How to Integrate Vertiport Operations into the Airspace? Introducing the EUREKA Project

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Innovative Air Mobility (IAM), as envisioned by the European Aviation Safety Agency, is "the safe, secure and sustainable air mobility of passengers and cargo enabled by new-generation technologies integrated into multimodal transportation system." Vertiports, new aircraft and new air traffic management systems are essential for implementing IAM. The European project EUREKA, running from 2023 to 2026, aims at enabling key solutions for vertiports. Solutions for arrival and departure for vertiports, collaborative traffic management, how to deal with emergencies and disruptions also the network flow, capacity and operational management are developed in the project. This paper introduces the EUREKA project and reports on the early progress.

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I. Introduction

Innovative Air Mobility (IAM) is defined as “the safe, secure and sustainable air mobility of passengers and cargo enabled by new-generation technologies integrated into multimodal transportation system” [1]. As early as 2025 the first VCAs are expected to begin to populate the skies over cities as envisioned by the European Aviation Safety Agency (EASA) [2]. IAM is to be understood as a subpart of Innovative Aerial Services (IAS): “the set of operations and/or services that are of benefit to the citizens and to the aviation market, and that are enabled by new airborne technologies; the operations and/or services include both the transportation of passengers and/or cargo and aerial operations (e.g. surveillance, inspections, mapping, telecommunications networking, etc.)” [1].

A literature review reported in [3] revealed infrastructure to be the top challenge associated with IAM. Further challenges identified in the review are safety, technology, regulations, air traffic management, communications, and operations, among others. According to EASA SC-VTOL-01 [4], the IAM infrastructure term ‘vertiport’ means ‘an area of land, water, or structure used or intended to be used for the landing and take-off of VTOL-capable aircraft (VCA)’. Vertiports need to be integrated into the urban landscape. At the same time, VCA operations have to be integrated into the airspace in a safe, efficient, and scalable manner.

The project EUREKA [5, 6], funded by the European Union and running from 2023 to 2026, aims at developing key solutions for vertiports and IAM. Four solutions are being developed:

- Arrival / departure to/from vertiport incl. route and trajectory
- Vertiport collaborative traffic management
- Vertiport disruption and emergency management
- Vertiport network flow, capacity and operational management

The project will provide recommendations for regulation/standardization and any information that will accelerate and harmonize the development of IAM, VCA operations and vertiports across Europe.

II. State of the Art

A. Definition of Terms

Within the IAM ecosystem, the following terms can be highlighted.

Table 1 Definition of stakeholders and terms.

Term	Definition	Source of the definition
Common Information Service (CIS)	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 uncrewed aircraft.	Implementing Regulation (EU) 2021/664
Local Vertiport Network	A set of vertiports operating under a unique vertiport network manager (VNM) at local level, i.e. in the same urban/geographical area.	EUREKA definition
Local Vertiport Network Manager	Any legal or natural person which manages the operations, the flow and the capacity of a local vertiport network supported by the VNM system. It will oversee the operations of the network, monitoring the compliance with the rules defined to reach the maximum level of capacity obtained by conducting a preliminary capacity assessment based on the routes and the vertiports part of the network.	EUREKA definition
Innovative Air Mobility (IAM)	The safe, secure and sustainable air mobility of passengers and cargo enabled by new-generation technologies integrated into multimodal transportation system.	EASA IAM Hub [1]
Innovative Aerial Services (IAS)	The set of operations and/or services that are of benefit to the citizens and to the aviation market, and that are enabled by new airborne technologies; the operations and/or services include both the transportation of passengers and/or cargo and aerial operations (e.g. surveillance, inspections, mapping, telecommunications networking, etc.);	EASA IAM Hub [1]
U-space airspace	A geographical zone designated by member states, where UAS operations are only allowed to take place with the support of U-space services.	Implementing Regulation (EU) 2021/664

U-space service	A service relying on digital services and automation of functions designed to support safe, secure and efficient access to U-space for a large number of UAS.	Implementing Regulation (EU) 2021/664
U-space service provider (USSP)	The U-space Service Provider (USSP) is defined by EASA as an organization authorized to provide U-space services within a designated U-space airspace.	EASA Draft acceptable means of compliance (AMC) and guidance material (GM) to opinion No 01/2020 on a high-level regulatory framework for the U-space
Vertiport	An area of land, water, or structure used or intended to be used for the landing and take-off of VTOL aircraft.	ISO 5491:2023, EASA SC-VTOL-01
Vertiport Operator	Any legal or natural person operating or intending to operate a vertiport. To ensure that aeronautical information services (AIS) providers obtain information that allows them to provide up-to-date pre-flight information and in-flight information, arrangements should be made in due time between AIS providers and the vertiport operator, to report to the responsible AIS unit: (1) information on vertiport conditions; (2) the operational status of associated facilities, services, and navigation aids within their area of responsibility; and (3) any other information that is considered to be of operational significance.	EASA PTS-VPT-DSN
VTOL-capable aircraft (VCA)	VTOL stands for "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 the take-off and landing.	Annex Va to EASA Opinion No 03/2023
VCA Operator	Any legal or natural person operating or intending to operate a VCA. The operator of a VCA used for commercial or non-commercial operations shall undergo a certification procedure and shall receive an air operator certificate (AOC). The main responsibilities of the AOC holder are to: establish appropriate procedures for the operational control of its aircraft; ensure that pilots are licensed, depending on the level of automation of the aircraft, appropriately rated, and remain competent; ensure that the operation of VCA complies with the applicable EU regulations and with the airspace requirements of the Member State where the operation is conducted.	EASA NPA 2022-06

B. Related Work

The term 'vertiport' has been established to describe IAM ground infrastructure. Institutions such as the Federal Aviation Authority (FAA) and NASA have developed concepts of operations (ConOps) [2, 3] with specifications that classify and define vertiports aligned to the design of VCA. Accordingly, the FAA has published an Engineering Brief No.105, Vertiport Design [9], in September 2022. The European counterpart is the "Prototype Technical Specifications for the Design of VFR Vertiports with Manned VTOL-Capable Aircraft Certified in the Enhanced Category (PTS-VPT-DSN)" [10], released in March 2022. As the title indicates, this guideline addresses VFR and manned VCA and describes the physical characteristics of a vertiport and the environment required for safe operation, such as the size of the obstacle-free volumes.

Traffic management of unmanned aircraft systems (UAS) is regulated in Europe through the U-space framework [11]. The PTS-VPT-DSN and other U-space projects serve as a reference for EUREKA, especially the CORUS-XUAM ConOps [6] about functionality of U-space; SPATIO [7] for separation management between unmanned aerial vehicles (UAVs); and AURA [8] for defining U-space information exchange with air traffic management systems. EUREKA also takes into account on-going projects like ENSURE [9], which specifies the definition of common air traffic management (ATM) U-space interface, and U-ELCOME [10] for the implementation of Europe-wide U-space services of lower levels U1 and U2.

Thus, EUREKA builds upon prior U-space initiatives, particularly CORUS-XUAM and AURA. The U-space regulatory framework (EU) 2021/664, 665, 666, along with the AMC/GM to (EU) 2021/664 and the prototype technical design specifications for the design of VFR vertiports for operation with crewed VTOL-capable aircraft certified in the enhanced category (PTS-VPT-DSN) serve as regulatory references and guidance. EASA has taken the lead in publishing U-space regulatory guidelines and providing an initial draft of vertiport design specifications. However, the U-space regulatory framework does not cover certified VCA operations and therefore does not regulate vertiport stakeholders and operations. The PTS focuses primarily on ground infrastructure design and provides initial sizing of obstacle-free operating volumes. Topics like integration into airport environments, airspace, ATM/U-space systems, roles and responsibilities, and non-nominal procedures are out of scope. Although CORUS-XUAM ConOps Ed. 4 lays the conceptual groundwork for EUREKA, it does not detail all aspects of vertiports, requiring further exploration of the introduced vertiport availability service, vertiport traffic zone (V-TZ), and U-space flight rules (UFR). AURA has played a critical role in integrating U-space traffic near airports in controlled airspace by establishing a standardized approach for critical information exchange between ATM and U-space systems. The (reverse) dynamic airspace re-configuration initiated by ATC or U-space service provider (USSP), as well as a new category of ATM-U-space shared airspace (AUSA) was introduced and validated. However, its impact on vertiport operations and traffic flows, and the integration of vertiport operators into this ecosystem has not been addressed. EUREKA aims to fill this vertiport gap by addressing these aspects and leveraging the progress made in previous U-space projects and regulatory guidance. Furthermore, EUREKA explores the extension of U-space services for VCA operations at vertiports.

For the definition of arrival and departure procedures at vertiports, in the second publication of the MOC-2 SC-VTOL16 [17], a first "Reference Volume Type 1" was proposed, which contains example parameter values for VTOL procedures to account for the diversity of VTOL designs. The VTOL procedures are based on the Category A helicopter regulations and are modified accordingly. Further EASA documents and Single European Sky ATM Research (SESAR) projects are being considered to propose applicable VCA routes and airspace designs in different environments. EASA NPA 2024-01 [18] proposes changes to enable IAM with manned VCA, e.g. the introduction of operations with VCA and the safe operation of manned VCA in ATM environment. SESAR projects such as Metropolis [19] and Metropolis 2 [20] are considering airspace concepts such as corridors or free routing, while CORUS-XUAM refers to corridors in the original U-space implementation. In addition, a paper on UFR [21] has been published, and NASA has also issued an Airspace and Procedural Design [22] that includes seven functional areas for air mobility research and operational development (Airspace Allocation, Airspace Construct, Approach and Departure Procedures, Contingency Procedures, Emergency Procedures, En Route Procedures, Off Nominal Procedures).

The Airport Collaborative Decision Making (A-CDM) concept [23] is a digital decision-making process that could potentially also be applied to vertiports. Additionally, the Airport Operation Plan (AOP) concept [25] can be of use as it is one single, common and collaboratively agreed plan, which is used by all airport stakeholders and provides common situational awareness. By applying this into the vertiport environment, the exchange of key information between vertiport stakeholders could be encouraged to improve situational awareness. The Total Airport Management Project [25] concept can be applied to ensure a close coordination between vertiport stakeholders and achieve predictability.

With IAM und U-space including new and more stakeholders, current disruption and emergency management regulations need to be adapted. According to this, there is a proposal to use an In-Time Aviation Safety Management System (IASMS) that can be extended to the design and operation of vertiports to provide the safety of IAM [26]. The ability to provide faster and more tailored safety management support by integrating reactive, proactive and predictive safety methods and data promotes the holistic development of safety models and the prudent application of safety information. In this way, IASMS ensures timely safety by warning of identified dangers and modeling emerging risks with the help of data analyses.

The performance of the vertiport traffic flow was evaluated by [27] e.g. taking into account the average delays of passengers and air taxis. Reference [27] has shown a flexible method to analyze future vertiport traffic flows and to support their strategic airside planning and integration. In [28] vertiport capacity and its interaction with vertiport layout and location were considered. Some modifications can affect the traffic flow and capacity of the airport, such as the layout of the airport and the number of gates. The DACUS (Data Collection and Usage for Safety) project [29] has developed strategies to balance demand and capacity in U-space. Regarding meteorology influences on IAM operations and thus vertiports EASA's SC-VTOL-01 [4] and MOC-2 SC-VTOL [17] should be considered.

C. Challenges of IAM

The previous section has already revealed some of the gaps and challenges the IAM ecosystem is facing. Further challenges are found for example in ref. [3], [30] and [31]. The following list summarizes the challenges most relevant for the EUREKA project.

- Regulatory framework [3]:
  - Standardization: Developing and implementing industry-wide standards for communication, navigation, and safety requirements to fill the gaps for VCA opration.
  - Responsibility: Defining responsibilities for managing different U-space airspace users (crewed, uncrewed, passenger-carrying, cargo, etc.) and operating vertiports in different operating environments and airspace classes.

- Technological integration [3]:
    - Advanced air traffic control (ATC) services: Elaborating potential advanced ATC capabilities to ensure necessary interfaces with IAM operations operating at vertiports in controlled airspace.
    - Advanced U-space services: Developing and implementing advanced services like automated traffic management, geofencing, and real-time geofencing and data sharing.
- Infrastructure development:
    - Ground and airspace infrastructure: Building the necessary ground-based and airspace infrastructure to support scalable IAM operations, including communication networks and vertiports [30].
    - Vertiports: Development and integration of vertiports into urban landscape, airport environment, and different airspace classes [3] [31].
- Operational challenges [3]:
    - Energy efficiency: Designing safe arrival, departure and enroute procedures according to the (limited) performance capabilities of electric VCA [3].
    - Weather resilience: Understanding the capabilities of VCAs to operate under various weather conditions and how this affects procedure design and vertiport (network) operations.
    - Interface with ATC: Establishing a safe and efficient procedural and collaborative interface with air traffic control to enable IAM operations inside airport environment and in controlled airspace.
    - Traffic mix: Managing safely different operations under different responsibilities (U-space, ATC) including but not limited to small unmanned aircraft systems (UAS), VCA, visual or instrument flight rules (VFR, IFR), passenger-carrying, crewed and uncrewed.
    - Vertiport operation: Define a safe, secure, efficient, and viable concept of operations that takes into account the variability of IAM characteristics.
    - Vertiport network: The functional design of vertiport networks is a key driver for the operational deployment of VCA and the implementation of IAM [31].
- Economic viability:
    - Cost-effective solutions: Ensuring that the development and operation of vertiports and U-space infrastructure are cost-effective and sustainable [30].

III. The EUREKA Project

EUREKA stands out as the first SESAR project to extend the current scope of the existing air traffic management, air operations and U-space regulatory framework for vertiport stakeholders. The extension includes the development of approach, and departure procedures to and from vertiports, while taking into account the specific requirements of crewed VCA. The procedures cover various scenarios and time frames, ranging from short-term solutions for segregated crewed VCA operations to long-term strategies involving advanced U-space services and fully integrated (un)crewed VCA operations. Beyond nominal use cases, EUREKA addresses the challenge of managing disturbances and emergencies within vertiport environment e.g. caused by disruptive UAS (cooperative and non-cooperative) and a crewed VCA in Critical Failure for Performance (CFP) state, leading to tactical changes in the U-space airspace configuration. Focusing on the creation of an IAM vertiport ecosystem, EUREKA introduces the vertiport collaborative traffic management system, which serves as the backbone for managing IAM traffic at a vertiport by centralizing vertiport airside ground information such as availability, schedules and capacity constraints, contributing to a comprehensive operational picture. To complete the holistic picture and to maintain the overall efficiency of multiple vertiports interacting with each other, ATM processes and airport throughput, EUREKA investigates the role of a newly defined vertiport network manager (VNM). This actor monitors and manages multiple vertiports distributed over an urban local network, located in controlled and uncontrolled airspace and co-located with airports.

Fig. 1 shows the timeline for expected evolvement of U-space services as envisioned in the CORUS-XUAM ConOps [12]. Initial U-space services (U1/U2) are to be deployed in the coming years (up to 2026). General U-space services (U3) are envisioned by the year 2035. The final goal is full U-space integration (U4) after 2035. EUREKA was kicked-off in 2023 at an initial technology readiness level (TRL) 2 (technology concept formulated) and will close in 2026 at TRL 7 (system prototype demonstration in operational environment). The following sections introduce the four individual EUREKA solutions.

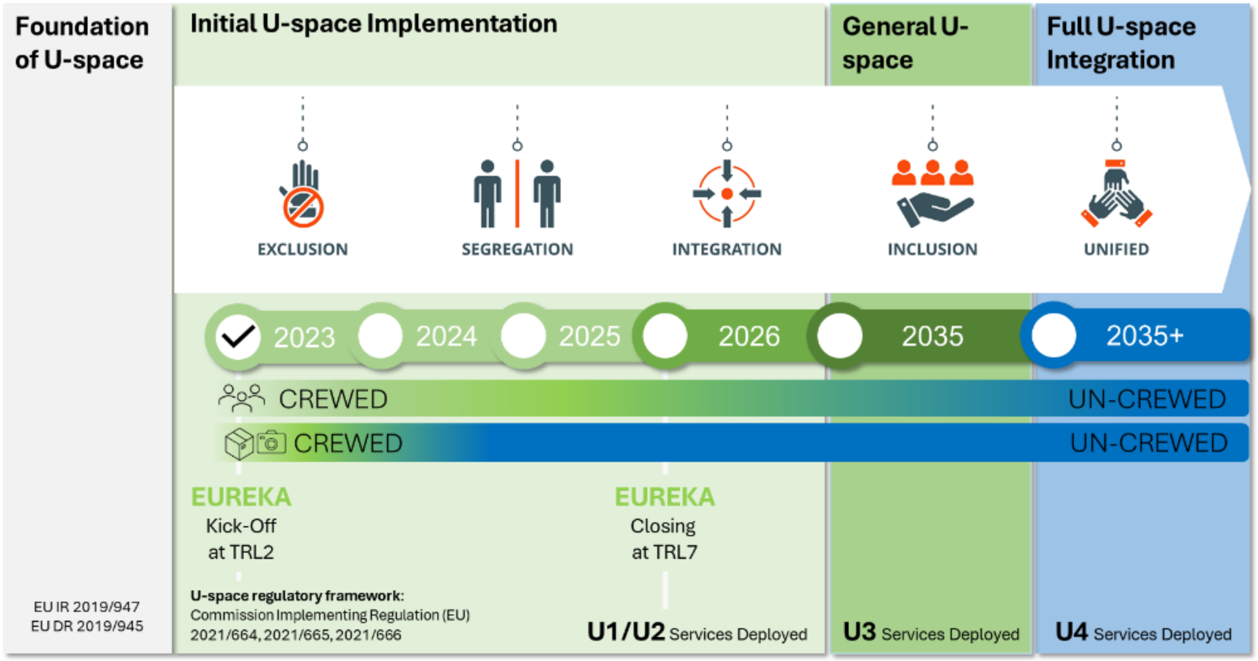

Fig. 1 Timeline for U-space evolvement and EUREKA contribution.

IV. Solution 1: Arrival / Departure to/from Vertiport incl. Route and Trajectory

A. Scope of the Solution

Solution 1 in the EUREKA project provides a comprehensive framework[10] for defining and designing arrival and departure procedures for VCA to and from vertiports, as well as the routes and associated trajectories between them. It addresses the specific needs of VCAs across various use cases and time horizons. The solution includes planning elements and methodologies for a unified description of vertiport arrival, departure, and en-route procedures, incorporating operational concepts, requirements, and airspace design guidelines. The scope of the solution is summarized as following:

- Approach, departure, and en-route procedures of crewed VCA for vertiports.
- Design criteria and requirements for crewed VCA operations in Visual Metrological Conditions (VMC).
- Routes to be designed/structured for uninterrupted flights and seamless operations with as few interventions as possible (ideally none).
- U-space supporting airspace and procedure design for crewed VCA.

It is worth mentioning that for reaching TRL7, this solution is limited to VMC and Visual Flight Rules (VFR) due to constraints of VCA capabilities.

B. Core Functions

For illustration purposes, Fig. 2 outlines the context and system boundary of solution 1. The main objective is to provide relevant aeronautical information that will eventually be published and utilized by key stakeholders during operations.

[10] In this context, 'framework' is defined as a qualitative abstraction for analyzing a system of interest (i.e., airspace and flight procedure)

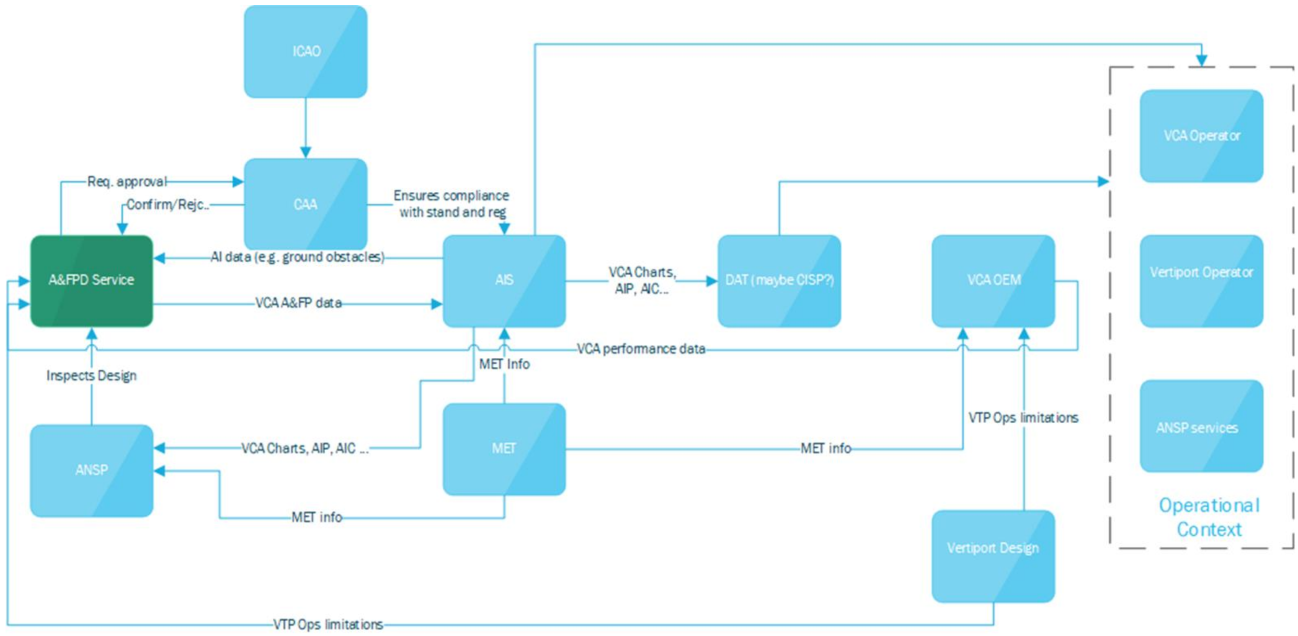

Fig. 2 VCA airspace and flight procedures design context.

The services and functions included in solution 1 are summarized as follows:

- Airspace design:
  - Solution 1 will develop airspace structures (such as urban corridors, vertiport approach/departure paths, and low-altitude routes) adapted for VCA operations in urban and suburban environments.
  - It will define entry/exit points, and airspace restrictions for safe integration with other airspace users.
- Flight procedure design:
  - Solution 1 will create flight procedures tailored for VCA, such as departure, approach, missed approach, and contingency procedures for urban vertiports.
  - Procedures will ensure safe separation minima in both normal and contingency situations, addressing vertical and lateral spacing requirements in dense environments.
  - Dynamic flight procedures (adaptive based on traffic density or weather conditions) may be incorporated where needed.
- Interoperability guidelines:
  - Solution1 will define the operational interfaces for integrating VCA flight procedures with existing ATM and U-Space systems.
- Safety and risk assessment:
  - Solution1 will provide a framework for conducting safety assessments of the proposed airspace structures and flight procedures, ensuring compliance with safety standards set by aviation authorities.
  - It will establish procedures for risk mitigation, particularly in urban operations where potential conflicts with other airspace users (helicopters, drones) are high.
- Performance criteria for VCA operations:
  - Solution1 will establish the performance standards that VCA operators and vehicles must meet to fly within the defined airspace. These criteria will focus on the required flight rules, and VCA capabilities.
- Regulatory compliance:
  - Solution1 will ensure that all designed airspace and flight procedures comply with national and international aviation regulations.
  - It will work closely with regulatory authorities to ensure that procedures can be approved for operational use.

C. Validation Methodology

The structured approach allows Solution 1 to develop a versatile framework for integrating VCA operations into today's airspace systems while preparing for future advancements. By addressing immediate needs and long-term regulatory requirements, the solution ensures VCA operations are safe, efficient, and scalable in various environments and automation levels. Furthermore, the project aims to achieve TRL7 maturity level within the project framework.

Table 2 Ongoing validation exercises in solution 1.

TRL	Exercises	Type	Platform
4	Concept evaluation of VCA airspace and flight procedures	Analytical assessment via expert judgment and fast time simulation	CAST [32] and U-Sky [33]
4	Airspace and procedure design, flight route design, ATM/U-space service management	Analytical assessment via expert judgment and fast time simulation	U-Sky [33]
4-5	Airspace and procedure design, flight route design, ATM/U-space service management	Analytical assessment via expert judgment and fast time simulation	U-Sky [33] and Droniq USSP
6	Evaluation of VCA airspace and procedures design	Testbed validations via real time simulation and expert judgment	Volocopter Flight Planning tool, Pilot-in-the-Loop (PiL) simulator, U-Sky [33]
6-7	Airspace and procedure design, flight route design, ATM/U-space service management	Testbed validations via real time simulation and expert judgment	U-Sky [33] and Droniq USSP
7	Flight evaluation	Flight-based validation and expert judgment	Demonstration flight and/or commercial flights

V. Solution 2: Vertiport Collaborative Traffic Management

A. Scope of the Solution

The main scope of this solution is to develop the collaborative traffic management process for the vertiport operations as vertiport collaborative traffic management (VCTM). As mentioned above, one challenge associated with VCA is their limited endurance. Thus, holding procedures from current aviation cannot be applied. Instead, the VCA flight must go from take-off to landing without a pause. There is the need to coordinate the required resources (Final Areas for Take-Off and Landing (FATO 1 and 2), and en-route flight path) before take-off. The collaborative aspect is the coordination of these three availabilities in a coherent set. VCTM is a cooperative process in which all the required IAM actors (vertiport manager, common information service provider (CISP), USSP, VCA operator/pilot) work together to make the best use of available resources, reducing the uncertainties in the operations. The aim is to enable safe flight by electric VCAs with very limited endurance. A secondary objective is to improve the overall performance of the IAM operations.

The key aspects of the solution are:

- Operations planning in the vertiport and in the U-space airspace: This involves making the best use of vertiport resources (such as timing slots, stands) and airspace, reducing the complexity for allocating IAM traffic in U-space volumes.
- Collaborative processes defining the responsibilities between the different IAM actors involved in the operations providing a continuous information sharing, in all phases of the flight, the tactical and strategic, pre-tactical, and tactical phases.
- Apply the existing airport collaborative decision making (A-CDM) concept to the vertiport infrastructure (V-CDM), to increase IAM operations' predictability, and provide a more precise target time of the operations.
- Prioritization process by vertiport manager, optimizing sequences for IAM traffic affected by operations constraints.

B. Core Functions

This solution establishes a CIS platform as a single and reliable source of all common, static and dynamic information, the unique point of access for information exchanges and coordination between U-space service providers, ATM and vertiports. Furthermore, the solution will enable the integration of the vertiport management service and USSPs, thus permitting the integration of information such as slots availability or ground services status and USSPs' data such as clearances, flight plans and information critical for IAM operations.

VCTM process will manage the VCAs' schedules from the ground perspective. These schedules will be correlated with the flight plans received from the CIS system, providing vertiport operators with a complete view of the operations. The VCTM will manage information on:

- Current state of the vertiports including availability of platforms, operational status, weather information.
- Expected capacity/demand of the vertiport.
- Expected IAM departure slot information aligned with the service time on the ground (battery change, charging services, addition of payload...).
- Potential misalignments between vertiport schedules and flight plans.
- The V-CDM concept will also monitor the vertiport operations; managing take-offs, landings, and in-flight operations of VCA vehicles ensuring that the vertiport can handle the expected volume of traffic. With the aims to improve predictability, reduce delays, and optimally utilize the available capacities and operational resources at the vertiport.

Solution 2 aims to develop a vertiport availability service that covers the operational conditions of the vertiports, as well as their capacity in terms of slots, enabling VCTM. Fig. 3 shows the stakeholders, modules and interfaces involved in solution 2. The vertiport availability service encompasses the distribution of vertiport-related information at the operational and management levels (between vertiport operator and CISP), allowing scheduling of VCA operations at vertiport facilities. This information is shared with the USSPs through the CISP and reflects the state of the vertiport (OPEN/CLOSED), as well as the capacity available of the vertiport in terms of slot availability. The Information Exchange Services (IXS) address the USSP interoperability in a multi-USSP environment. The relevant information to be addressed by these services in this solution are the network ID messages and U-plan information. The Flight Permission Module is used to provide functionalities to authorities or entities in order to facilitate communication between the authorities and the U-space ecosystem. These functionalities may include authorities' permission for a U-plan that affects airspaces that require authorization to enter, as well as vertiport clearance requests to be received from the USSP and responses to be received by the correspondent vertiport operator.

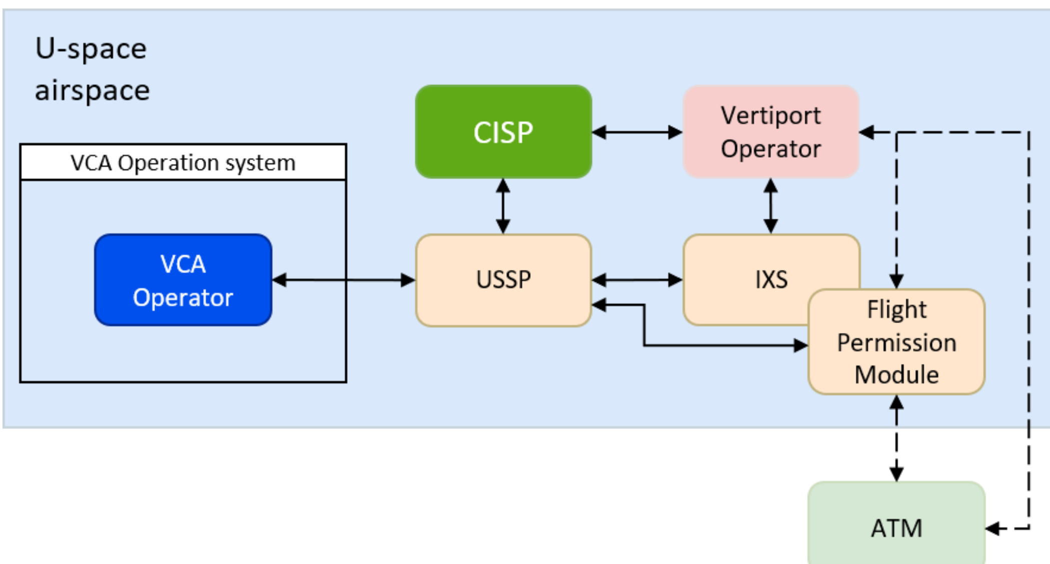

Fig. 3 Functional diagram of the stakeholders and modules involved in solution 2.

C. Validation Methodology

The location for the validation activities of solution 2 will be Balearic Islands using the vertiports of Palma de Mallorca Airport (PMI) and Menorca Airport (MAH). EUREKA solution 2 will be validated through a series of activities, at different maturity levels as shown in Table 3. The following use cases and flight phases will be in focus:

- Flight authorization process
- Dynamic Airspace Reconfiguration (DAR) origination during strategic assessment

- Flight activation process
- Hold position instruction
- VCA in route
- Touchdown and lift off area (TLOF) vertiport of destination update
- Landing request process
- VCA cargo operation and multiple UAS sharing the U-space airspace.

Table 3 Ongoing validation exercises in solution 2.

TRL	Exercises	Type	Platform/prototype/system used
4	Analytical assessment of VCA flight authorization, activation process and take-off in a vertiport in airport environment minimizing impact on manned traffic Analytical assessment of VCA cruise flight in corridor Analytical assessment of VCA flight landing at destination vertiport in airport environment minimizing impact on manned traffic VCA operation in vertiport and corridor prototyping (in lab) Expert workshop	Analytical assessment prototyping (in lab) workshop	Simulator for analytical assessment. Vertiport Manager System, USSP, CISP, VCA Ground Control Station (GCS).
6	Real time simulation for VCA flight authorization, activation process and take-off in a vertiport in airport simulation environment minimizing impact on simulated manned traffic Real time simulation for simulating the VCA corridor flight Real time simulation for landing at destination vertiport in airport environment minimizing impact on manned traffic	Real time simulation	Vertiport Manager System, USSP, CISP, VCA GCS.
7	VCA flight authorization, activation process and take-off live trial in a vertiport in a real airport environment Real VCA flight in corridor Real VCA landing at vertiport in airport environment	Flight trials	Vertiport Manager System of PMI and MAH, USSP, CISP, VCA GCS.

VI. Solution 3: Vertiport Disruption and Emergency Management

A. Scope of the Solution

EUREKA solution 3 is dedicated to creating operational procedures and tools that empower vertiports, USSPs and Air Traffic Service Providers (ATSPs) to handle disruption and emergency situations on vertiports effectively. The main objective is to validate a disruption & emergency management service for vertiports, to restore normal operations with minimal safety and operational impacts. This service supports vertiports in managing disruptive occurrences such as manned VCA-critical failure for performance (CFP) situations resulting from energy shortage, as well as non-conformant UAS and negligent UAS use-cases in airport environment. The key components of the solution are:

- Focus on airport environment: The vertiports considered are integrated into airport environment, in a U-space within controlled area. Solution 3 has been designed as a U-space solution. Due to the proximity of the two types of airspace, the risk of infringement will be addressed. Additionally, interaction between ATC and USSP has been identified as one of the main research questions;
- Dedicated contingency & emergency management procedures: The solution intends to establish specific protocols for vertiports, ensuring swift responses to disruptions; for example, some procedures such as VCA priority landing or direct landing on a vertiport will be addressed;
- Management of mixed traffic: Solution 3 assumes that both VCA operations and UAS operations, all of which compose IAS, may use vertiports as an operational site;
- Dynamic Airspace Reconfiguration (DAR): Upon the initiative of the ATC, it enables real-time adjustments in airspace structure; in addition, the reverse DAR, initiated by USSP, is also considered in the solution as a way to support emergency caused by UAS (such as a fly-away event for example).

B. Core Functions

The system architecture for solution 3, illustrated in Fig. 4Fig. 4, considers a vertiport situated within an airport environment. The airport is located within controlled airspace (CTR, Class D type airspace). Therefore, solution 3 focuses mostly on a single operational environment: U-space airspace within controlled airspace.

The initial definition of the vertiport operator's role as found in Table 1 is extended in the solution. The vertiport operator manages operations on the ground (i.e. allocation of parking positions, ground movement control etc.). He is also responsible for real time availability of the FATO as well as providing the necessary conditions for maintaining its suitability and availability over time. During contingency and emergency situations, the vertiport operator is in charge of emergency response coordination, with the other stakeholders involved such as USSP and/or air traffic controller (ATCO).

Following further assumptions are taken on location and airspace: It is assumed that vertiports are in controlled airspace (within urban environments, integrated into U-space); contingency and emergency management: it is assumed that future regulatory updates will address vertiport-specific contingency and emergency protocols and operational procedures; high UAS traffic: an increasing UAS density is assumed, positioning vertiports as essential for managing mixed traffic in urban areas.

The core functions of the solution are:

- Contingency and emergency management: The solution aims at establishing protocols and operational procedures for real-time contingency / emergency situations; including status information sharing among stakeholders (USSP, ATCO, vertiport traffic zone (VTZ) manager, vertiport operator) with prioritized communication or visual status displays on systems like human-machine-interfaces (HMIs).
- Procedures for VCA pilots: Manned VCAs must guarantee a Continuous Safe Flight and Landing (CSFL) when encountering a CFP. Any new operating methods applied to manned VCAs are conditioned by these provisions or requirements. However, there are still procedures to be defined and recommended that could support the pilot also under CSFL conditions – such as priority landing, direct landing or dedicated corridor through DAR – and this is one of the rationales of the solution;
- U-space services integration: Incorporates foundational (U1) and initial (U2) U-space services such as tracking, airspace management, and conflict resolution. The main U3 U-space services that solution 3 plans to address are: tactical operational information exchange, vertiport availability or collaborative interface with ATC for example;
- Containment requirements: The solution highlights the importance of containment requirements for UAS tracking and identification systems;

Together, these functions aim to support safe and efficient vertiport operations in line with Specific Operations Risk Assessment (SORA) procedures.

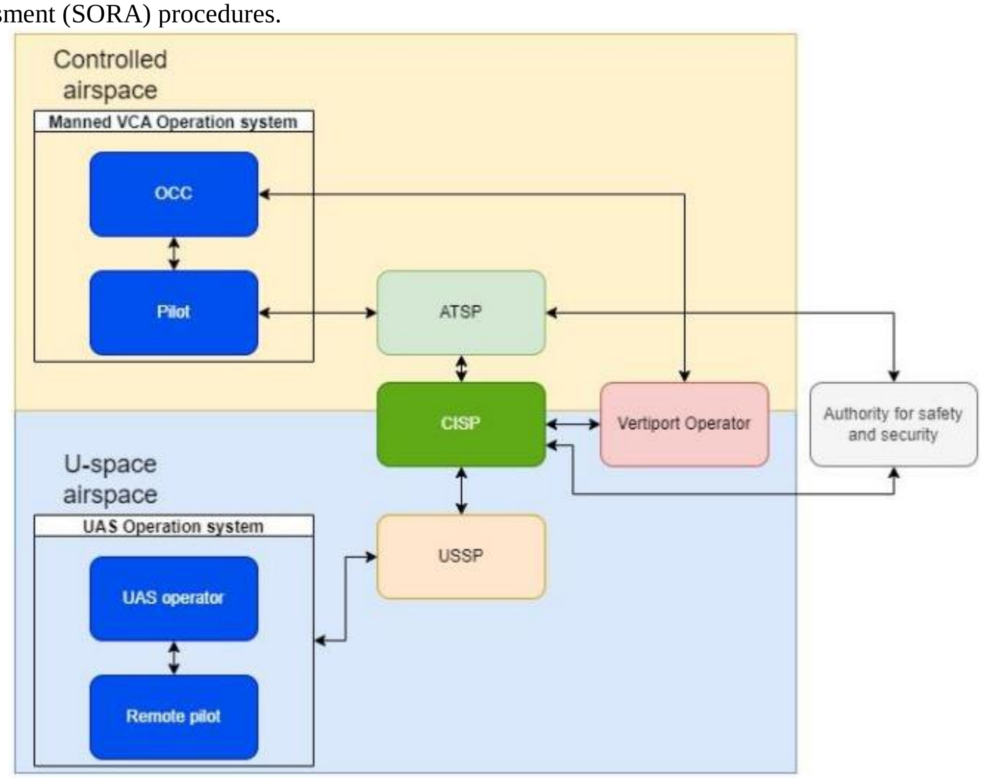

Fig. 4 System architecture of solution 3.

C. Methodology of Validation

As of today, solution 3 plans to conduct fast-time simulation, real-time simulations and possible live-trial. The location considered is a vertiport located in Paris region. The activities shall focus on:

- Manned VCA CFP arising from energy shortage: Testing impact on vertiport and airspace management;
- Disruptive UAS situations: Evaluating response strategies in case of non-conformant UAS (in flight-geography or in time) as well as negligent drones;
- Dynamic airspace reconfiguration: Assessing coordination between ATC unit, USSPs, and vertiport operators for effective contingency/ emergency response.

These validation activities simulations aim to refine operational procedures and validate the disruption & emergency service for vertiports for broader use.

VII. Solution 4: Vertiport Network Flow, Capacity and Operational Management

A. Scope of the Solution

The focus of the solution is on the management of the vertiport network capacity and on the vertiport network operations (both ground and air operation) to allow efficient and safe network operations with a holistic view. Managing network capacity involves optimizing the utilization of resources across multiple vertiports, such as landing pads, parking areas, charging stations, and maintenance facilities. It requires balancing demand with availability to prevent bottlenecks while accommodating varying levels of traffic at different locations within the network. This aspect also includes planning for peak usage periods, adjusting capacity dynamically in response to real-time conditions, and ensuring that each vertiport contributes effectively to the overall system. A holistic view is critical to achieving these goals, as it enables the integration of various systems data sources and link with other stakeholders (e.g. USSP, CISP, ATM), This approach ensures that decisions are not made in isolation but are instead informed by a comprehensive understanding of the network as a whole. The setting is a local closed network of vertiports in an urban/sub-urban environment, including one of the vertiports in a complex environment such as an airport. The local vertiport network manager (VNM) serves as a centralized system overseeing and coordinating operations within a local network of vertiports (e.g. regional/city). The "overseeing" capability is related to the capability of monitoring performances, managing data and identify issues of the vertiport network. The "coordinating" capability is referred to scheduling, and allocation of resources of the network. Its primary function is to ensure efficient and safe management of vertiport facilities in the context of urban air mobility. The main pillars on how VNM might work are depicted as following:

- Centralized management: The VNM acts as a central hub overseeing multiple vertiport locations within a specified region or network.
- Data aggregation: It gathers and aggregates data and information from various sources, including vertiport facilities, CISP, airspace management systems, weather services, and more. Some examples of data are: availability of landing/takeoff pads, turnaround times, resource status, traffic throughput, scheduling information, weather data etc.

The key components considered in the solution are:

- User interface: Provides a user-friendly interface for operators, stakeholders, and administrators to access and manage vertiport-related operations and data.
- Analytics and reporting: Generate reports and analytics based on operational data to optimize resource allocation, identify trends, and improve overall performance.
- Automation and artificial intelligence (AI) integration: Utilizes automation and AI for efficient scheduling, predictive maintenance, and decision-making based on real-time data.

In detail, the work package develops conceptual and operational descriptions in an environment based on the following assumptions: The end-users are the IAM operators (both for passenger and cargo operations); The different types of air traffic (conventional aircraft, IAM) are separated; the IAM flights operate according to the U-space requirements.

Since this solution considers the new entity of vertiport and the network of vertiports in the landscape of U-space airspace operations, one of the goals is the assessment of integration of the network of vertiports, the related links with system technologies and U-space services as well as the impact on U-space operation. In addition, the evaluation of capacity metrics is conducted and the impact of the vertiport network flow on the existing scenario is investigated. This solution foresees the vertiport network operations, in either uncontrolled or controlled airspace, and in which one vertiport is located at an airport in congested airspace.

B. Core Functions

Today, vertiport operations are possible without U-space airspace but are subject to various regulations and constraints. Operators must adhere to existing aviation regulations and guidelines from aviation authorities. Traditional aviation lacks a network manager concept for rotorcraft and does not have vertiport networks. The solution's method involves establishing a network of vertiports within the same urban or regional area. This network, managed by a single operator, would provide necessary facilities for IAM traffic and connect vertiports via corridors, each with its U-space airspace volume, see Fig. 5. The focus is on exploring the benefits of U-space services at the network level and how such a network can optimize capacity and operations. The role of the VNM is introduced to oversee and coordinate operations within a local vertiport network, ensuring efficient and safe management in the context of IAM.

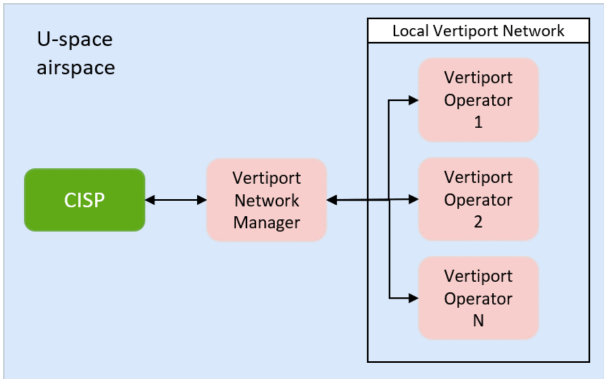

Fig. 5 Functional diagram of solution 4 introducing the vertiport network manager.

Core functionalities/services:

- Flight scheduling and coordination: Receives flight schedules, optimizes slot allocation to minimize congestion and enhance efficiency.
- Resource allocation: Manages resources like landing pads, charging stations, and passenger areas, allocating them based on demand and priority.
- Communication and information exchange: Facilitates communication between vertiports, air traffic systems, and stakeholders, sharing real-time information on weather and operational updates.
- Passenger services: Oversees check-in procedures, security checks, and ground transportation to ensure a seamless passenger experience.
- Integration with U-space systems: Ensures compliance with UAS traffic management and airspace regulations.

To evaluate the effects and the potential benefits deriving from the introduction of the new local VNM stakeholder, solution 4 will develop some use cases considering two different assumptions:

- Operations in full U-space, with ATM only informed. The crewed VCAs are considered as active users of U-space. Each vertiport has its U-space airspace volume;
- Operations in U-space with ATM as active actor. In this case ATC can act on U-space airspace volumes and vertiports (open/close) through DAR and specific functionalities.

C. Validation Methodology

The solution includes five use cases: the interaction between the local VNM and the CISP; the management of a IAM operator's application to the VNM during the strategic phase; the pre-tactical phase; and the tactical phase. Additionally, it addresses the ATM/ATC request for vertiport closure due to an emergency, such as a priority Helicopter Emergency Medical Service (HEMS) flight entering U-space airspace and landing at the vertiport during either the tactical or pre-tactical phase.

The solution targets the TRL7 maturity, starting from the initial maturity level of TRL2. The location for the validation activities will be in Rome Fiumicino using the vertiports within the regulatory sandbox framework and the ones foreseen in the context of the Italian Pilot Project for eVTOL [35]. One of the vertiports under investigation as part of the network is located near to the Rome Fiumicino airport, which is a high-density traffic airport, in a sub-urban area. The second one is in the city center of Rome, in a hilly area, in a populated environment. EUREKA solution 4 will be validated through a series of activities, at different maturity levels, including real time simulations, flight trials and fast time simulations as shown in Table 4.

Table 4 Ongoing validation exercises in solution 4.

TRL	Exercises	Type	Platform/prototype/system used
4	Fast time simulation to evaluate the capacity for the network of vertiports using VCA traffic sample.	Fast time simulation	Airtop Simulator [36]
6	Real time simulation to test the interoperability and the data and services exchange between the Local VNM, USSP and the CISP using vertiports information.	Real time simulation	Local Vertiport Network Manager System, USSP, CISP
7	Flight trials with real eVTOL and UAS flying in a corridor and landing at vertiport in airport environment. During the flight trial a use case "ATM/ATC request for vertiport closure due to emergency" will be demonstrated, related to the tactical and pre-tactical phase	Flight trials	Local Vertiport Network Manager, USSP, CISP

The validation of the operational concept will utilize several platforms and systems, including Automatic Dependent Surveillance Broadcast (ADS-B) and onboard devices for remote identification (also called UTM box, see e.g. [37]), the d-flight USSP platform for U-space services, the d-flight Italian National CISP platform, and the UrbanV-Vertiport Network Management Platform. Ground equipment for meteorological observation and forecasting, the Leonardo ATM/ATC real-time simulation platform, Volocopter VCA Volocity, and the Techno Sky UAS vehicle will also be part of the validation process. Additionally, the validation will involve Rome Test Vertiports, synthetic traffic data (both crewed and uncrewed) from simulation tools, and real traffic data from flight trials of one VCA and one UAS. This will occur within U-space airspace, encompassing both volume and corridor, as well as controlled airspace for coordination, such as DAR. The involvement of air traffic controllers, pilots, and remote pilots will be essential for the validation process. The overview of the validation platforms is shown below in Fig. 6.

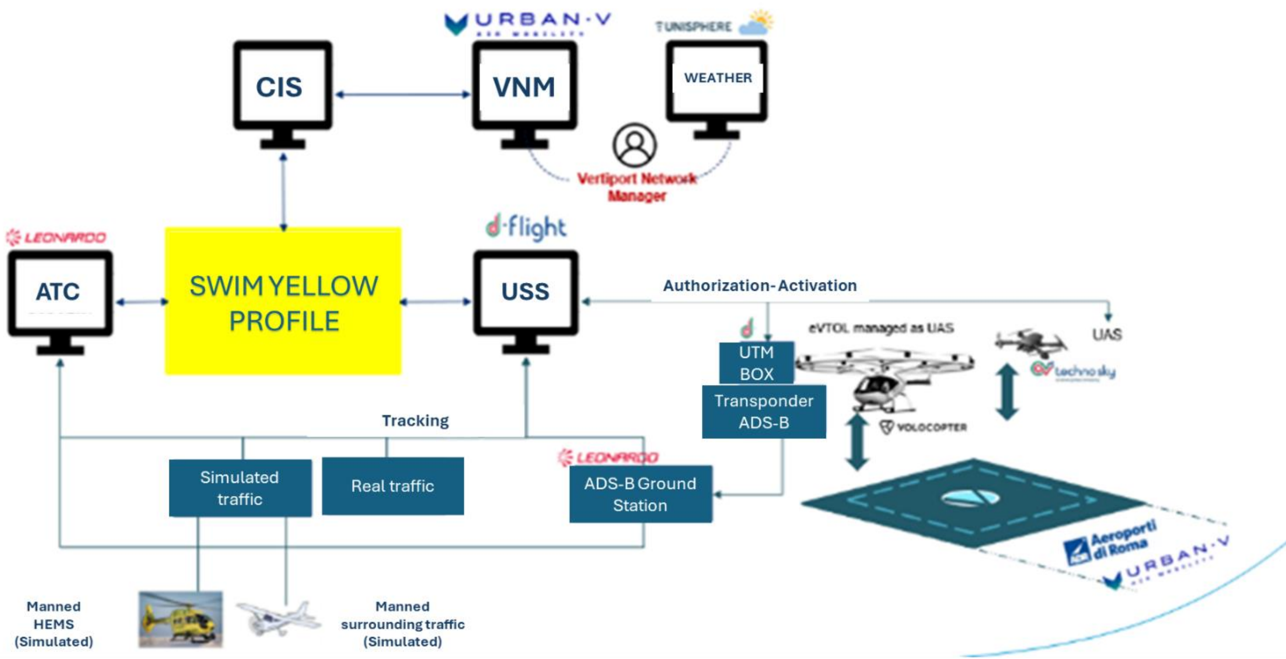

Fig. 6 Validation platforms used for solution 4.

VIII. Discussion

When diving into IAM literature, an ambiguity of terms can be found [38]. Even the usage of very basic terms such as IAM, IAS, or alternatively advanced air mobility (AAM) as used outside of Europe, is debatable. For example, EASA documents [38] and [40] define IAM as a sub-part of IAS. However, other EASA sources such as the IAM Hub [1], that is meant to inform and digitally connect all IAM stakeholders, shows IAM and IAS as separate domains in the introductory diagram. The ambiguity of new terms, and following the ambiguity of definitions of new stakeholders and their roles, is one reason why harmonization between different projects and also within the four EUREKA solutions is challenging. Therefore, the EUREKA project has a dedicated work package on harmonization. This paper has tried to find a common language for all four EUREKA solutions. However, it as to be noted that harmonization (of terminology, roles, architectures, etc.) is an ongoing process and that the initial definitions shown in this paper might be updated throughout the project's runtime.

The EASA regulations are equally binding for all European member states. However, the member states have certain flexibility on how to implement new U-space regulations. One example is the introduction of a centralized CISP; another example is IXS in solution 2 for validation activities of multi-USSPs in Spain. Thus, details of U-space architecture might initially vary between different European states.

Current EASA doctrine is to enable initial crewed VCA operations as VFR flights without the obligation to make use of U-space as seen in the initial procedure design of solution 1. Actually, the U-space regulatory [11] is explicitly not meant for VCA. Thus, the other EUREKA solutions push the current boundaries of the U-space framework to investigate the potential benefits of U-space services for VCA operation at vertiports. Initially, SESAR had considered that VCA would be part of U-space and that CORUS-XUAM [12] had answered the research question "can U-space support Urban Air Mobility" as it was then known. That project had concluded that yes, U-space would be beneficial for VCA. Though the level of risk associated with passenger transport might require a higher level of performance of the service providers. This was harmonious with – although not the same as – NASA's approach on provider of services to UAM (PSU) [41]. However, in the intervening period EASA has stated that VCA will initially fly VFR and it is to be discussed whether VCA will start outside U-space and then always be outside U-space. These two views are both considered in EUREKA currently; that VCA may fly in U-space and that they may not.

IX. Conclusion and Outlook

This paper has introduced four solutions of the SESAR project EUREKA that aim at safely and efficiently integrating vertiport operations into the airspace. The following initial conclusions can be drawn:

- Infrastructure has been identified as main challenge for the implementation of IAM. Further challenges are safety, technology, regulations, air traffic management, communications, and operations, among others.
- The current U-space regulatory framework does not cover certified VCA operations and therefore does not regulate vertiport stakeholders and operations. EUREKA aims to fill this vertiport gap by addressing vertiport operations and leveraging the progress made in previous U-space projects and regulatory guidance.
- A framework for defining and designing arrival and departure procedures for VCA to and from vertiports, as well as the routes and associated trajectories between them are needed for VCA operations in VFR or U-space. EUREKA is developing this framework.
- The airport collaborative decision making (A-CDM) concept is suggested to be adapted to the vertiport infrastructure (V-CDM), to increase IAM operations' predictability, and provide a more precise target time of the operations.
- The vertiport availability service encompasses the distribution of vertiport-related information at the operational and management levels, allowing scheduling of VCA operations at vertiport facilities. This information is shared with the USSPs through the CISP and reflects the state of the vertiport (OPEN/CLOSED), as well as the capacity available of the vertiport in terms of slot availability.
- It is suggested that a vertiport operator manages, operations on the ground (i.e. allocation of parking positions, ground movement control etc.), is responsible for real time availability of the FATO as well as providing the necessary conditions for maintaining its suitability and availability over time. During contingency and emergency situations, the vertiport operator is in charge of emergency response coordination (sets up and maintains protocols for handling emergencies), provides Rescue and Firefighting Services (RFFS), coordinates with emergency services, VCA operators, and Law Enforcement Authorities (LEA).
- The new and optional role of vertiport network manager is suggested for managing the operations, the flow and the capacity of a local vertiport network. It will oversee the operations of the network, monitor the compliance with the rules defined to reach the maximum level of capacity obtained by conducting a preliminary capacity assessment based on the routes and the vertiports part of the network.

EUREKA is a SESAR fast track project with the aim to develop the four solutions from TRL 2 to 7. At the time this paper is written, the concept phase has been completed and the solutions are reaching TRL 3-4 through analytical assessment and fast-time simulation. Real-time simulations are currently under preparation. Selected scenarios will be demonstrated in flight trials under operational conditions to reach TRL 7 until the project's end in 2026.

Disclaimer

This paper represents the view of the authors.

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