documents/2003/07/10/03-17460/special-air-traffic-rules-in-the-vicinity-of-los-angeles-international-airport, Jul. 2003, (accessed on 6 May 2026).

[71] D. Wing and W. Cotton, "For Spacious Skies: Self-Separation with "Autonomous Flight Rules" in US Domestic Airspace," in *11th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference*. Virginia Beach, VA: American Institute of Aeronautics and Astronautics, Sep. 2011. [Online]. Available: https://doi.org/10.2514/6.2011-6865

[72] K. Balakrishnan, J. Polastre, J. Mooberry, R. Golding, and P. Sachs, "Blueprint for the Sky - The roadmap for the safe integration of autonomous aircraft," https://www.airbus.com/sites/g/files/jlcbta136/files/2022-07/Airbus-whitepaper-integration-autonomous-vehicles.pdf, 2018, (accessed on 15 March 2026).

[73] EASA and EUROCONTROL, "UAS ATM Integration - Operational Concept," https://www.eurocontrol.int/sites/default/files/publication/files/uas-atm-integration-operational-concept-v1.0-release

[74] D. Wing, A. Lacher, W. Ryan, W. Cotton, R. Stilwell, J. Maris, and P. Vajda, "Digital Flight: A New Cooperative Operating Mode to Complement VFR and IFR," NASA, Tech. Rep. NASA/TM–20220013225, Sep. 2022, (accessed on 15 March 2026). [Online]. Available: https://ntrs.nasa.gov/api/citations/20220013225/downloads/NASA-TM-20220013225.pdf

[75] FAA Office of NextGen and ICN Info-Centric National Airspace System, "Initial Concept of Operations for an Info-Centric National Airspace System," https://www.faa.gov/sites/faa.gov/files/ICN-ConOps-Dec2022.pdf, Dec. 2022, (accessed on 15 March 2026).

[76] Committee SC-288, "DO-398A Operational Services and Environment Definition (OSED) for Uncrewed Aircraft Systems Detect and Avoid Systems (DAA)," Dec. 2023.

[77] JARUS, "JARUS Whitepaper on the Automation of the Airspace Environment," http://jarus-rpas.org/wp-content/uploads/2024/02/JARUS-Whitepaper-Automation-of-the-Airspace-Environment-v1.0.pdf, Jan. 2024, (accessed on 15 March 2026).

[78] T. F. Sievers, D. Geister, G. Schwoch, N. Peinecke, B. I. Schuchardt, A. Volkert, and T. J. Lieb, "DLR Blueprint – Initial ConOps of U-Space Flight Rules (UFR)," DLR Institute of Flight Guidance, Tech. Rep., 2024, accessed on 15 March 2026. [Online]. Available: https://elib.dlr.de/203268/

[79] SKYbrary Aviation Safety, "Operational Flight Plan (OFP)," https://skybrary.aero/articles/operational-flight-plan-ofp, (accessed on 9 February 2026).

[80] EUROCONTROL, "FPL2012 to eFPL Transition-Mixed Mode," https://www.eurocontrol.int/sites/default/files/2025-03/eurocontrol-flight-dispatcher-days-2025-ff-ice-transition-mixed-mode.pdf, Brussels, Belgium, May 2025, (accessed on 13 February 2026).

[81] EUROCONTROL, "Introduction to FF-ICE," https://www.eurocontrol.int/sites/default/files/2025-03/eurocontrol-flight-dispatcher-days-2025-introduction-to-ff-ice.pdf, Brussels, Belgium, May 2025, (accessed on 13 February 2026).

[82] ICAO, "Flight & Flow Information for a Collaborative Environment (FF-ICE) - A Concept to Support Future ATM Operations," https://www2023.icao.int/airnavigation/FFICE/Documents/FF-ICE

[83] EASA, "Easy Access Rules for the Small Category of VCA," https://www.easa.europa.eu/en/document-library/easy-access-rules/easy-access-rules-small-category-vca, 2024, (accessed on 6 August 2025).

[84] A. T. Altun, "Contingency management of the advanced air mobility system of systems: Uas/uam, integrated atm/utm and infrastructures," Ph.D. dissertation, Cranfield University, Faculty of Engineering and Applied Sciences, 2026.

[85] ICAO, *Procedures for Air Navigation Services (PANS) - Air Traffic Management (Doc 4444)*, 16th ed. Montréal, Quebec, Canada: ICAO, 2016.

[86] NUAIR, "High-Density Automated Vertiport Concept of Operations," Contractor or Grantee Report 20210016168, May 2021, (accessed on 23 December 2021). [Online].

Available: https://ntrs.nasa.gov/api/citations/20210016168/downloads/20210016168_MJohnson_VertiportAtmtnConOpsRprt_final_corrected.pdf

[87] European Commission, "Commission Implementing Regulation (EU) 2023/1770," https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R1770, Sep. 2023, (accessed on 24 February 2026).

[88] SKYbrary Aviation Safety, "Controller Pilot Data Link Communications (CPDLC)," https://skybrary.aero/articles/controller-pilot-data-link-communications-cpdlc, (accessed on 24 February 2026).

[89] K. Schweiger, A. König, I. C. Metz, F. Naser, M. Swaid, R. Abdellaoui, and B. I. Schuchardt, "HorizonUAM: operational challenges and necessary frameworks to ensure safe and efficient vertidrome operations," *CEAS Aeronautical Journal*, Jul. 2024. [Online]. Available: https://doi.org/10.1007/s13272-024-00754-6

[90] EASA, "Acceptable Means of Compliance and Guidance Material to Regulation (EU) 2021/664 on a regulatory framework for the U-space," https://www.easa.europa.eu/en/downloads/137405/en, Dec. 2021, (accessed on 2 February 2026).

[91] ICAO, *Doc 10039, Manual on System Wide Information Management (SWIM) Concept*, ICAO, Montréal, Quebec, Canada, 2015.

[92] Flight Safety Foundation, "New Words for a New Era in Aviation," https://flightsafety.org/wp-content/uploads/2025/05/New-Words-for-a-New-Era-FINAL.pdf, May 2025, (accessed on 1 May 2026).

[93] WG-105 UAS, "Operational Services and Environment Definition for RPAS Automatic Take-off and Landing," https://www.eurocae.net/product/ed-252-operational-services-and-environment-definition-for-rpas-automatic-take-off-and-landing/, May 2018, (accessed on 6 March 2026).

[94] S. Schmerwitz, T. Dautermann, H. Lenz, and T. Lueken, "GNSS SOLUTIONS FOR INCREASED GA AND ROTORCRAFT AIRPORT ACCESSIBILITY DEMONSTRATION," in *Paper 0163*, Sep. 2019, (accessed on 6 March 2026). [Online]. Available: https://dspace-erf.nlr.nl/server/api/core/bitstreams/4524ebdf-8b1b-44cf-8908-48c08cba748b/content

[95] Airbus Helicopters, Leonardo Helicopters, and ENAV, "FINAL - SESAR Solution Guidance YY (LLR)," SESAR Solution 113 03 SPR Solution 113 D11, Jun. 2016, (accessed on 6 March 2026). [Online]. Available: https://www.sesarju.eu/sites/default/files/documents/solution/Sol113%2003%20SPR%20Solution%20%20113%2004.10-D11-FINAL%20-%20SESAR%20Solution%20Guidance%20YY%20(LLR)%20-%20GEN.pdf

[96] European Commission, "Commission Implementing Regulation (EU) 2021/665," https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R0665, Apr. 2021, (accessed on 17 March 2026).

[97] European Commission, "Commission Implementing Regulation (EU) 2021/666," https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R0666, Apr. 2021, (accessed on 16 March 2026).

[98] ICAO, *Manual on Remotely Piloted Aircraft Systems (RPAS)*, 1st ed. Montréal, Quebec, Canada: ICAO, 2015.

[99] ICAO, *Heliport Manual (Doc 9261)*, 5th ed. Montréal, Quebec, Canada: ICAO, 2021.

[100] ENAC, “Requisiti nazionali per le operazioni, lo spazio aereo e le infrastrutture per gli aeromobili con capacità di decollo e atterraggio verticale (VCA),” https://www.enac.gov.it/app/uploads/2024/06/Regolamento-Criteri-nazionali-per-VCA-Ed.1_rev.0-1.pdf, Mar. 2024, (accessed on 6 May 2026).