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Di-PEGASUS knowledge base and stakeholders' requirements

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Abstract:

The Di-PEGASUS knowledge base and stakeholders' requirements deliverable provides a review of the state-of-the-art and practice related to the new digital technologies that will be developed in WP2 - Aircraft and Airspace digital technologies and WP3 - Digital innovative ground maintenance technologies. Thus, it sets the knowledge baseline upon which the new digital technologies that will be developed as part of Di-PEGASUS will build. Furthermore, D1.1 identifies the stakeholder requirements that relate to the new digital technologies, which will help shape the outputs of WP2 and WP3.

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LIST OF ACRONYMS

Acronym	Definition
3D	Three-dimensional
ACAS-X	Next-Generation Airborne Collision Avoidance System
AI	Artificial Intelligence
ATC	Air Traffic Control
BVLoS	Beyond Visual Line of Sight
CD&R	Conflict Detection and Resolution
D2MAV	Deep Distributed Multi-Agent Variable framework
DD-MARL	Deep Distributed Multi-Agent Reinforcement Learning
DRL	Deep Reinforcement Learning
EASA	European Union Aviation Safety Agency
eVTOL	Electric Vertical Take-Off and Landing
GCS	Ground Control Station
HMI	Human-Machine Interface
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
IVHM	Integrated Vehicle Health Management
MAASA	Multi-Agent Autonomous Separation Assurance
MADDPG	Multi-Agent Deep Deterministic Policy Gradient
MARL	Multi-Agent Reinforcement Learning
MAS	Multi-Agent System
MOCU	Multi-robot Operator Control Unit
MRO	Maintenance and Repair Operations
NDT	Non-Destructive Testing
OEM	Original Equipment Manufacturer
OR	Operations Research
PAMELA	Process for Advanced Management of End-of-Life Aircraft
SHM	Structural Health Monitoring
SME	Small and Medium-sized Enterprise

TCAS	Traffic Alert and Collision Avoidance System
UAM	Urban Air Mobility
UAS	Unmanned Aircraft Systems
UAVs	Unmanned Aerial Vehicle
UTM	Unmanned Aircraft Systems Traffic Management

EXECUTIVE SUMMARY

The current document, titled D1.1 “Di-PEGASUS knowledge base and stakeholders’ requirements”, has been developed within the framework of the Di-PEGASUS project which is funded by the European Union’s Horizon Europe Research and Innovation Programme under Grant Agreement No 101096000.

The first part of this document outlines the state-of-the-art and practice related to the new digital technologies that will be developed in Di-PEGASUS WP2 “Aircraft and Airspace digital technologies” and WP3 “Digital innovative ground maintenance technologies”. More specifically, it focuses on swarm intelligence for multi-agent behaviour; new generation control station HMI for AI tasked UAS; flexible fleet and operations management; safe automatic landing aids at vertiports; health management of landed aircraft; innovative de-icing and biofouling mitigation strategies in vertiports and water airports; and sustainable circular economy in aircraft, vertiports and water airports. For each of these areas, this report sets the knowledge baseline upon which the new digital technologies that will be developed as part of Di-PEGASUS will build. Furthermore, this document provides a summary of completed and ongoing projects that are related to Di-PEGASUS. It is essential that these projects are identified both to draw lessons from them and build upon their work, but also to explore possible synergies.

The second part of this document focuses on the requirements identified for the new technologies that will be developed as part of Di-PEGASUS. The requirements were drawn by the Di-PEGASUS consortium partners, who engaged with stakeholders who are both prosumers and end-users of the Di-PEGASUS technologies in order to identify and analyse their needs, requirements, concerns, barriers, and opportunities. The engagement considered the technical, business, social, and legislative aspects underpinning the transformative technologies that will be developed as part of Di-PEGASUS, and how these fit within the wider context of the seaplane and drone markets. More specifically, this document sets out the methods used to identify the stakeholders related to each technology and how the data was collected in each case, before outlining the requirements related to drones and seaplane technologies. These requirements will feed into the next stages of Di-PEGASUS, by both shaping the technologies that will be developed as part of WP2 and WP3 and the business cases that will be developed as part of T1.5.

1. PROJECT OVERVIEW

Di-PEGASUS overall objective is to enable fully autonomous cost-effective and environmentally friendly operations for seaplanes, Vertical Take-Off and Landing (VTOL) and drones. This objective will be achieved by developing several enabling technologies targeting both the air and the ground side. In addition, Di-PEGASUS proposes to develop a digital platform to evaluate the viability of specific business models at particular locations (i.e. Greece, Italy and France), according to the digital technologies available, and the Key Performance Indicators (KPIs) (incl. cost-effectiveness, job creation, emissions savings, investment costs), in order to make recommendations to policy makers and relevant stakeholders that will host these services. This platform should also support the assessment of regulatory compliance to identify the safety assurance process that the technologies will need to follow, as well as the gaps in existing regulations that will need to be addressed.

The adoption of the above-mentioned possible technologies and services though could be hindered by negative impacts on the environment, the society and/or due to a lack of economic feasibility. Di-PEGASUS aims at overcoming all the barriers by applying an innovative multi-disciplinary two-pronged methodological approach, throughout the project duration. Such approach will be:

- **top-down:** it will consist of a structured desk research (Di-PEGASUS knowledge base), the analysis of Di-PEGASUS solutions' regulatory compliance, the benchmark and comparative analysis of existing business models, the definition of the business models requirements for Di-PEGASUS solutions;
- **bottom-up:** it will apply different methodologies for field research to reinforce, complement, test and validate the desk research. Engagement of relevant stakeholders will start right from the beginning of the project and will consist in collecting their specific needs through focus groups, interviews and surveys, creating a community of interested stakeholders to design and test Di-PEGASUS solutions also through three use cases. The bottom-up approach will complement the top-down approach in ensuring first-hand, expert knowledge transfer and exchange of competencies, as well as validation of Di-PEGASUS solutions.

This bi-directional approach (Figure 1) will ensure that there is a solid scientific background and that the developed solution answers the specific needs of the relevant stakeholders and end-users.



Figure 1: Di-PEGASUS' approach

In addition, in order to avoid reluctance as far as possible, Di-PEGASUS will apply a co-design and use-case-driven approach by applying design thinking principles for better User Experience (UX). Co-design includes three phases:

1. understanding and clearly defining the issues (WP1),
2. developing potential solutions (WP2-3-4),
3. testing these solutions (WP5).

The process is cyclical rather than sequential and may require reassessing or change at any point in the process. The process aims to change the mindset and behaviour of the stakeholders, encouraging and supporting innovative processes and solutions as they work to identify the "sweet spot" where change can evolve. Indeed, a participatory design of a service increases the chance for it to be accepted by the end-users. Use cases (WP5) are at the centre of knowledge based on the Di-PEGASUS project and represent the tool to acquire knowledge, develop and test specific solutions and refine the outputs of other work packages (e.g., WP2-4). The use cases were selected with the final aim of covering as many cases as possible regarding type of application context, type of technology tested, type of stakeholders involved and related impacts. Due to the high level of innovation and thus low TRLs of the solutions, use cases are not meant to be implemented as full scale demonstrations. Instead, they will be implemented by involving relevant stakeholders from the early phases of the development in co-design and evaluation activities through focus groups and surveys. This approach will ensure that business models are developed with a user centred approach to guarantee a successful scale up and exploitation of the technologies.

To reach its goal Di-PEGASUS will implement the above-mentioned methodological approach and build on four pillars (Figure 2):

- **Pillar 1:** AI-based Transformative Autonomous Technologies
- **Pillar 2:** Impact assessment and Cost-Benefit Analysis
- **Pillar 3:** Impact Assessment in real use cases

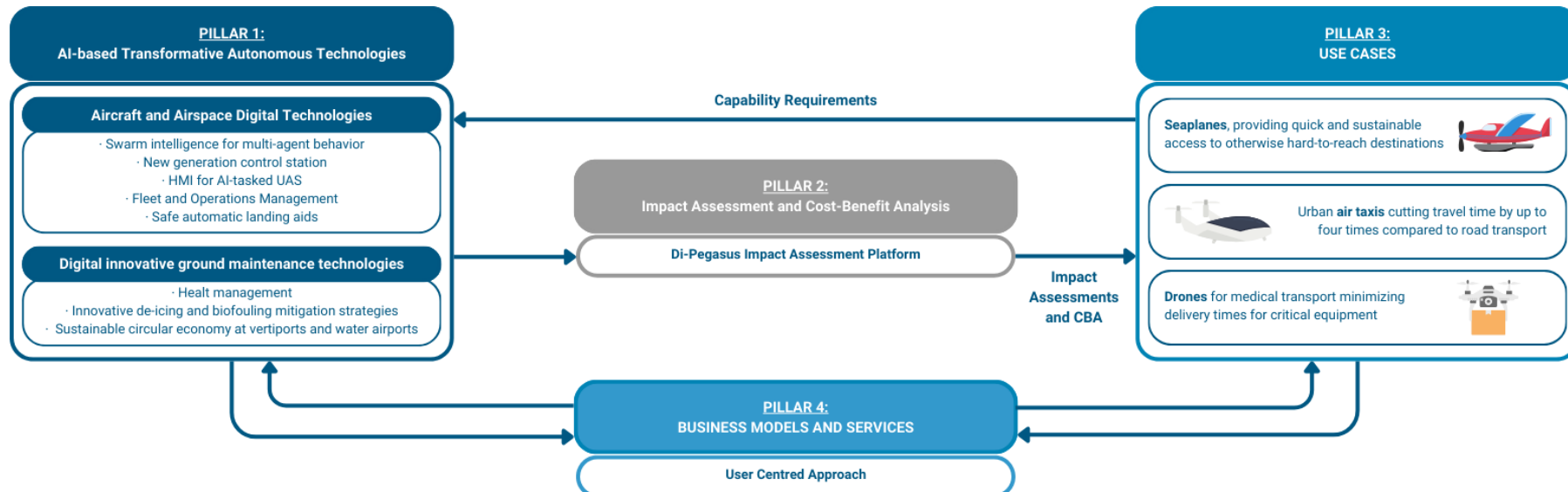


Figure 2: Di-PEGASUS' conceptual framework

2. INTRODUCTION

2.1. Objectives and scope of the document

This deliverable includes the outputs of two tasks, T1.1 and T1.2 aiming to:

- Provide a review of the state-of-the-art and practice related to the new digital technologies that will be developed in WP2 - Aircraft and Airspace digital technologies and WP3 - Digital innovative ground maintenance technologies. Thus, it sets the knowledge baseline upon which the new digital technologies that will be developed as part of Di-PEGASUS will build.
- Identify and provide the stakeholder requirements that relate to the new digital technologies, which will help shape the outputs of WP2 and WP3.

2.2. Document structure

This document comprises 4 sections:

1. **Introduction** describes the objectives, scope and structure of the deliverable.
2. **Di-PEGASUS knowledge base** includes the description of the state-of-the-art and practice related to the new digital technologies that will be developed as part of Di-PEGASUS.
3. **Stakeholder requirements** describes the methodology followed to elicit the stakeholder requirements and outlines the requirements that resulted from the engagement with the stakeholders.
4. **Conclusions** summarises the content of the report and outlines how it links to the Di-PEGASUS next steps.

3. DI-PEGASUS KNOWLEDGE BASE

This Chapter includes the state-of-the-art and practice update that will set the knowledge baseline for the digital technologies that will be developed as part of Di-PEGASUS. The digital technologies will build upon this knowledge base to develop innovative solutions for aviation technologies. Each of the following sections will outline the state-of-the-art in relation to the technologies that will be developed as part of WP2 (Section 3.1) and WP3 (Section 3.2).

3.1. Aircraft and Airspace digital technologies

Unmanned Aircraft Systems Traffic Management (UTM) is a rapidly evolving field that is set to redefine the future of airspace digital technology. At present, two major initiatives are leading the charge to fully enable UTM: NASA's UTM in the United States (Federal Aviation Administration, 2020) and U-space in Europe.

U-space is a collection of innovative services that rely on advanced digitalisation and automated procedures to ensure safe, efficient, and secure access to airspace for a large number of drones. The SESAR Joint Undertaking introduced the U-space concept of operation in 2017 (SESAR, 2017), outlining a vision for making U-space operational to enable complex UAS operations with a high degree of automation in all types of operational environments. In line with the International Civil Aviation Organisation (ICAO) recommendations, SESAR defined four U-space service levels, known as U-levels, each with increasing connectivity and automation:

- U1: Foundation services like pre-tactical geofencing or e-registration and e-identification of UAS.
- U2: Initial flight management services, such as operation planning, weather and traffic awareness, and strategical deconfliction.
- U3: Advanced services, featuring dynamic geo-fencing, automation of drone deconfliction and the close collaboration with the Air Traffic Control (ATC).
- U4: Fully operational services, enhancing cooperation with manned aviation, requiring integrated interfaces, connectivity, automation, and the development of Beyond Visual Line of Sight (BVLoS) operations.

In 2021, U-space was implemented as the European regulatory framework by European Commission (European Union Aviation Safety Agency, 2024) and came into force in January 2023. This framework establishes the rules, requirements, and procedures for the safe deployment of UAS across Europe. The regulation has been continuously updated, with the latest being Commission Implementing Regulation 2024/1109 (European Union Aviation Safety Agency, 2024), which addresses competent authority requirements and administrative procedures for the certification, oversight, and enforcement of the continuing airworthiness of certified unmanned aircraft systems.

The CORUS project (SESAR Joint Undertaking, 2019), further categorized the U-space concept of operations into eight main groups of services, as depicted in Figure 3.

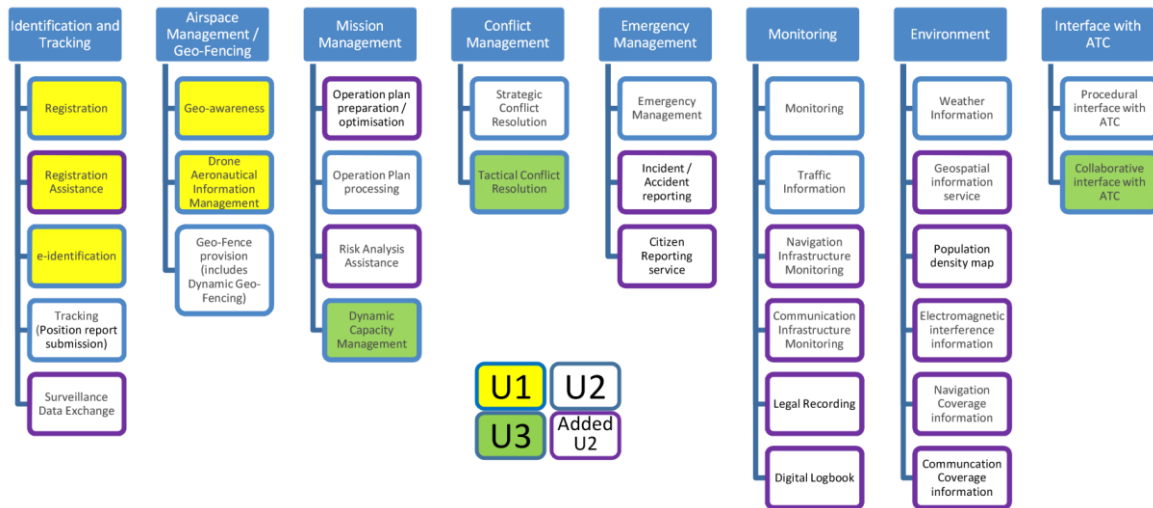


Figure 3: U-space services as outlined by CORUS project (SESAR Joint Undertaking, 2019)

Di-Pegasus is developing a range of aircraft and airspace digital technologies that align with the eight categories of U-space services. These technologies include:

1. **Swarm intelligence for multi-agent behaviour:** This technology enables multiple drones to operate in a coordinated manner, similar to a swarm of bees or a flock of birds. It falls under the category of mission management, conflict management, and emergency management.
2. **Control station HMI for Artificial Intelligence (AI) tasked Unmanned Aircraft Systems (UAS):** This technology involves the development of a human-machine interface (HMI) for controlling UAS. It contributes to the Interface with the ATC category.
3. **Flexible fleet and operations management:** This technology allows for the efficient management of a fleet of drones and their operations, contributing to the monitoring category.
4. **Safe automatic landing aids at Vertiports:** This technology ensures the safe and automatic landing of drones at Vertiports. It contributes to mission management, and emergency management category.

Figure 4 provides a detailed breakdown of how each subtopic falls under the categories of U-space services.

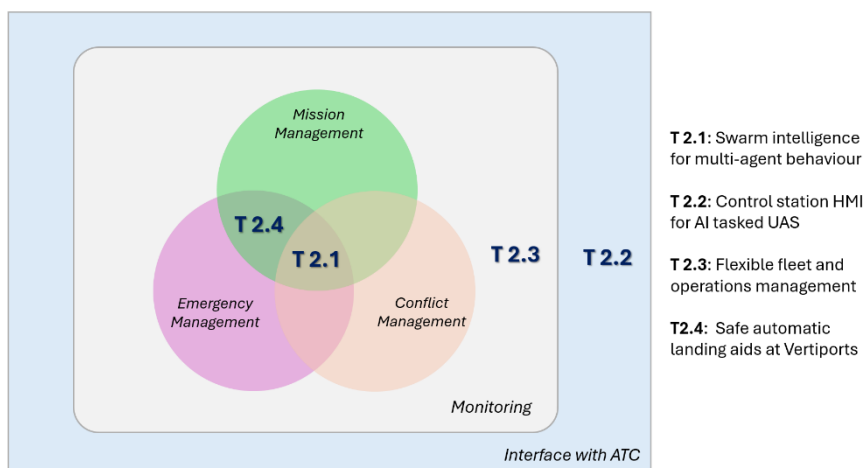


Figure 4 Alignment of Di-Pegasus technologies with U-space service categories

3.1.1. Swarm intelligence for multi-agent behaviour

In the aviation sector, Conflict Detection and Resolution (CD&R) has gained significant attention due to the ongoing expansion of global air transportation. The CD&R for manned and unmanned aviation has been thoroughly examined by Ribeiro, Ellerbroek and Hoekstra (2020).

Traditionally, ATC is responsible for managing air traffic to prevent collisions between aircraft. This is achieved through several stages of the flight. Pre-flight strategic deconfliction is typically performed through rescheduling and ground delay. If a conflict is detected mid-flight with sufficient time to react, ATC performs separation management to provide an optimal resolution strategy. In urgent situations, the Traffic Alert and Collision Avoidance System (TCAS) (Harman, 1989) and Ground Proximity Warning System can be activated onboard the aircraft as the last line of defence against mid-air collisions. However, TCAS is currently limited to large aircraft and cannot meet the safety and operational requirements of modern airspace.

The Next-Generation Airborne Collision Avoidance System (ACAS-X) (Jeannin et al., 2015; Kochenderfer, Holland and Chryssanthacopoulos, no date) has been developed with the aim of replacing the international standard for aircraft collision avoidance. ACAS-X uses an optimized numeric table for different airspace models with a Markov Decision Process and dynamic programming, making it significantly more robust than TCAS.

Although ACAS-X has shown success, it only considers pairs of aircraft without any other obstructions. This raises questions about its adaptability in Unmanned Aircraft Systems (UAS), where the environment is denser with obstacles and actions are more rapid. Particularly in Multi-Agent System (MAS) operations, pairwise collision avoidance may not be sufficient. Further research and development are needed to address these challenges.

CD&R in UTM goes beyond what has been considered for manned aviation. The EU-funded BUBBLES project (SESAR Joint Undertaking, 2022a) has created a concept of operations (CONOPS) that outlines how U-space services can be utilized to reduce the risk of collisions between UAS and other aircraft. This CONOPS has been introduced as a new SESAR solution called the "U-space Separation Management Service", an advanced U3 service that has been validated through a flight test campaign. Additionally, BUBBLES has developed a set of tools for separation management, both with and without AI, including a trajectory simulator, CNS monitoring, and a U-space simulator designed to simulate abnormal and faulty conditions.

Building on existing research into detect-and-avoid (DAA) systems and the remain-well-clear (RWC) concept, the URClearED project (SESAR Joint Undertaking, 2022b) aimed to build an architecture to prevent mid-air conflicts of UAS. The project also explored emerging concepts in air mobility, such as On-Demand Mobility and Urban Air Mobility, while aligning with existing RWC and DAA standards. More recently, the SPATIO project (SESAR Joint Undertaking, 2023) has focused on managing the separation of large numbers of UAS, addressing both strategic and tactical aspects within the U-space airspace capacity.

Multi-Agent Reinforcement Learning

A MAS is a system composed of multiple interacting intelligent agents. These agents, which can be software programs, machines or robots, are capable of interacting and sharing information with each other. MAS is particularly effective in addressing complex problems that are beyond the capabilities of an individual agent or a monolithic system. MAS finds applications in a wide range of fields such as computer networks, blockchain,

energy management and robotics. UASs are increasingly using MAS for tasks like search and rescue operations (Arnold, Yamaguchi and Tanaka, 2018).

In recent years, Deep Reinforcement Learning (DRL) has made a significant advance in MAS, leading to the development of Multi-Agent Reinforcement Learning (MARL) algorithms. In MARL, agents strive to learn an optimal policy that maximizes the long-term cumulative reward through interactions with the environment. Comprehensive reviews on the application of MARL in various fields can be found in Oroojlooy, Jadid and Hajinezhad (2021) and Du et al. (2023). Lowe et al. (2020) argue that traditional reinforcement approaches, such as deep Q-Learning, are not sufficiently effective for multi-agent systems. As training progresses, each agent's policy and the environment are dynamically changing, so the past experience replay is ineffective for stabilizing deep Q-learning. Consequently, a general-purpose multi-agent learning algorithm called Multi-Agent Deep Deterministic Policy Gradient (MADDPG) is introduced (Lowe et al., 2020). The premise of MADDPG is that even when the policies change, the environment can be treated as stationary if the actions taken by all agents are known. As a result, MADDPG can be applied in mixed cooperative-competitive environments.

However, MADDPG assumes perfect communication networks among agents with full observation for all agents. To address this limitation, Wang, Everett and How (2020) introduced an extension to MADDPG called Deep Recurrent Multi-Agent Actor-Critic to handle partially observable environments.

MARL in Aviation

MARL can be applied to a wide range of aviation applications. This includes flight planning, ground delay, maintenance, traffic management, attitude control, collision avoidance, fault tolerance, and adaptive control. Razzaghi et al. (2022) conducted a comprehensive review of reinforcement learning in aviation applications.

Brittain and Wei (2019) were the pioneers in addressing the problem of enroute ATC automation in structured airspace using DRL. They initiated their work with the Deep Distributed Multi-Agent Reinforcement Learning (DD-MARL) framework. This framework employs an Actor-Critic model that integrates Proximal Policy Optimisation to stabilise the learning process. In particular, the training approach employs a centralised learning and decentralised execution strategy where one neural network is learned and shared by all agents. Proximal Policy Optimisation is a recent policy-based algorithm that utilizes a neural network to approximate both the policy (actor) and the value (critic) (Schulman et al., 2017). The observations in their studies include distance to the goal, aircraft speed, aircraft acceleration, a route identifier, and the loss of separation distance.

The Deep Distributed Multi-Agent Variable framework (D2MAV) further extends the DD-MARL framework by encoding intruder aircraft information using the Long Short-Term Memory network (Brittain and Wei, 2021). D2MAV-A is a newer variation that enhances D2MAV by replacing the Long Short-Term Memory networks with attention networks, improving the reward function, and adopting a parallel computing method. By utilizing attention networks, variable scalability can be managed with fewer computational resources (Brittain, Yang and Wei, 2020). D2MAV-A has been integrated with a safety module called Dropout and Data Augmentation (Guo, Brittain and Wei, 2021) to incorporate uncertainties, thereby enhancing the robustness of D2MAV-A.

All the aforementioned studies by Brittain and Wei consider homogeneous agents where all agents are optimising the same reward function. This assumption is lifted in the most recent study where a decentralized architecture with heterogeneous agents is considered. This is referred to as the Multi-Agent Autonomous

Separation Assurance (MAASA) framework (Brittain and Wei, 2022). In the MAASA framework, the intention learning model is also implemented for agents to predict the action of intruder aircrafts.

Areas for improvement in MARL for UTM

While Brittain and Wei's frameworks (DD-MARL, D2MAV, D2MAV-A, MAASA) demonstrate successful deconfliction in their case studies, questions arise regarding their applicability to more complex scenarios. Firstly, they only consider a 2D scenario where aircraft routes are predefined, and deviations from these routes are not permitted. This assumption limits the action spaces in their studies to three actions: decelerate, accelerate, and maintain constant velocity. As a result, these frameworks are unable to handle emergency mitigation. Secondly, an issue with N-nearest aircraft logic used in Brittain and Wei studies was noticed by Joris Mollinga et al. (2020). A minor change in the aircraft location may result in a different ordering of the N-nearest aircraft, leading to a different permutation. However, the neural networks should learn that these permutations represent nearly identical airspace conditions. This issue highlights a potential limitation in the learning capability of the models used in these studies.

There are many potentials for enhancing Brittain and Wei's framework (D2MAV, D2MAV-A, MAASA). Firstly, the action space could be expanded to include more actions in 3D space and incorporate actions related to emergency encounters. Brittain and Wei's use of the Actor-Critic model and Proximal Policy Optimization could be replaced with improved versions such as Asynchronous Advantage Actor-Critic (Simões, Lau and Paulo Reis, 2020) and Distributed Proximal Policy Optimization (Nicolas Heess et al., 2017). Additionally, novel concepts from the MADDPG family could be integrated into this framework to build a general-purpose multi-agent learning algorithm.

3.1.2. Control station HMI for AI tasked UAS

The rapid evolution and cost reduction in UAS technology has significantly expanded their civil applications. This trend includes not only single-drone operations but also complex missions involving fleets of drones, both in formation and swarm flights. The multi-UAS paradigm offers several advantages over single-drone deployments, including the ability to perform multiple simultaneous interventions, increased efficiency, complementarity in tasks, enhanced reliability through redundancy, improved safety, and cost efficiency. However, the success of these operations heavily depends on the quality of the Human-Machine Interface (HMI) used for their management, control and monitoring.

Despite the advantages of multi-UAS, safety remains a critical concern, particularly due to the high number of accidents attributed to operator errors, often stemming from poorly designed user interfaces (Cooke et al., 2006; McCarley and Wickens, 2004). Effective HMI design is crucial in mitigating these errors and enhancing the overall reliability of UAS operations. Human interaction with UAS can range from high to low levels of automation. High workloads are often dealt with manual control, whereas lower workloads are associated with autonomous mission execution. The level of automation directly influences operator performance. Therefore, innovative HMIs that deal with UASs with varying levels of automation are essential to reduce the negative impact of human errors and to improve mission success rates. Proper distribution of tasks between human operators and automated systems, addressing the lack of direct sensory input, ensuring efficient communication, preventing information overload, minimizing discomfort from simulation tools, and assisting in

maintaining situational awareness are all critical considerations. Effective HMI design should mitigate these factors by supporting clear and efficient communication between the operator and the UAS, particularly during mission planning and execution (Luongo, et al., 2019). A comprehensive analysis of the technologies utilized in HMIs for the command and control of UAS, along with the associated issues, can be found in Terwilliger et al. (2014) and (Vincenzi, et al., 2015).

Current HMIs exhibit several issues, including a lack of standardization, leading to extensive training requirements and poor transfer of skills between systems. Information presentation is often suboptimal, failing to support high-stakes decision-making. Furthermore, HMIs need greater adaptability to adjust to automation levels and enhance situational awareness. Sensory isolation due to the physical separation of operators from the aircraft exacerbates these challenges. A standard setup for small UAS involves two operators, one controlling manually with a handheld device and the other adjusting autonomous parameters on a laptop. However, this setup has limitations like reduced situational awareness and poor user interface design. Researchers at the Space and Naval Warfare Systems Center Pacific are developing the Multi-robot Operator Control Unit (MOCU) to address these issues (Stroumtsos, et al., 2013). MOCU aims to improve usability and interoperability across various unmanned systems, featuring a modular, flexible design, and an awareness and system safety. A more innovative control for UAS involves touch-sensitive portable devices like phones and tablets. A critical aspect of designing these HMIs is effectively presenting data within limited screen space while ensuring interactivity. A possible solution suggested in (Arhipainen, et al., 2013) is three-dimensional (3D) HMI, which could enhance user tasks. Researchers developed and evaluated a series of conceptual 3D HMI to better understand user experience. Their findings showed that context-aware service multitasking improves user interaction by simplifying and speeding it up. These insights are relevant for UAS controls, where reduced reaction time and enhanced situational awareness are crucial. A 3D HMI can help monitor map locations, telemetry data, and real-time video more effectively.

In the context of HMIs for UAS, the open-source projects of Ground Control Station (GCS) for commercial off-the-shelf autopilot systems (e.g., ArduPilot) are noteworthy for offering a range of functionalities tailored to different user preferences and levels of expertise. On desktop platforms, options like Mission Planner, APM Planner 2, MAVProxy, QGroundControl, UgCS, and LOGOS deliver comprehensive features such as 2D/3D map, mission planning, waypoint setting, telemetry data analysis, and parameter tuning. They supply to both novice and advanced users, allowing for customisation and fine-tuning of drone missions. For mobile devices, GCS apps like QGroundControl, Tower (formerly DroidPlanner 3), MAVPilot, AndroPilot, and SidePilot bring mission planning capabilities, real-time telemetry monitoring, and vehicle configuration options to users on the go (ArduPilot Documentation, 2024). These apps provide intuitive interfaces and support different features and functionalities, enhancing the user experience and facilitating seamless drone operations. However, these open-source GCS applications are generally geared towards UAS composed by GCS and one or few UASs with low autonomy, lacking advanced features for controlling and monitoring multiple drones simultaneously. These limitations hinder their use in professional, high-autonomy applications, especially in scenarios requiring complex coordination and sophisticated anti-collision systems. Consequently, recent efforts focus on developing advanced HMI for drone fleet traffic management.

In recent years, operations of highly automated or even autonomous UAS - potentially AI-tasked - in low-altitude airspace (Aweiss et al. 2018; Peinecke and Kuenz, 2017) are shifting away from the traditional human-in-the-loop paradigm, and ground-based operators directly control UAS flights, towards a supervisory control paradigm

known as human-on-the-loop (Pongsakornsathien, et al., 2021). This shift introduces the concept of UTM that is responsible for managing UAS air traffic, ensuring that routes are planned and executed with special attention to avoid no-fly zones and ensuring safe operations through Separation Assurance and Collision Avoidance (Kopardekar, et al., 2016) (Prevot, et al., 2016). In the context of UTM, the research presented by (Friedrich & Vollrath, 2021) is particularly relevant. This study focuses on developing an advanced HMI for monitoring safety risks in small urban UAS operations. Utilising Ecological Interface Design principles, the HMI enhances operator understanding by visualizing system constraints across various resolution levels while limiting display complexity. It supports parallel visual search with function-specific icons that change hues according to system states, facilitating quick identification of critical conditions. Emphasizing situational awareness, the HMI enables operators to effectively manage safety-critical failures. Another notable research by Feuerriegel et al. (2021) focuses on reducing latency in information exchanges between humans and UASs by developing an HMI featuring various views. This HMI presents a virtual world in both 2D and 3D for real-time flight monitoring, as well as a dedicated view for sensing.

In conclusion, the field of HMI for UAS fleet management has seen significant development, particularly with the emergence of open-source solutions. While these open-source solutions have made notable advances in sophistication, they still fall short in fully supporting the UTM paradigm. Undoubtedly, the concepts put forth by various studies in recent years are remarkable and hold promise for the future of UTM and UAS operations. Nevertheless, it is essential to recognize that these concepts require further optimization, which will lead to an effective commercial-level use, control and monitoring of AI-tasked UAS.

3.1.3. Flexible fleet and operations management

Operators of fleets of small delivery vehicles need a flexible solution for scheduling both delivery and Maintenance and Repair Operations (MRO). Traditional Operations Research (OR) methods as described below are too inflexible, require dedicated in-house expertise (usually at the PhD level) and even so, cannot guarantee satisfactory results.

Scheduling problems have always been a core part of operations and computer science research (Leung, 2004). Over the decades, this research has been applied to both industrial and service domains, including manufacturing (Frazzon et al., 2017), maintenance (Geurtsen et al., 2023), field service (Beniaminy et al., 2009), crew scheduling (Feng et al., 2023), and many others. In each scenario, the scheduling problem involves fulfilling the demand, which consists of operations, by assigning some or all of the operations to resources such as humans, machines, and tools - over certain time intervals. A solution to a scheduling problem must comply with problem-dependent constraints and solution quality is assessed by problem-specific objectives.

A substantial body of research exists for such scheduling problems, including methods from linear programming (He et al., 2020), heuristic search (Khare and Agrawal, 2021), genetic algorithms (Neumann et al., 2023), constraint programming (Fatemi-Anaraki et al., 2023), and beyond. However, the general-purpose mathematical nature of current approaches has limited the spread of OR in industry, since each industrial application, even if similar to a well-researched problem, has its own unique challenges. These challenges often involve additional problem dimensions. For example, in shop floor scheduling, there could be a need to plan not only for machines but also for operators and fixtures. Complications may also involve additional constraints,

like resource-specific time windows or variable constraints on resource allocation for each operation. They may also involve context-dependent operation characteristics, where the duration of one operation depends on the preceding task executed on the same machine.

Additionally, real-life problems require optimization of custom objectives, such as maximizing the value of operations that can be scheduled within a given time interval or optimizing multiple objectives (Zhao et al., 2022). In many OR cases, even when the problem is stated in an appropriate formalism, such as Mixed-Integer Linear Programming, available general-purpose solvers might struggle to identify an efficient or even a feasible solution within a reasonable amount of time. This leads to the need to revise the solution approach, such as developing custom heuristic algorithms (Camur et al., 2021) or utilising simulation modelling (Camur et al., 2023). Given these complications, development and implementation of a solution usually requires OR specialists to create and maintain custom code tailored to each application. This remains the case throughout the lifetime of the deployed solution, since problem characteristics almost always evolve over time and the code must be adapted accordingly. Therefore, broader impact and adoption of scheduling algorithms currently necessitates significant investment, cost justification, and dedicated OR experts. Recent efforts to solve OR problems are using AI/Machine Learning techniques. These techniques include reinforcement learning (Moerland et al., 2022), policy gradient learning (Paduraru & Dimitrakopoulos, 2019) and equation-free analyses (Samaey et al., 2008; Pu et al., 2021).

3.1.4. Safe automatic landing aids at Vertiports

The domain of new air mobility (New Air Mobility or Advanced Air Mobility) is a new aeronautical field based on the combination of technological breakthroughs in aviation (new aircraft configurations with vertical take-off and landing capacities, new propulsion system based either full electric or combining electric and thermal power sources and convertors) and new use cases such as urban air taxis, inter-city commuting, logistics transport or emergency medical transport drones. Traditionally, legacy aircraft & rotorcrafts are required to operate outside of cities due to major constraints in safety, noise and general environmental impacts on overflown populations. The different technical innovations brought by Advanced Air Mobility allow aerial transportation companies to redefine their operations by reducing the gap between major airfields and city centres, as well as by proposing new small aerial services previously incompatible with legacy aircraft.

New Air Mobility will thus require new infrastructures to allow it to be operated closer to end-users, compatible with these new VTOL aircraft. These "vertiports" will have to combine several main requirements (safety of aircraft, users and the environment, electric recharging capacities, or location inside cities and close to interconnections of other means of transport). To support the development of these new services while keeping its safety approach, EASA has been the first authority to release preliminary specifications for these vertiports in 2022 (EASA, 2022).

Following the EASA lead, several other authorities have released documents either on vertiports design or on VTOL operations, including in Australia (Civil Aviation Safety Authority, 2024), the United States (FAA Airports, 2024), and the United Kingdom (UK Civil Aviation Authority, 2023).

These different sources of information help to identify the main patterns of vertiports (size, distinctive signs from heliports) and the equipment and visual elements (markings, lightings, ground-based positioning system)

that could be available to help the aircraft to land on, take-off from and navigate around these vertiports. These definitions are mandatory to select the right perception systems and algorithms, either classical or AI-augmented, and ensure that the chosen solutions will be compatible with most future vertiports.

Another important aspect on these new platforms are the operational procedures and the equipment that can be embedded on of the new aircraft. EASA has been one of the first authorities to publish dedicated rules for VTOL, with the "Special Condition for small-category VTOL aircraft" released in July 2019, followed by the "Proposed Means of Compliance with the Special Condition VTOL" in June 2021. FAA released airworthiness criteria for specific projects (Joby & Archer) and in April 2023 to publish a general "Concept of Operations for UAM". These documents, followed by others from various authorities, have helped to progressively build general rules to design and operate such aircraft, thus defining the main means of compliance for advanced functions like a safe automatic landing capacity.

Vertiports are also largely inspired from current rotorcraft platforms (heliports), with similar approaches in terms of platform design, of dedicated approach, landing and taking-off corridors, as well as ground and light identification markings. To define a consistent autoland function and the associated equipment, the following operational documents can thus be used as a baseline:

- ICAO – Annex 14 – Aerodromes Vol II – Heliports Ed4, July 2013
- ICAO – PinS GNSS helicopter approaches to visual heliports (PANSOPS & Annex14 Vol II), April 2016
- ICAO – DOC8168 – Aircraft Operations Vol I – Flight procedures Ed6, 2018
- ICAO – PinS procedure Design Criteria (PANSOPS Helicopter), September 2020
- Helicopter Point in Space Operations in Controlled and Uncontrolled Airspace, generic safety case – Ed2.1, Eurocontrol, January 2023

Using such procedures may limit the technologies that can be used given associated minimum operational performance specifications, but it will ensure that proposed solutions are easier to demonstrate and will facilitate the integration of these new aircraft in the different considered airspaces.

One last important factor in designing a safe automatic landing function will be to provide appropriate navigation and perception systems for precision approach and landing systems in various environments (urban, suburban, regional). Several technologies can be used to this purpose:

- Airborne navigation systems using GNSS with spatial-based augmentation system, like EGNOS in Europe or WAAS in America (for example, RTCA/DO-229A describes the minimum operational performance specifications for such systems).
- Vision-based systems using either or both visible and infra-red wavelengths (Kawamura et al. 2021; Doer et al., 2020)
- Radar-based solutions (Doer et al., 2020) or existing products like the Tactical Automatic Landing System from Sierra Nevada Corporation.
- Ground-based systems relying on beacons detection (solution under patenting from SafranED)

It is noted, however, that the majority of existing literature focuses on small UAV applications; control laws to perform landing using existing equipment like GPS, Red Green Blue/ Infra-red camera or radar; and small

demonstrations. There is limited literature that deals directly with UAM size aircraft and Original Equipment Manufacturers (OEM).

3.2. Digital innovative ground maintenance technologies

3.2.1. Health management of landed aircraft

Integrated Vehicle Health Management (IVHM) involves sophisticated systems designed to enhance condition-based maintenance, reduce unplanned maintenance activities, and diminish associated costs. It functions by leveraging data from various subsystems of a vehicle to assess their health, their impact on each other, and on the vehicle, optimizing maintenance decisions and improving aircraft reliability and availability.

The essence of IVHM lies in its ability to integrate advanced technologies such as sensor technology, control and systems engineering, communications technology, and AI. Ezhilarasu et al. (2019) explored how reasoning technology has historically contributed to the growth of IVHM by reviewing various reasoning strategies, systems, their architectures, components, and applications in aerospace health monitoring (Ezhilarasu et al., 2019). Despite advancements, the field faces challenges, particularly at the vehicle level health monitoring where comprehensive integration across all systems and subsystems is crucial. The paper examines these challenges, presents solutions, and emphasises the necessity for further research in reasoning applications to maximise the capabilities of IVHM. The outcomes of this project will also contribute to the necessity of research in IVHM-based predictive maintenance operations.

With the growth in UAS operations, there is an evident need for IVHM. Koschlik et al. (2023) emphasise the development of an IVHM system that leverages multi-stakeholder digital twins for real-time health monitoring and data sharing across stakeholders, aiming to improve maintenance practices and ensure airworthiness (Koschlik et al., 2023). The paper proposes a close-loop operational procedure for UASs including continuous monitoring of the health state of the UAS and diagnosis based on data analysis. Another focus is acoustic monitoring, which detects irregularities in propeller blades and assesses their condition in a vertiport environment to provide efficient and integrated procedures. This vertiport is modular and features several sensors, cameras, and microphones. The digital architecture manages data flow from on-board and on-ground sources into the digital twin based on events. The study has a good potential to inspire the development of a monitoring mechanism for Di-PEGASUS.

In another study, Chang et al. (2019) discuss the integration of advanced technologies like AI, big data, blockchain, and digital twins into the commercial aviation industry to enhance maintenance support and health management. It emphasizes the digital transformation driven by the rapid advancements in electronic hardware, software, and computational power (Chang et al., 2019). The paper then discuss industry's movements towards digitalization, showcasing efforts by Airbus with its Skywise platform, Boeing's AnalytX, UTC Aerospace Systems-Collins Aerospace's new service products, and Rolls Royce's R2 Data Labs. These platforms aim to optimize operations, enhance predictive maintenance, and improve customer service through data integration and analysis. This study provides insights into the future of commercial aviation maintenance and support, advocating for a data-driven approach to achieve efficiency and innovation.

Another recent concept is MRO 4.0 (Khan, 2023). It refers to the integration of the fourth industrial revolution's technologies into the MRO processes within the aerospace, defence, and other sectors. This digital transformation aims to enhance operational efficiency, improve safety, reduce costs, and optimize the lifecycle management of assets through predictive maintenance, improved data sharing and analysis, and automation. MRO 4.0 utilises connected devices and smart technologies to enable real-time monitoring, condition-based maintenance, and more accurate, data-driven decision-making. It represents a shift from traditional, manually intensive MRO practices to more proactive, predictive, and automated processes, facilitating greater reliability and availability of assets while minimizing downtime and maintenance-related expenses.

The aviation industry also faces significant challenges due to the digital revolution in various operational areas. Schmücker et al. (2021) address the challenges and potential benefits of digital transformation in aviation maintenance focusing on the repair process of fibre-reinforced composite structures (Schmücker et al., 2021). It highlights the traditionally manual and paper-based processes prevalent in aircraft MRO, which lead to inefficiencies and limited interoperability. The authors defend a holistic digitalization approach, emphasizing the necessity of a unified data management concept to ensure consistency throughout the repair process. This vision for digital transformation encompasses not only the optimisation of individual process steps but also the collaborative involvement of all stakeholders in a digitally interconnected ecosystem. The paper underscores the importance of adopting the discussed technologies to facilitate a shift towards more sustainable, efficient, and data-driven maintenance practices in the aviation sector.

Another key concept is Structural Health Monitoring (SHM). It refers to the process of implementing, often in real-time, a damage detection and characterization strategy for engineering structures (Balageas Güemes, 2006). The core idea behind SHM is to diagnose the health/condition of a structure using data collected from different sensors embedded in or attached to the structure. These sensors measure parameters such as stress, vibration, temperature, or the presence of cracks or corrosion, which can point to a possible problem in the structural integrity and performance of the structure. SHM is vital for ensuring that landed UASs are maintained in a state that guarantees safe operation, optimizes maintenance routines, extends their usable life, and supports regulatory compliance.

In SHM context, Yagci et al. (2020) presents a SHM approach that uses digital twin to optimize the maintenance and operation of high-pressure turbine discs in civil aviation engines (Yagci et al., 2020). By integrating data from various engineering disciplines—such as thermodynamics, material science, and structural engineering—into a cohesive digital model, the authors aimed to closely monitor the low cycle fatigue life of turbine discs based on real operational data rather than relying on conservative estimates from designed flight profiles. The digital twin developed for the Rolls Royce BR725 aero engine, used in Gulfstream G650 aircraft, showcases the practical application of this SHM approach. It simulates engine conditions to predict the remaining useful life of the turbine discs, enabling more precise maintenance scheduling and potentially extending the components' service life.

Structural monitoring of composite materials is another significant issue because of their extensive use in UASs. Alvarez-Montoya et al. (2020) focused on advancing SHM through the development of an innovative health and usage monitoring system for UASs (Alvarez-Montoya et al., 2020). This system integrates fibre Bragg gratings into the composite material of a UAS's wing to monitor strain and detect damage in real-time during flight. Utilizing 20 fibre Bragg gratings embedded in the UAS's front spar, the authors implemented a miniaturised data

acquisition and a wireless transmission subsystem for remote sensing. The health and usage monitoring system were validated across 16 flights, employing a damage detection methodology that leverages strain field pattern recognition through a self-organizing map-based procedure for clustering operational conditions and principal component analysis for damage classification. This approach achieved high accuracy and F1 scores showing that the system is capable of automatically detecting damage under various flight conditions and types of damages.

Sadeghi et al. (2024) have also approached SHM, for the integration of Digital Twins (DTs) within the aviation industry, highlighting their key role in condition monitoring and fleet management (Sadeghi et al., 2024). DTs, defined as virtual representations of physical systems that use data to simulate and predict their conditions, are increasingly seen as a basis of the fourth industrial revolution's impact on aviation. Sadeghi et al.'s work (2024) points out the importance of DTs in enhancing aircraft reliability and safety while reducing maintenance and operational costs. They also explored various applications of DTs in the aviation sector, including real-time, accurate, and predictive condition monitoring methods. Despite the promising advancements, the paper acknowledges the challenges associated with DT implementation, such as data integration, standardisation, and ensuring interoperability among different data sources. It also outlines future trends, indicating a shift towards more intelligent systems that could revolutionise aircraft maintenance and support.

While SHM provides a continuous overview of structural health, identifying potential issues in real-time, non-destructive testing (NDT) offers a detailed and localised inspection required to confirm the presence and extent of anomalies. SHM and NDT form a comprehensive approach to structural integrity management ensuring that structures are monitored effectively and maintained efficiently. Tian (2023) explores the evolution and advancement of NDT methods critical for assessing the integrity of composite materials used in aerospace applications (Tian, 2023). With the aerospace industry's increasing reliance on carbon fibre composites for their superior mechanical strength, low density, and high fatigue resistance, the need for advanced NDT techniques becomes essential to detect potential defects that could affect the performance and safety of these structures. The review covers NDT methods such as visual inspection, resonance testing, acoustic emission, eddy current testing, ultrasonic testing, laser shearography, infra-red thermography, and X-ray. Each method's strengths and limitations are discussed, highlighting the challenges in detecting defects within the anisotropic nature of composite materials. The paper emphasizes the growing importance of developing hybrid NDT methods and deep-learning-based automated inspections to address these challenges. Proposed solutions include leveraging the synergies of different NDT techniques and employing machine learning algorithms for more efficient and accurate defect detection.

Considering these developments, it should be stated that traditional maintenance operations are transforming into more predictive and data-driven approaches, taking advantage of sophisticated sensor technologies, AI, digital twins and advanced data analytics. Di-PEGASUS will take the developments of SHM and NDT as a baseline and will increase the integration of these technologies to provide autonomous and cost-effective operations. The project will also explore novel solutions for the incorporation of data management concepts, ensuring uniformity and precision throughout maintenance and operational procedures. Finally, the project will push the boundaries of these technologies to propose a digital interconnected ecosystem to improve data-driven decision-making and digitally transformed processes. Consequently, Di-PEGASUS should also help address the challenges around regulatory issues and stakeholder participation in the aviation industry.

3.2.2. De-icing and biofouling mitigation strategies in vertiports/ water airports

Biofouling and ice formation are expected to affect vertiport and water airport infrastructure, depending on the operating conditions (e.g. operation in marine or aquatic environment) and weather conditions (e.g. sub-zero temperatures). Therefore, implementing de-icing and biofouling mitigation strategies is a crucial component of our project to ensure the safety and efficiency of these facilities.

Biofouling mitigation strategies

Biofouling is defined as the adhesion and growth of biological organisms on surfaces of manufactured structures submerged in a marine or aquatic environment. Biofouling formation consists of an initial algae biofilm adhesion on the surface and a macrofouling layer that consists of larger organisms such as barnacles, oysters and seaweed (Cao et al., 2011). Biofouling accumulation has adverse effects for underwater and marine structures. In ships, extended biofouling formation can increase drag and lead to a 40% increase in fuel consumption (Champ, 2000). It also adds weight to submerged structures, increasing the overall load exerted on the structure and decreasing the structure's fatigue life (Relini et al., 1998). In addition, the metabolic byproducts of the bioaccumulation organisms cause biocorrosion that degrades metal structures and materials, reducing their structural integrity and life-time expectancy (Videla, 2003; Habibi and Gan, 2016). Biofouling formation is a major issue in marine structures that needs to be addressed. Current biofouling cleaning methods are based on mechanical and abrasive tools and methods to remove the biofouling from immersed surfaces (Lindholdt et al., 2015). Abrasive cleaning deteriorates the structure surface and can remove protective coating from structural components, shortening their lifespan. In addition, current fouling control methods use biocidal antifouling coatings that are proven to be harmful to marine life and enter the food chain (Abbott et al., 2000, Almeida, Diamantino and de Sousa, 2007).

An alternative method that eliminates environmental pollution and does not abrade the structural parts, is based on the use of ultrasonic techniques. Ultrasonic antifouling systems use high power low frequency ultrasonic guided waves at the frequency range of 20-40kHz. Ultrasonic Probes are attached on the structure surface generating ultrasonic waves that propagate through the material causing mechanical micro-vibrations. This causes compression and expansion in the water (or the liquid that contains fouling micro-organisms) leading to cavitation bubbles that produce shock waves when they collapse, while increasing the temperature locally between 4000oC – 6000oC (Aghapour Aktij et al., 2020; Kohn, 2013; Ahmad et al., 2012). The cavitation bubbles disrupt the formation and attachment of fouling micro-organisms (i.e. algae) on the surface to be protected.

During wave propagation on a flat plate, optimum ultrasonic biofouling results are achieved through antisymmetric wave propagation mode (Carellan et al., 2014). Ultrasonic trials in marine environments over a period of 35 days indicated the effectiveness of sonification methods in preventing fouling formation and growth on the test plate (Habibi and Gan, 2016). Ultrasonic waves of 20kHz inhibit cyanobacteria and algae growth while disturbing cell cycle and division. Increased durations in the use of ultrasonic waves proved to decrease cell density and algae growth rates (Ahn et al., 2003). Similar results on the effectiveness of ultrasonic technology in preventing fouling have been also reported in other studies (Estévez-Calvar et al., 2018; Guo, Lee and Khoo, 2011).

Another method of removing marine biofilms from structures and anti-fouling coatings is the use of ultrasonically activated steam. This method removes biofilm accumulation without harming the structure or

damaging the coating surface, compared to the conventional high-pressure water blast cleaning methods (Salta et al., 2016). Additionally, the use of ultrasonic cavitation has been generally proven to be a promising method in preventing and cleaning biofouling accumulation on ship hulls (Park and Lee, 2018; Huang et al., 2024).

The use of ultrasonic waves can be used to prevent fouling growth at heat exchangers and convective heat transfer systems. Improved antifouling results were reported with increasing ultrasonic power. In addition, after ultrasonic treatment the fouling layers become looser and easier to remove (Hou et al., 2018). A different study by Geng et al. (2021) reported superior fouling mitigation performance by combining ultrasonic and electrolytic methods on heat transfer surfaces. The combined use of electrolytic and ultrasonic treatment was proved more effective when compared to using either of the two methods alone, and it can be reliably applied in real heat exchanger systems.

Multiple antifouling ultrasonic systems are commercially available and have been primarily developed for fouling prevention in ship hulls and yachts. Lead manufactures like Sonihull and Hasytec produce ultrasonic antifouling systems that rely on the use of high-power ultrasonic transducers that are attached on the surface to be protected. Different versions of their systems that are optimised for industrial use are also available (Sonihull, 2024; Hasytec, 2024). Another system that is used to control algae growth on surfaces submerged in water bodies such as lakes, ponds and reservoirs is the LG Sonic system. This technology is based on the use of high-power ultrasonic speakers that are submerged in water and emit ultrasonic waves. The ultrasonic waves disrupt the photosynthesis patterns of algae and stop algae growth without harming other aquatic lifeforms (LG Sonic, 2024).

De-icing strategies

Ice formation on airport and vertiport infrastructure, aprons and runways is an unavoidable phenomenon in sub-zero weather conditions that challenges the facilities' safe operation. Current de-icing techniques use heating, mechanical means such as snowblower trucks and manual labour, and de-icing liquids. De-icing liquids are commonly sprayed on aircraft and surfaces, but, even though they are effective in removing ice, they are proven to be harmful to the environment and aquatic life. Persistence of de-icing chemicals was found on soil and in ground water environment at abandoned airports even two years after any de-icing activities have stopped (Breedveld et al., 2003; Øvstedal and Wejden, 2007). In addition, de-icing chemicals can cause damage to runway lights, ground support equipment, and runway and aprons pavement. Due to prolonged exposure to de-icing liquids cracking, peeling and disintegration can occur on concrete pavements. Through open surface cracks, water can penetrate the concrete structure, causing further surface deterioration. In addition, during freezing conditions any water that filled the surface cracks freezes and expands, causing further surface deterioration of the pavement (Kozuba and Pil'a, 2019). To limit the use of harmful and toxic de-icing products, eco-friendly fillers have been developed for the construction of concrete pavement and road surfaces that can be potentially applied at vertiport runways, aprons and walkways. Eco-friendly asphalt mixtures cause the de-icing salts to migrate in the ice layer during condensation creating pores, reducing its strength and making it easier to break and remove (Meng et al., 2022). The use of superhydrophobic coating on asphalt and road surfaces can promote anti-icing and easier ice removal with minimal environmental impact. The use of hydrophobic coatings on road surface delays freezing times and decreases the adhesion strength of ice layers (Cui et al., 2024; Chen et al., 2018).

An innovative method to mitigate ice formation while limiting the use of harmful de-icing products is the use of ultrasonic techniques. Ultrasonic de-icing methods rely on the use of low frequency, high power ultrasonic guided waves that cause mechanical vibrations to break the adhesion between the ice and the treated surface (Rekuvienė et al., 2024). The generated ultrasonic waves propagate on the surface in the form of shear and Lamb waves. Interactions between shear wave propagation result in the secondary generation of harmonic longitudinal waves. These waves propagate on the interface between ice and plate surface causing interfacial transverse shear forces. When the generated shear stresses exerted on the ice/substrate interface are greater than the ice adhesion strength, the ice layer breaks and debonds (Wang, Xu and Huang, 2017; Tan et al., 2016). The damping losses of guided waves propagation cause local temperature increases on the material/ice interface, leading to ice melting in those areas. Water droplets are subsequently formed on the ice interface, where the collapse of cavitation micro bubbles contributes to the debonding of the ice layer. In general, the main contributing factor in ultrasonic de-icing is the micro vibrations caused by the generation of guided and Lamb waves on the material/ice interface (Wang, Xu and Huang, 2017). Ultrasonic de-icing methods are more effective and efficient compared to conventional heating de-icing methods as they can use ten times less power, while they result in faster ice debonding and removal times (Daniliuk et al., 2020).

Habibi et al. (2015) presented a de-icing approach for wind turbine blades that combines the use of ultrasonic waves and low frequency mechanical vibrations to prevent and remove ice layers. The methodology presented a modelling analysis to determine optimal ultrasonic frequency and transducer placement. Additional modelling analysis has been performed to evaluate the impact of low frequency mechanical vibrations on ice removal and to determine the optimum placement of shakers that will generate these accelerations without affecting the blade's fatigue life. Another study (Wang, Xu and Su, 2020) proposed a model to describe and assess ice detachment behaviour using ultrasonic waves and to predict the time required for ice removal. In addition, an ultrasonic de-icing system has been developed operating at frequencies greater than 20Hz with a power output of 440W. De-icing trials were carried out under laboratory conditions. Test results indicated that optimum de-icing performance is achieved at 34 kHz. Experimental results indicated that simultaneously with ultrasonic de-icing, crack formation was observed between the metal substrate and the ice layer. The crack density was rapidly increased and within 3 sec into the de-icing process, ice debonding has initiated. Further ice cracking and debonding evolution was observed during the de-icing test.

For increased de-icing effectiveness a combination of electrothermal and ultrasonic de-icing systems can be used. The synergetic effect of ultrasonic and heating systems reduced the required de-icing time by 59% compared to the electrothermal de-icing method alone. Therefore, the combined electrothermal ultrasonic method demonstrates great potential for applications where rapid ice-removal is required (Xu et al., 2024).

This section has discussed current biofouling and de-icing strategies and the issues arising from the utilisation of these methods on vertiport and water airport infrastructure. Innovative ultrasonic techniques offer promising alternatives to de-icing and antifouling methods, eliminating the use of biocidal paints and de-icing liquids that are harmful to the environment. The current review of state of art aligns with the Di-PEGASUS objectives for the development of novel, harmless and cost-effective de-icing and antibiofouling solutions for water airports and vertiports. In the next steps, ultrasonic antifouling and de-icing trials will be carried out in laboratory conditions on metal plates and materials used for the fabrication of vertiport and water airport structures. The performance and effectiveness of the ultrasonic system will be assessed, and the collected data will be analysed and

validated. Furthermore, based on the results, conclusions and recommendations for future and real-life applications will be derived and discussed.

3.2.3. Sustainable circular economy in aircraft and vertiports/water airports

The consequences of climate change have directed the scientific community to more sustainable and resource effective solutions in all sectors, including aviation. The adoption of Circular Economy policies can significantly contribute to this effort. Circular Economy focuses on reusing, recycling, and repurposing materials to significantly reduce waste and environmental impact. However, the aviation industry's current material management, recycling, and reuse processes are still underdeveloped, especially when it comes to more complex materials, such as composites. The transition to a more sustainable aviation system can be boosted by digitalisation. Digital technologies such as data mining, big data analytics, Internet of Things (IoT) and digital platforms can enhance the data collection, analysis and dissemination, optimise material flows and connect stakeholders interested in the recycling process.

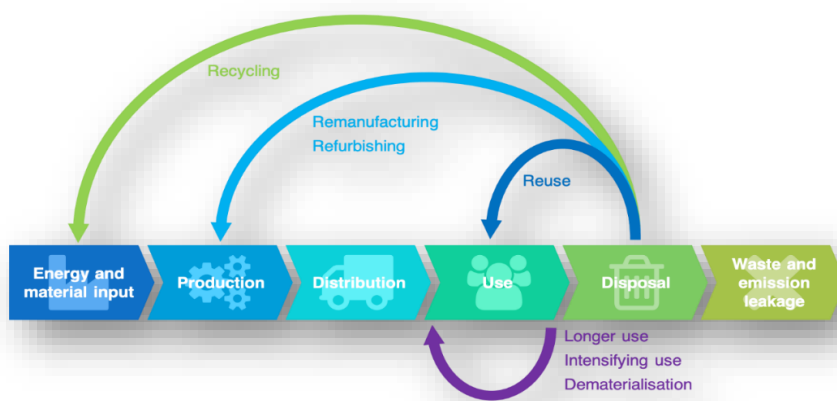


Figure 5 Circular Economy illustration (Fragkos, 2022)

The International Air Transport Association (IATA) reports that more than 15000 commercial aircraft have been retired between 1980 and 2015, and about 1000 aircraft are expected to be retired annually, with an average operational age of 26 years (SGI Aviation, 2018). As the number of retired aircraft increases, so does the volume of waste potentially ending up in landfills. Aircraft retiring today are mostly from the 1980s and 1990s, when most planes were constructed with metallic components. The metallic parts can be successfully recycled, a process well studied and managed by companies such as Boeing and Airbus. The production and decommissioning of aircraft make less than 1% of the emissions associated with their lifecycle and more than 99% of the emissions arise from their daily operation (Scholz, 2022). However, it remains crucial to establish a recycling framework to minimize environmental impact and prevent additional waste.

In the early 2000s, Airbus and Boeing made efforts to address the environmental challenges that come with the retirement of aircraft. Airbus led the Process for Advanced Management of End-of-Life Aircraft (PAMELA) project between 2005 and 2007. This project was the first to recycle an entire aircraft, successfully reclaiming and reusing up to 85% by weight of an Airbus A300. In 2007, Airbus and more shareholders established Tarmac Aerosave company, as an extension of the PAMELA project. To date, Tarmac Aerosave has recycled more than 300 aircraft, achieving a recovery rate of 92% of their total weight. (Wong et al., 2017; Tarmac Aerosave, 2023).

In 2015, Boeing with the Aircraft Fleet Recycling Association led the “ecoDemonstator” programme. Through ecoDemonstator, they managed to recycle a Boeing 757 commercial aircraft and reclaim 90% of its weight. Approximately half of the plane’s weight was repurposed as parts for other aircraft, while the remaining 40% was recycled for various other uses (Boeing, 2020).

The environmental and economic aspects of aircraft recycling have been recently studied by Scheelhaase et al. (2021). The researchers explain that aircraft recycling addresses environmental concerns and offers economic benefits simultaneously. Recycling can reduce costs associated with raw material extraction and processing, improving the economic viability of the aviation sector.

Today, nearly 50% of a modern aircraft’s weight comprises carbon composite materials. These composites enhance durability and reduce weight compared to the metallic components used in earlier decades. However, the recycling of composite materials remains underdeveloped and economically challenging. Although the first generation of aircraft mainly made from carbon composites is expected to retire in the next 10 to 20 years, the research community is already trying to build the framework of recycling these materials. Boeing aims to achieve 100% recycling of carbon waste, with zero composites ending up in landfills.

Considering that the most valuable parts, such as the engine, avionics, and landing gears, are already reused second-hand after specific maintenance operations, there are also various approaches to recycling or reusing the remaining aircraft assets. An example and recent study (Hyvärinen et al., 2023) has proposed a business model for closed-loop recycling of polymeric composite parts. A virgin polypropylene finger pinch shroud, utilized in the Airbus A350, was chosen as an illustrative product due to its basic shape, facilitating simple measurement and production. The study offered a complete recycling process, employing breaking down the part into component levels by melting or required reprocessing and discussing the pros and cons for original equipment and third-party manufacturers, and airlines. The authors have stated that recycling and regenerating parts with similar functions through the same material is feasible. They have also emphasized the challenging points related to the business model, including lack of experience in recycling materials, prejudice of customers to use recycled materials and regulatory problems.

UASs are primarily made of carbon composite materials to ensure they are as lightweight as possible. This design allows UASs to operate for longer durations, cover greater distances, carry more sensors, and contributes to the electromagnetic properties of the system. Other materials used are aluminium and plastic. Di-PEGASUS aims to study all materials used in UASs, vertiports, and water airports. It will explore methods to construct these systems using materials decommissioned from retired aircraft. By employing big data and data analytics, Di-PEGASUS aims to establish a methodology for efficient material reuse, while environmental and cost assessments will ensure the long-term sustainability of this approach.

3.3. Review of EU projects and links to Di-PEGASUS

This section provides a summary of completed and ongoing projects that are related to Di-PEGASUS. It is essential that these projects are identified both to draw lessons from them and build upon their work, but also to explore possible synergies. The summary included here will be expanded throughout the duration of the project as part of T6.2, which focuses on synergies with other EU initiatives towards European digital platforms. More specifically, as part of T6.2, Di-PEGASUS has started to establish an open discussion with related projects

and initiatives to develop a roadmap for joint actions relevant to the project's areas of focus and the technologies it will develop. The aim of this collaboration is to share and exchange knowledge, and disseminate results insights to citizens, businesses, and decision-makers across Europe and beyond. Table 1 includes the summary of related projects.

Table 1 Completed and ongoing EU projects related to Di-PEGASUS

Name of project	Short description of scope	How this relates to Di-Pegasus	Status
<u>SPATIO</u>	SPATIO (u-Space sePARaTION management) will research the U-space services addressing separation between UASs, in particular, strategic and tactical conflict resolution services and the relationship between separation and capacity in U-space airspaces. i.e., the relation with the Dynamic Capacity Management service.	The development of conflict detection and resolution for U-space will inform the aircraft and airspace digital technologies developed as part of Di-PEGASUS.	Ongoing (09/2023-08/2026)
<u>U-ELCOMÉ</u>	U-ELCOMÉ is aiming at the fully scalable market uptake of U1 and U2 U-space services through a set of tests and demonstrations in various operational environments and European locations. To do so, U-ELCOMÉ develops, tests and demonstrates SESAR solutions across 15 locations distributed in Spain, Italy and France.	Development of U1 and U2 U-Space services will inform the aircraft and airspace digital technologies developed as part of Di-PEGASUS.	Completed (11/2022-05/2025)
<u>CERTIFLIGHT</u>	CERTIFLIGHT proposes a new U-space service for the legal certification of tracks generated by UASs and aircrafts flights, through the introduction of a new disruptive EGNSS-IoT digital system.	Development of new U-Space service for the legal certification of tracks generated by UAS and aircraft flights will inform the aircraft and airspace digital technologies developed as part of Di-PEGASUS..	Completed (11/2022-05/2025)
<u>SHEPHERD</u>	The main objective of the SHEPHERD ("Standards Evaluation Project supporting European Regulations for Drones") project is to build upon the work performed by the AW-Drones project and complement the analysis previously performed to technically assess the suitability of the standards listed by AW-Drones.	The analysed standards may be of interest for the Di-PEGASUS project.	Completed (05/2022-05/2024)
<u>Fly2Plan</u>	Enabling a new model aviation data system-of-systems seeks to develop a new model for aviation data exchange to allow new entrants in	Development of a new model for data exchange can support the development of all	Completed (11/2020-03/2022)

	urban air mobility and autonomous operations to participate.	technologies developed as part of Di-PEGASUS as well as their future dissemination and implementation.	
<u>TAS-S</u>	The main objective is to develop fundamental secure autonomous systems covering both the technical and social aspects of security.	Secure and Autonomous system development that can inform the aircraft and airspace digital technologies developed as part of Di-PEGASUS.	Completed (11/2020-10/2024)
<u>GreenML5G</u>	The project investigated how to reduce energy expenditure for deep reinforcement learning modules. The overall output of the project is to create green machine learning algorithms for radio resource management.	The outputs of the project could inform the autonomous technologies developed as part of Di-PEGASUS.	Completed (04/2021-12/2023)
<u>MultiAcT</u>	A UK-Canada joint funded project that developed a UAS for the accurate and fast identification and location of defects in aircraft structures by non-contact means using active thermography.	Development of an unmanned maintenance system for grounded aircraft that could support the development of Di-PEGASUS technologies.	Completed (05/2018-05/2021)
<u>AMEC</u>	The Advanced Mobility Ecosystem Consortium (AMEC) is aiming to demonstrate the commercial and operational viability of Advanced Aerial Mobility in the UK. This is an efficient, electric mode of aerial transport complementary to existing transport infrastructure, helping to deliver both increased connectivity and net zero emission target.	Reference Advanced Aerial Mobility (AAM) operations, and demonstration of eVTOL aircraft.	Completed (07/2022 – 06/2024)
<u>AMU-LED</u>	AMU-LED is a Very Large-Scale Demonstration project funded by SESAR Joint Undertaking under the European Union's Horizon 2020 research and innovation programme that aims to demonstrate the safe integration of different types of manned and unmanned aircraft operations in urban environments to realise increasingly sustainable smart cities.	Reference of Unmanned aircraft operations in urban environments for Di-Pegasus's Use Case 2.	Completed (01/2021 – 02/2023)
<u>CORUS-XUAM</u>	The CORUS-XUAM project refine the U-space Concept of Operation for U-space (UTM in	Reference architecture describing the	Completed

	Europe) and extend it to address the Urban Air Mobility (UAM). Six Very Large Demonstrations (VLD) campaigns in seven different European locations were conducted in the project.	advanced services integrating a U-space ConOps for Urban Air Mobility (UAM) flight operations.	(01/2021 - 04/2023)
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3.4. Knowledge base summary

Table 2 provides a summary of the knowledge base outlined in the above sections, including a description of the methods used for the review, and the next steps for Di-PEGASUS in relation to each of the technologies to be developed.

Table 2 Knowledge base summary

Technology	Short description of the method(s) used for the state-of-the-art review	Main findings from the state-of-the-art review	Next steps for Di-PEGASUS
Swarm intelligence for multi-agent behaviour	The state-of-the-art review was based on a technical review of recent AI trends, a case study on existing EU projects, and a comparison with traditional air traffic management solutions in manned aviation.	Current AI research in aviation is in its early stages, with unrealistic assumptions and limited generalization. A significant gap exists in research on MAS under strict UTM regulations. MARL using DRL is the leading AI technique for MAS.	Establish an AI-integrated software framework to enable rapid development and testing of new algorithms for multi-agent systems. The framework shall be generalized and extendable to different airspace regulation and use cases.
Control station HMI for AI tasked UAS	The method used for the state-of-the-art review involved a comprehensive analysis of recent and relevant literature on HMI systems for UAS. The review focused on identifying key advancements, challenges, and trends in HMI design for multi-UAS operations,	The state-of-the-art review highlights the critical role of effective HMIs in managing multi-UAS operations, emphasizing that poor design leads to operator errors and accidents. Current HMIs face challenges like lack of standardization, limited adaptability, and suboptimal situational	The HMI to be developed will focus on addressing the challenges of enabling a single operator to control multiple autonomous UAS, driven by AI systems. To achieve this, the key priorities will be enhancing the operator's situational awareness and ensuring efficient,

	including both open-source and proprietary solutions. It also examined the evolution from traditional human-in-the-loop to human-on-the-loop control paradigms in the context of UAS UTM.	awareness. While open-source GCS software offers useful features, it lacks the sophistication needed for advanced multi-UAS management. The shift to the human-on-the-loop paradigm, especially in UTM, demands innovative HMI solutions. Despite progress, further optimization is needed for effective commercial application, particularly in AI-driven UAS operations.	straightforward management of the drone fleet. The graphical interface will incorporate cutting-edge design principles used in modern apps, ensuring it is both intuitive and responsive.
Flexible fleet and operations management	The state-of-the-art review was based on a thorough analysis of existing literature and technical reports, as well as insights from industry best practice.	Overall, fleet and operations management present significant challenges in being fully digitised and automated, due to the unique characteristics of different operations. This means that optimisation of algorithms requires tailoring to local circumstances and substantial effort to do so, which is often not possible or efficient. This leads to operations usually not being fully automated, and performed on a site-by-site basis.	The next steps include developing set of software services to optimise resource allocation and use, including aircraft and ground infrastructure. In addition, to validate these services, a simulation-based environment will be considered.
Safe automatic landing aids at Vertiports	Analysis of existing regulation on vertiport design and approach/landing procedures, and desktop search on	Initial documentation on vertiport and eVTOL operations derive mainly from legacy documents and procedures on	Discussion with ADP (and other stakeholders of Paris AAM ecosystem) on the requirements for safe

	recent autolandings techniques and perception means.	helicopter flight operations.	automatic landing aids at vertiports and review of real-life applications.
Health management of landed aircraft	<p>The state-of-the-art review included an examination of recent developments in IVHM, SHM, and NDT. Historical and contemporary strategies on the latest developments in digital transformation for aircraft maintenance, regulatory frameworks and the use of AI, big data, digital twins, and sensors have been investigated.</p>	<ol style="list-style-type: none"> 1. Advancements in IVHM: IVHM has a significant improvement to provide high level reliability for aircraft through optimisation of maintenance procedures, using key developments of AI, digital twins, and big data analytics, which facilitate predictive maintenance and operational efficiency. 2. Digital Transformation Trends: Industrial players in aviation have pioneered digitalising their revolutionised maintenance, repair, and overhaul processes under the context of MRO 4.0. 3. SHM and NDT: Through real-time defect detection systems using hybrid methods and machine learning, SHM and NDT approaches have provided a synergistic effect to monitor structural integrity. 4. Regulatory and Stakeholder Engagement: Multi-stakeholder collaboration is crucial for the efficient application of IVHM or SHM systems, to ensure interoperability 	<ol style="list-style-type: none"> 1. Identifying the KPIs for digital and cutting-edge ground maintenance systems. 2. Seeking an optimal system-level ground maintenance architecture using the developments of IVHM and SHM experiences. 3. Evaluating the possible solutions for an innovative ground maintenance structure and discussing proposed KPIs and architecture.

		and standardization of different data sources.	
De-icing and biofouling mitigation strategies in vertiports/ water airports	The state-of-the-art review was based on a thorough analysis of latest literature, guidance and results of experiments and trials of antifouling and de-icing methods.	<p><i>Antifouling methods</i></p> <ul style="list-style-type: none"> -Abrasive cleaning methods deteriorate the structure's surface and can remove protective coating from structural components. -Biocidal paints are effective against biofouling formation but are harmful to marine life and enter food chain. -Ultrasonic antifouling methods prevent the formation of biofouling and causes no damage to the surface to be protected. Ultrasonic methods are eco-friendly alternatives to conventional methods, and they can reduce the use of harmful biocidal coatings. <p><i>De-icing methods</i></p> <ul style="list-style-type: none"> -De-icing liquids are effective in mitigating ice formation but are harmful to the environment and can cause damage to runway lights, ground support equipment, and runway and aprons pavements. - Eco-friendly asphalt mixtures cause de-icing salts to migrate in the ice 	<ul style="list-style-type: none"> -Ultrasonic antifouling and de-icing trials will be carried out in laboratory conditions on metal plates and materials used for the fabrication of vertiport and water airport structures. -The performance and effectiveness of the ultrasonic system will be assessed, and the collected data will be analysed and validated. -Conclusions and recommendations for future and real-life applications will be derived and discussed.

		<p>layer interface during condensation creating pores. The adhesion strength of ice is reduced, making it easier to break and remove.</p> <p>- Hydrophobic coatings delays freezing times, and decreases the adhesion strength of ice layers. Hydrophobic coatings promote anti-icing and easier ice removal with minimal environmental impact.</p> <p>-Ultrasonic guided waves cause the ice layer to break and debond of the surface. In addition, ultrasonic wave damping cause local temperature increases that result in local ice melting. Ultrasonic methods are eco-friendly alternatives to conventional methods, as they use less power compared to electric heating, and can reduce the use of environmentally harmful de-icing liquids.</p>	
<p>Sustainable circular economy in aircraft and vertiports/ water airports</p>	<p>The state-of-the-art review was conducted through an analysis of relevant academic literature, industry reports, and case studies focusing on aircraft recycling and circular economy</p>	<p>The review revealed that while the recycling of metallic aircraft components is well-established and managed by companies like Boeing and Airbus, the recycling of composite materials is still in its infancy. Modern</p>	<p>Di-PEGASUS will explore methods to reuse materials from retired aircraft in UASs, vertiports, and water airports. The project will focus on establishing a sustainable recycling framework, improving</p>

	<p>practices, with an emphasis on metallic and composite materials.</p>	<p>aircraft are increasingly composed of carbon composites, which present unique challenges due to their complex structure. The review also identified regulatory and market challenges, such as customer reluctance to use recycled materials, which must be addressed to advance sustainable practices in the aviation industry.</p>	<p>material recovery rates, and ensuring the environmental and economic viability of these approaches.</p>
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4. STAKEHOLDERS' REQUIREMENTS

For this task the Di-PEGASUS team engaged with stakeholders who are both prosumers and end-users of the Di-PEGASUS technologies in order to identify and analyse their needs, requirements, concerns, barriers, and opportunities. The engagement considered the technical, business, social, and legislative aspects underpinning the transformative technologies that will be developed as part of Di-PEGASUS, and how these fit within the wider context of UAM, and the seaplane and drone markets.

4.1. Methodology

The following sections describe the methodology followed to identify the relevant stakeholders and draw out their requirements in relation to the new technologies that will be developed as part of Di-PEGASUS. Table 3 summarises the methods and activities described in Sections 3.1.1 and 3.1.2. As shown, the data collection was organised around the modes to which the new technologies relate.

As part of the engagement, all participants were informed that they will be contacted again in later phases of the project to discuss the technologies developed in real use cases (WP5). As such, this phase was also essential for building good connections with the participants, gaining their interest and trust, and establishing collaborative relationships wherever this seemed appropriate. In order to establish these connections with stakeholders, especially when they were engaged in person through interviews or workshops, the discussions were broadened to cover the wider technical, business, social, and legislative contexts where drones, seaplanes, and UAM aircraft operate. As such, the data collected will also contribute to later tasks and deliverables and is already helping to shape up the work on businesses models for the new technologies that will be developed as part of Di-PEGASUS (T1.5).

Table 3 Stakeholder identification and data collection methods

	Drones (Italian use case led by DBL)	Seaplanes (Greek use case led by UAGEAN)	UAM (French use case led by SAFRAN)
Relevant technologies	<ol style="list-style-type: none"> Swarm intelligence for multi-agent behaviour New generation control station HMI for AI tasked UAS Flexible fleet and operation management software 	<ol style="list-style-type: none"> Flexible fleet and operation management software Health management of landed aircraft tool De-icing and biofouling mitigation technologies Sustainable Circular Economy framework 	<ol style="list-style-type: none"> Auto-landing aid at vertiports Health management of landed aircraft tool De-icing and biofouling mitigation technologies Sustainable Circular Economy framework
Stakeholders identified	Industry representatives SMEs Drone operators Research Engineers Airports Emilia Romagna region	Seaplane operators Seaplane manufacturers Water airport operators Government officials	Government officials Regulators Airports Public transport operators Vertiport operators
Data collection methods	Workshop	Interviews Questionnaires	Interviews

4.1.1. Stakeholder identification

In order to make best use of the available resources and connections, the stakeholder identification process was led by each use case leader, focusing on drone, seaplane and UAM aircraft technologies. Each leader set out a stakeholder identification plan aimed at drawing from local knowledge in the use case locations as well as internationally. The first stakeholders contacted were direct contacts of consortium members, followed by stakeholders identified through desk research and snowballing. The following sections provide a detailed description of the approach taken for each type of technology.

Drone technologies

Deep Blue and ITL, as main contributors to the planning and execution of the Italian use case on the usage of drone technologies for transportation of goods in region Emilia-Romagna, collaborated to identify representative stakeholders for a workshop, held in Bologna on May 27th, 2024. The identification of the most significant stakeholders has been conducted in a collaborative way, with an initial brainstorming involving team members of Deep Blue and ITL, followed by a number of informal bilateral meetings (including in-person conversations at the TRA conference in Dublin, April 2024). The need to have a wide coverage of the whole drone-based goods transport value chain has been met by the final attendees of the workshop, whose characteristics are listed in Table 4 below.

Table 4 Characteristics of stakeholders who attended the workshop on drone technology requirements

Company /Affiliation	Type of stakeholder
Deep Blue	Project partner
EuroUSC-Italia	Project partner
ITL	Project partner
UPS Italia	Logistics Industry
Bologna Airport	Airport Operator
TAUA Tech	SME, Electronic Design and Production
Zephyr Aerospace	SME, Services and consultancy in the field of UAS
Metaprojects	Private Research Centre, UAS Operator
MECH-Clust ER	Mechatronics and Motors Cluster of the Emilia-Romagna Region

The involvement of potential users from various business sectors and producers of drone-related technologies, alongside public stakeholders from the Emilia-Romagna region, ensured comprehensive coverage of all necessary stakeholder categories for this stage of the project.

Seaplane technologies

To identify the relevant stakeholders for the seaplane and water airport technologies, the teams UAEGEAN and MH carried out a short stakeholder mapping exercise, ensuring that they could provide input related to the technical, business, social, and legislative aspects of each technology. It is noted that the stakeholder mapping exercise was complemented by the consortium workshops, described later in this section.

The initial stakeholder mapping exercise identified four groups of stakeholders: seaplane operators, seaplane manufacturers, water airport operators, and government officials. All stakeholders were invited by email in a formal invitation, which was accompanied by an information letter and consent form about the Di-PEGASUS

project, outlining their expected input and how it is going to be used (the information letter, consent form, and list of questions used for the interviews are provided in Appendix A). The stakeholders contacted covered both the Greek market and international seaplane operations. The first group of stakeholders that were contacted drew from the existing pools of contacts of UAEGEAN and MH. The stakeholders contacted later were recommended by the participants or were identified through further research and mapping. The characteristics of the stakeholders who were eventually interviewed are summarised in Table 5. It is noted that 3 of these stakeholders were based in Greece, and 5 represented organisations based in Asia, Europe and the Americas.

Table 5 Interviewed stakeholders for the seaplane and water airports technologies

Type of organisation	Role	Expertise						
		Ground operations	Passenger	Freight	Technical	Regulatory	Business	Governance
Seaplane operator	CEO							
Seaplane operator	Ground operations manager							
Water airport operator	President							
Seaplane operator	Head of Corporate Strategy							
Seaplane operator	President							
Seaplane operator	CEO							
Seaplane operator	Consultant							
Seaplane manufacturer	Head of Sales and Marketing							

UAM and vertiport technologies

The UAM Use Case selected for Di-PEGASUS is fully aligned with a French UAM initiative called “Paris Region AAM (Advanced Air Mobility) Alliance”. This initiative, initially named “ReInvent Air Mobility”, has been launched in 2020 by Paris Region, ADP Group (Paris Airports operator) and RATP (the French public urban transport operator). This UAM alliance is an industrial and academic ecosystem around the eVTOL market. Safran Electronics & Defense, which leads the UAM Use Case in Di-PEGASUS, belongs to the 30 partners which have been selected in this Alliance. The Paris Region AAM Alliance is a comprehensive community which covers the full spectrum of activities related to UAM use cases: air services operators, ground/ urban infrastructure manufacturers and operators, aircraft manufacturers, technology providers, academic partners and institutional stakeholders (contributing to public acceptance studies).

The activities performed by the partners of this Alliance address the main challenges for the development of the UAM market, including acceptability, safety and qualification of uses. A series of commissioning activities and flight test campaigns are carried out by the partners of this Alliance on several contributing UAM topics: noise impact, integration into airspace (UTM and conventional ATM), maintenance and recharging operations, passenger routes, anti-collision. As such, this set of stakeholders is expected to provide essential and

comprehensive feedback regarding the requirements for UAM and vertiport technologies, when the data collection is concluded.

Di-PEGASUS Consortium workshops

In addition to the stakeholder identification that was carried out in each pilot location as part of this deliverable, further progress was made during the Di-PEGASUS consortium meeting in Thessaloniki on 4 June 2024. More specifically, EUROUSC organised a workshop that aimed to familiarise the consortium members with the upcoming use cases, and identify stakeholders and change agents, challenges and required resources, and an action plan for each use case. The first part of this exercise involved identifying the stakeholders related to each use case and rating them according to their knowledge/ expertise and influence. The stakeholders identified are included in Figures 6-8.

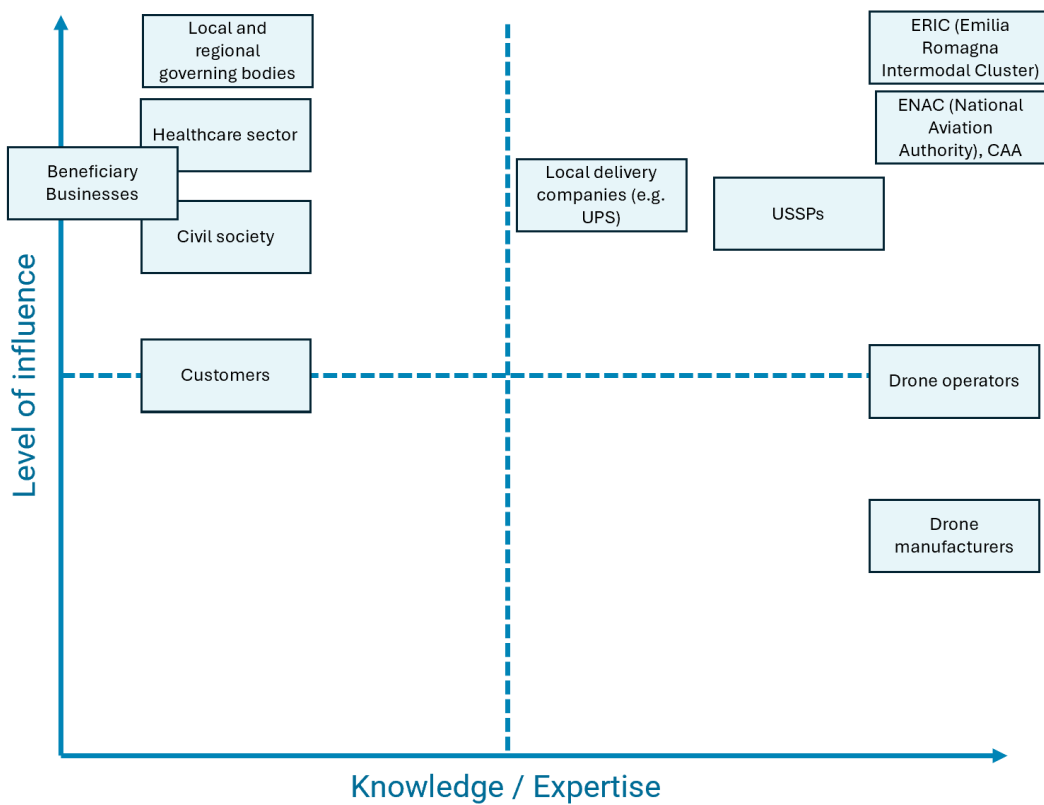


Figure 6: Stakeholders identified for drone technologies focusing on use case 1- Italy

Note: USSPs stands for U-Space Service Providers, CAA stands for Civil Aviation Authority

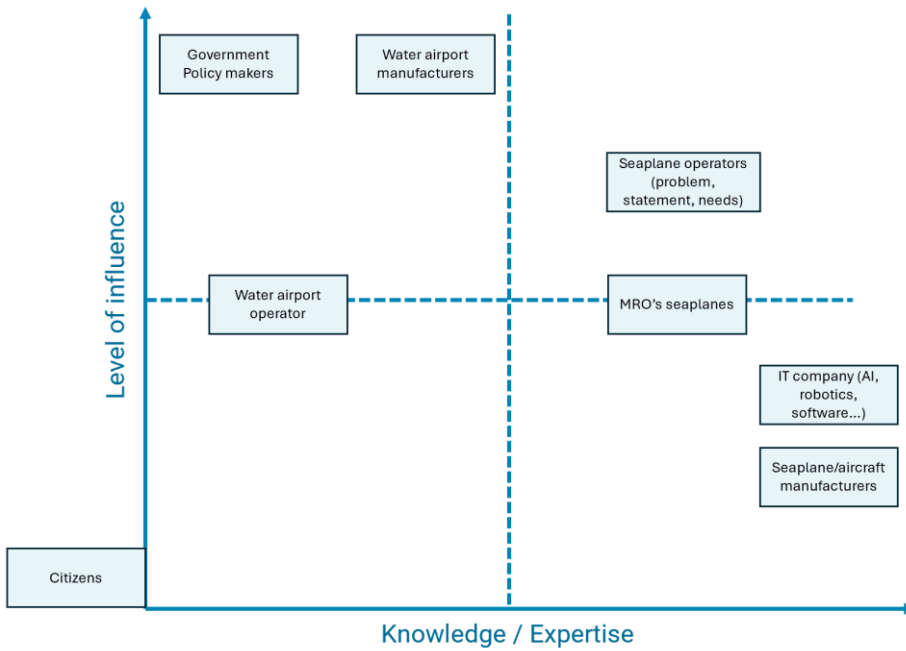


Figure 7 Stakeholders identified for seaplane technologies focusing on use case 2 - Greece

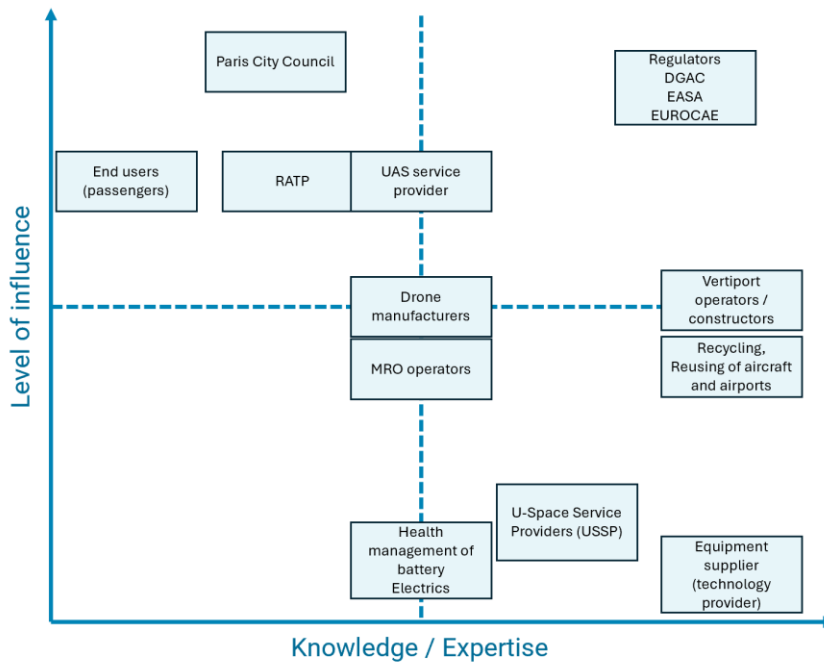


Figure 8 Stakeholders identified for UAM technologies focusing on use case 3 – France

Note: DGAC stands for Direction générale de l'aviation civile or General Directorate for Civil Aviation; EASA stands for European Union Aviation Safety Agency; EUROCAE stands for European Organisation for Civil Aviation Equipment.

The workshop indicated that citizen and passengers are the less important stakeholders for all the three use cases, which can be explained by the fact that passengers are not expected to directly interact with the Di-PEGASUS technologies. However, the regulatory bodies were found to be the most important ones. Moreover, for the Italian use case, the involvement of the local delivery companies and the Emilia Romagna Intermodal Cluster seems crucial for the use case implementation. On the other hand, seaplane operators play a key role for the Greek use case. The local and regional governing bodies are considered as stakeholders with a high level of influence but little expertise in the drone/ seaplane/ UAM vehicle sectors. By contrast, manufacturers are considered very experienced but with little influence. Similarly, operators are considered stakeholders with a high level of knowledge and with a medium level of influence, greater than the manufacturers but not as powerful as the authorities.

Overall, the workshop further stressed the need to maintain the engagement with local and international stakeholders, both to validate the new technologies against their requirements, but also to disseminate the technologies and ensure they can be successfully integrated in the aviation market through viable business models. While this exercise is meant to inform future stages of Di-PEGASUS, it provided valuable validation of the contacts that were made to identify the requirements included in this report. Further stakeholders identified as part of this exercise will be considered going forward, to ensure that the use cases take a holistic approach when examining how the new technologies developed as part of Di-PEGASUS can be promoted through different business models and fit within different contexts. The full outputs of the exercise can be found in Appendix B.

4.1.2. Data collection

The data was collected through a variety of methods, depending on the type of stakeholder that was engaged with, and the level of input they offered. It is noted that in some cases there was less interest than expected from stakeholders. In order to ensure that there are no gaps in the requirements gathered, where necessary the input in Section 3.1.2 has been strengthened using information from the literature, with a particular focus on developments that have happened over the last two years.

Drone technologies

On 27th May 2024, ITL and DBL organised a workshop with Italian stakeholders focusing on innovative strategies for drone deliveries in the Emilia-Romagna region, attended by fifteen participants¹. The workshop aimed at bringing together the Di-PEGASUS technologies' potential prosumers and end-users, including citizens and local administrators, to discuss the challenges and opportunities of drone deliveries, and at establishing a direct dialogue between stakeholders and the Di-PEGASUS partners. The discussion, based on the Italian Di-PEGASUS use case in Emilia-Romagna, focused on:

- The development of digital technologies that enable fully autonomous cost-effective and environmentally friendly aircraft operations in low altitude airspace;

¹ For more information see: <https://research.dblue.it/di-pegasus/workshop/> and <https://research.dblue.it/di-pegasus/2024/02/20/workshop-di-pegasus/>

- The development of digital technologies that enable cost-effective and environmentally friendly aircraft ground operations;
- The definition of the necessary prerequisites for the development of such technologies.

The workshop was divided in three parts:

1. Introduction of Di-PEGASUS to the stakeholders with a focus on the relevant technologies for the Italian use case;
2. An interactive session with stakeholders to gather their input and feedback on the implementation of the technologies discussed, based on a questionnaire with specific points to be addressed for the Italian use case, which was developed for this specific occasion by the Di-PEGASUS technical partners. The interactive session was divided into 2 parts:
 - a. A session facilitated by the interactive tool Mentimeter to gather feedback from participants about the general usability of drones for goods delivery, as well as overall issues related to drone operations (i.e. fleet composition, drone control and monitoring, simultaneous drone operations and delivery operations automation and simulation);
 - b. A brainwalking session on three specific topics, namely fleet composition, drone control and operations. For each topic, a poster was prepared with more precise questions to be addressed. Participants were walking through the posters and adding their input by using sticky-notes. At each poster, a facilitator (DBL and EuroUSC) was guiding the discussion and stimulating an exchange between participants.
3. A networking session, where stakeholders introduced themselves and their organisations and discussed possible collaborations and synergies with Di-PEGASUS project.

The results of interactive Session 2a are available in Appendix C, while the outcomes of interactive Session 2b are reported in the form of stakeholders' needs and expectations in Section 4.2 of this document.

Seaplane technologies

The data collection for the seaplane technologies is organised in two parts, reflecting the type of input expected from the stakeholders involved. These parts were:

- One-to-one interviews
- Technical questionnaires

The first part involved one-to-one stakeholder interviews with Greek and international seaplane and water airport operators, and seaplane manufacturers. A total of 6 interviews took place with 8 participants, all of which were senior-level stakeholders from 1 seaplane manufacturer, 1 water airport operator, 4 seaplane operators. These were carried out by UAEGEAN and MH and were in-depth, semi-structured interviews that lasted on average one hour. The interviews with Greek stakeholders took place in person in Athens, while the rest were organised online. The interviews with Greek stakeholders were carried out in Greek. In order to facilitate the interview process, the participants were given the option to receive the interview questionnaire in advance. Participants were asked to elaborate on their answers where this was considered necessary, offering rich background information on the seaplane business and operations across the world. It is noted that those participants who

agreed to participate were sent a consent form prepared by UAEGEAN and approved by EUROUSC, which they signed ahead of their interview (a blank copy is provided in Appendix A). Finally, in order to draw out the requirements, each interview was transcribed and imported in the computer-assisted qualitative data analysis software NVivo. The text was then coded using an inductive method using as nodes the types of requirements sought.

The characteristics of the stakeholders that were interviewed are included in Table 4. All participants held senior roles and had extensive managerial experience in their organisations or their fields. However, they were not always able to respond to detailed technical questions about the new technologies that will be developed as part of Di-PEGASUS, which meant that their input had to be complemented by technical experts.

The second part of data collection involved two detailed technical questionnaires that were focused on the innovative de-icing and biofouling mitigation methods, and the flexible fleet and operations management services to be developed in WP2 and WP3. The questionnaires were developed collaboratively by CERTH, NUREGO, MH and UAEGEAN, with UAEGEAN coordinating the process to ensure consistency. The two questionnaires are provided in Appendix D. The questionnaires were given to all interviewees included in Table 4 (only one interviewee was not given the questionnaire about the flexible fleet and operations management services as it was not relevant to them). In addition, the technical questionnaire on the innovative de-icing and biofouling mitigation methods was sent out to 24 water airports and seaplane operators across the world. As explained above, the response rates were lower than expected and only 2 responses were received (both for the flexible fleet and operations management services). As such, Section 3.2 explains in detail how any potential gaps have been covered.

UAM technologies

Safran disseminated a survey (Appendix E) that covers both business and technological topics in relation to UAM technologies. The results of this survey were complemented by interviews and discussions between Safran and ADP.

4.2. Requirements for drone technologies

The “brainwalking” session of the stakeholders’ workshop for the Italian use case (see section 4.1.2) has been used to elicit high-level needs and requirements for the development of innovative drone-based technologies for the transportation of goods that will be developed in WP2 and WP3.

The following subsections outline the needs and requirements that emerged during the workshop. The list is not meant to be exhaustive, but it represents a good picture of the priorities and main challenges identified by the stakeholders at the current stage of the project.

4.2.1. Fleet composition

This section outlines the insight gained on the topic of fleet composition, which comprised three exercises. In Exercise 1, participants were asked to imagine the optimal fleet composition in terms of payload capacities. As shown in Table 6, the participants’ responses showed that the ideal fleet would be composed by few heavy duty drones, some large drones and many small and medium drones.

Table 6 Fleet composition Exercise 1 - Optimal fleet composition

Payload capacity	Quantity in the fleet			
	None	Few <10% of the fleet	Some 10% to 40% of the fleet	Majority >40% of the fleet
Small (<1 kg)			X X	X X X
Medium (2-5 kg)				X X X X X
Large (5-10 kg)		X X X	X X X X X X	X
Heavy-duty (>20 kg)		X X X	X X X X	X

In Exercise 2, the participants were asked to define the optimal range for drones in the fleet and how many of each would be needed in each case. According to their responses, shown in Table 7, an optimal fleet would be composed by: few ultra-long range drones, some long and extra-long range drones and many short and medium range drones.

Table 7 Fleet composition Exercise 2 - Percentage of fleet composition

	Percentage of fleet composition			
	None	Few (<10%)	Some (10-40%)	Many (>40%)
Short range (<10 km)		X X	X	X X X X X X
Medium (<20 km)		X		X X X X
Long (<50 km)			X X X X X	X
Extra-long (<100 km)		X X	X X X	
Ultra-long (>100 km)		X X X X		

Finally, in Exercise 3, the participants were asked to indicate for each range class, what would be the typical delivery frequencies. As shown in Table 8, short range would be used very frequently, while medium range average frequently and long, extra and ultra-long range would not be used very often.

Table 8 Fleet composition Exercise 3 - Typical delivery frequencies

	Very frequent	Average frequency	Infrequent
Short range (<10 km)	X X X X X X X	X	
Medium (<20 km)	X X	X X X X X X X	
Long (<50 km)	X	X X	X X X

This section presents the requirements identified on the topic of drone operations, which comprised 2 exercises. In Exercise 1 the participants were asked what factors would influence their decision to group multiple drone flights. The list below shows the available responses, with those in bold being the most preferred.

1. Possibility to deliver simultaneously all the items in an order.
2. **Simplification of flight and delivery operations (e.g. file one flight plan to air traffic control as opposed to multiple plans one for each drone, group deliveries to same area/location).**
3. **Reduced number of operators required for monitoring/ controlling the flights (e.g. one operator monitoring/ controlling the group as opposed to dedicated operators for each drone).**
4. Reduced fuel/ battery usage (e.g. flying in formation to reduce aerodynamic drag).
5. Reduced environmental impact.
6. Possibility to deliver large goods by means of multiple drones.
7. Other (please specify): The participants wrote "to guarantee the delivery, security and resilience" and "(transporting) lifesaving drugs".

In Exercise 2 the participants were asked about the innovative solutions that could have a significantly positive impact on different delivery operations. Table 9 summarises the participants' contributions.

Table 9 Innovative solutions that could have a significantly positive impact on different delivery operations

Areas of focus	Innovative solutions
Supply chain (parts, materials, equipment)	<ul style="list-style-type: none"> • Transport of dangerous goods (e.g. radioactive drugs) • Decommissioning of maritime oil & gas platforms
Maintenance (scheduled)	<ul style="list-style-type: none"> • Periodical check of big photovoltaic generators (e.g. checking cell status) • Check of marine water quality (sea pollution monitoring)
Repair (unscheduled)	<ul style="list-style-type: none"> • Pipes check for water loss analysis • Roofs checking (looking for cracks and climatic dispersions)
Ordering	<ul style="list-style-type: none"> • Regulatory harmonisation • Controlled reception areas
Integration of new equipment/ parts	<ul style="list-style-type: none"> • Control Systems: <ul style="list-style-type: none"> ○ Hanging loads ○ Quicker delivery ○ Safer ○ Evolution: Hanging load transport with fleet • Check of high-density logistic nodes • Embedded safety

Figure 11 shows a picture of the exercises on the drone operations, taken during the workshop.

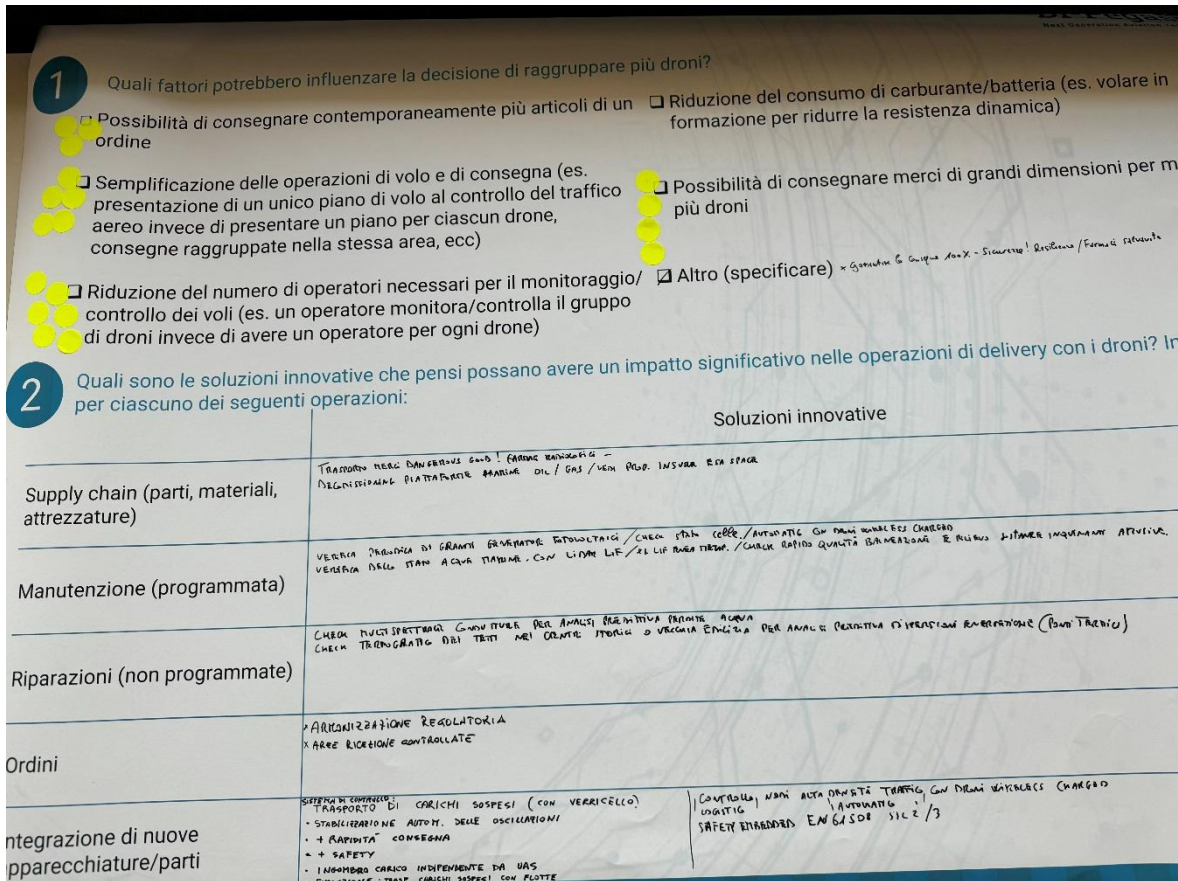


Figure 11 - Drone operations exercises

Other relevant aspects that emerged from exercises is the importance of dynamic operational management tools that go beyond static planning. Stakeholders noted that the ability to integrate battery charging and maintenance requirements into daily schedules is essential for minimizing downtime and ensuring continuity of service. Furthermore, they stressed the need for functionalities that allow rapid rescheduling and mission reallocation in response to unexpected events, such as technical failures or sudden airspace closures. Stakeholders also expressed interest in solutions that enable coordinated swarm operations when multiple drones are required for a single delivery, ensuring synchronized arrival and optimized resource utilization.

4.3. Requirements for seaplane technologies

The following sections outline the requirements identified for seaplane technologies and broader insights about the seaplane market, as these were identified during the interviews with stakeholders.

4.3.1. Business and regulatory requirements

This section focuses on the business and regulatory requirements for seaplane operations, within which the new technologies developed as part of Di-PEGASUS will be deployed. This information was gathered through

the semi-structured interviews with 8 experts and highlights the diversity in business models deployed in seaplane operations.

Taking into account the limited number of operators and operations of seaplanes across the world, the people interviewed are considered a representative sample of the experts in the field (all except one had more than 10 years of experience in the field, with four having over 15 years). Nevertheless, due to the small number and diverse backgrounds of interviewees, it is difficult to draw generalised quantitative conclusions from the interviews. This is also related to the variety of business models that the participants' organisations deploy, as well as that some are operators and some are manufacturers of seaplanes. This means that in some cases (for example when asked to rank their business costs) the participants gave very different responses, which would lose their value if provided the form of aggregate numbers. In addition, some of the participants did not provide quantitative responses to all questions, but instead provided descriptions and context for the seaplane market. For example, the seaplane manufacturers provided estimates how costs and revenues are structured for seaplane operators, based on the knowledge they have gained by having them as clients. As such, this section mainly includes a qualitative analysis of the responses, while providing key quantitative information gathered during the interviews. The diversity and depth of responses provide a solid foundation for T1.5, where business models for the seaplane technologies will be examined and developed.

The participants represented three seaplane operators, one of which had a small fleet (2 seaplanes), one had a medium fleet (5 seaplanes), and another had a significantly larger fleet (65 seaplanes). Collectively, the participants had experience in seaplane operations or seaplane business development in Greece, the Maldives, Canada, Turkey, Dubai, the US Virgin Islands, East Timor, and Antarctica.

As explained, the participants deploy different types of business models for their businesses, including large tourism-focus operations (sightseeing, transfer to resorts, charter flights for resorts), scheduled flights; and leasing aircraft, maintenance and pilot services. Across the interviews, it was clear that seaplane operations are a niche that deploys varied business models, albeit with a strong focus on luxury travel and tourism. In terms of **business costs**, the participants highlighted that they tend to be high, although for different reasons in different places of the world. Some common themes emerged in terms of high business costs. Firstly, all participants agreed that maintenance is expensive, especially when seaplanes operate in saline water, while costs can be driven further up by the lack of local expertise, or the type of seaplane deployed (for example twin engine aircraft have higher maintenance costs). Secondly, the participants highlighted that seaplanes are an expensive means of transport, which is usually profitable in high-end destinations and with high-end tourists who are already on an expensive holiday and are able to afford to travel by seaplane. On the contrary, all participants agreed that, although seaplanes can help serve remote destinations and increase accessibility for places with limited connections, scheduled routes simply cannot be profitable without public subsidies. Only very limited examples of such applications were mentioned during the interviews, with almost all participants focusing on luxury markets. As such, the main sources of revenue cited and the typical customers concentrated around touristic activities (hotels, cruise ships and sightseeing/ thematic flights), and the typical customers cited were either tourists or tourist businesses (hotels, resorts) who charter seaplanes to transport their customers.

Furthermore, the interviews showed that there are some challenges that are unique to the niche character of seaplanes. Firstly, due to the small size of the global seaplane market, there is a limited number of pilots and co-pilots, which drives up the cost particularly for smaller carriers as pilots tend to be expensive and absorbed

by larger operators. Some of the participants explained that training their pilots in their own training centres can reduce costs, although they still require a significant amount of training. Some participants argued that the lack of experienced pilots leads to higher accident rates and therefore insurance costs, although this was not confirmed by others. Secondly, the participants highlighted that seasonality is an issue, due to the weather (for example very short days in Northern Canada) or the short touristic seasons, which means that operators need to “follow the summer” and operate in more than one place, or focus on markets that have longer seasons, such as serving excursions for cruise passengers. Furthermore, the participants explained that seaplanes have a specific profitable flying range of under 30 minutes or within a distance between 30-130 nautical miles. As such, they can serve limited purposes and destinations, especially when they operate without any subsidy. In terms of entering new markets, the participants highlighted the need for international players to be allowed to enter new markets and set up their operations within a favourable regulatory environment. The participants argued that government support is quintessential for the success of a seaplane operation, both in the form of tailored and flexible regulations, and through favourable business and fuel tax rates. There was a general agreement that regulations in North America are more favourable than those in Europe, which were regarded as complex and limiting for new seaplane operations. The participants also explained that even though political support for new seaplane operations is crucial, barriers can arise even when there is willingness to introduce seaplanes in a new market. Some of the participants argued that these barriers are posed by bureaucrats responsible for implementing the legislation, who are posing barriers to operators due to their lack of experience, lack of willingness to help, or even deliberately. Furthermore, the participants argued that legislation itself is often not tailored to the unique characteristics of seaplanes (for example, authorities may try to incorporate seaplanes in existing aircraft legislation) and ends up introducing unnecessary complexities and barriers to operations. These comments also applied to the Greek context, where the participants highlighted the lack of dedicated, experienced or willing officials supporting the launch of seaplane operations. Approximately half of the participants had experience in the Greek market, while all of them considered it fully attractive. In addition, the participants considered that the Greek public either have a positive view or no view at all on seaplane operations, but will certainly welcome their operations once launched.

4.3.2. Technical requirements

Requirements for de-icing and biofouling mitigation methods

This section presents the technical requirements for the development of innovative de-icing and biofouling mitigation methods for seaplane technologies that will be developed in WP3. For the determination of technical requirements for seaplane technologies, a detailed technical questionnaire oriented to de-icing and biofouling mitigation methods was sent to stakeholders related to water airport operation. This technical questionnaire was sent to 24 water airports and seaplane operators across the world and included in Appendix D.

The input from the technical questionnaire aimed to determine the types of infrastructure used at water airports and the current strategies that are deployed to address the issues caused by biofouling and ice formation. The aim of the technical questionnaire was also to gain further understanding on the fabrication of water airport infrastructures and floating platforms, and on the current de-icing and antifouling methods that are potentially applied in water airports. However, no response has been received from relevant stakeholders. Therefore,

relevant technical information relating to water airport structures such as platforms and docks were drawn from the literature, technical brochures and online sources from manufacturers of such facilities and equipment.

Water airports operation relies on the use of floating platforms, docks, access bridges, dock gangways etc. These structures and equipment are equivalent to those met in marinas and yacht harbours. Materials such as plastic, aluminium, steel, wood and concrete are used for the fabrication of a variety of structures and equipment in marinas (Design Guide for Marinas, 2022; 'Marinas, Harbours and Fishing Docks', 2023; Boat Dock Systems, 2024; Nautix EXPO, 2024; WALCON, 2024).

Biofouling accumulation occurs primarily in parts of these structures that are submerged in water. Consequently, fouling is expected on float blocks, and on submerged surfaces of structural frames. Untreated bioaccumulation increases the applied weight and reduces the buoyancy levels required for safe operation. Furthermore, the increased weight exerted on the platforms can cause further structural degradation and decrease the overall lifespan. Moreover, due metabolic by-products of fouling organisms, biocorrosion can occur on surfaces of floating dock frames, leading to material degradation and increase the risk of structural failure.

Furthermore, if operation in freezing weather conditions is permitted at water airports, ice formation is more concerning on the deck surfaces of floating docks, pontoons, gangways and dock bridges where personnel and passengers walk. On these surfaces ice formation needs to be addressed in order to ensure safe operation and avoid potential injuries due to slippery conditions. Due to direct proximity to the water, no de-icing liquids can be applied on these surfaces. Therefore, ice formation should be manually removed off these surfaces if required. Common marina structures, materials involved for their fabrication as well as common antifouling and de-icing methods are presented in Table 10.

Table 10: Structure types for marinas and water airports

Structure Type	Part	Material	Current anti-fouling method	De-icing method
Floating docks, dock fingers and pontoons	Float	Foam filled polyethylene	Abrasive cleaning, biocidal paint	-
		Polystyrene encased in concrete		
		Wood		
	Frame	Floating polyethylene blocks (for modular floating docks)	Abrasive cleaning, biocidal paint for submerged parts	-
		Steel		
		Stainless Steel		
		Aluminium		
		Concrete		
	Deck panel	Wood	-	Manual labour

		Composite		
		Drawn aluminium extrusions		
		Aluminium sheet		
		Polyethylene (for modular floating docks)		
		Concrete		
Docking bridges and gangways	Float	Polyethylene – foam filled	Abrasive cleaning, biocidal paint	-
		Polystyrene floats encased in fibre-reinforced concrete		
		Wood		
	Frame	Steel	Abrasive cleaning, biocidal paint for submerged parts	-
		Aluminium		
		Wood		
		Plastic		
	Deck pannel	Wood	-	Manual labour
		Composite		
		Aluminium		
Plastic				
Breakwaters	Structure	Concrete encased styrofoam	Abrasive cleaning, biocidal paint for submerged parts if required	-
		Concrete		
		steel		
Sheet piles	-	Concrete	Abrasive cleaning, biocidal paint	-
		Steel		
		Aluminium		
		Vinyl		
		Composite		

For the objectives of WP3, innovative antifouling and de-icing mitigation strategies will be developed in order to prevent icing and fouling formation on structures and facilities of water airports, without resorting to the use of

biocidal paints and de-icing liquids that are harmful to the environment and to aquatic life. The innovative ultrasonic antifouling and de-icing method will be based on the use of an ultrasonic system that must comply to the requirements presented in Table 11.

Table 11: Water airport de-icing and anti-fouling system requirements

	Requirement
1	The ultrasonic system must be robust, waterproof and capable of operating at a temperature range from -20°C to 50°C.
2	The system must be capable of continuous operation.
3	The system must be capable of producing high power ultrasonic waves that will disrupt or prevent the formation of biofouling, and prevent ice formation or cause interfacial decohesion between the ice and substrate layer.
4	The system must be consisted of multiple transducers in order to cover the largest possible area without power loss due to ultrasonic wave attenuation.
5	The ultrasonic system must be portable and easy to install without causing any damage on the treated surfaces.
6	The system must not interfere with other aircraft or ground operation systems.
7	The system should not cause any health and safety issues to the area of operation.

General technical requirements

During the interviews, the participants were asked which types of technological innovations would benefit their business and operations. They generally showed an interest in the technologies developed as part of Di-PEGASUS and agreed to continue their engagement with the project. In addition, they provided some insights into broader technical requirements, which provide useful insights into the wider context where Di-PEGASUS technologies could be deployed. More specifically, the participants' views on seaplane electrification varied, with one participant being confident that electric seaplanes will be available before 2030, and the others regarding zero-emission seaplanes a desirable but distant target, as the available technology is not sufficiently mature. The potential for electrification opens up further opportunities for Di-PEGASUS technologies such as the deployment of circular economy principles. One participant mentioned a range of innovations that would be useful in Greek operations, including systems information sharing between low-altitude civil aviation operators and military aviation authorities to facilitate flight scheduling and coordination, the use of drones for safer operations within ports, Mobility as a Service applications, and routing applications that will take into account weather conditions. This provides valuable baseline information for the Greek use case that will be developed in WP5.

Fleet Operation Management Requirements

Considering the characteristics of the seaplane market described in the previous sections, including the strong seasonality, demand variability, and high maintenance costs, fleets need to be managed in a way that allows dynamic flight planning based on passenger demand (origin, destination, time slot), with the goal of maximizing fleet utilization, reducing delays, and minimizing operational costs (Frazzon et al., 2017; Neumann et al., 2023). For example, in high-demand tourist contexts, if the demand on a route exceeds the capacity of a single seaplane, there is a need to schedule and manage multiple aircraft on the same route, coordinating slots and turn-around times to avoid congestion and ensure punctuality (Frazzon et al., 2017).

In addition, fleet management must also take into account refuelling and maintenance needs, which are particularly critical for operations in marine environments where maintenance costs are high and resource availability is limited. A flight scheduled after a long route may require a refuelling or maintenance window before departure to prevent service interruptions (He et al., 2020; Koschlik et al., 2023). For electric aircraft, planning must include charging management (charging scheduling) and energy load balancing to ensure operational availability and cost optimization (Vehlhaber and Salazar, 2024). Finally, the system must integrate regulatory and operational constraints into the planning logic, such as the availability of water airports and docking areas, slot limits, and safety rules.

4.3.1. Social requirements

Finally, the participants were asked to briefly comment on the social aspects of seaplane operations. There was a general agreement across all participants that there is a positive (or at least neutral) perception of seaplanes among the public, even if commercial applications are extremely limited. At the same time, all participants acknowledged that although currently seaplanes are geared towards high-end tourist markets, they have significant potential and should serve the wider public, through increasing connectivity to underserved or remote destinations. As mentioned above, this was only considered possible with the initiative and subsidies of national and local governments. In this sense, seaplanes were seen as complimentary to, not competing with, commercial aviation, and as faster and more expensive option than ferries. However, only one of the participants said that their seaplanes are fully accessible to people with disabilities or limited mobility, while others considered improving physical accessibility as impossible or “not part of the design of the seaplane”. These findings provide useful contextual information for the development of business models in T1.5.

4.4. Requirements for UAM technologies

This Section contains an overview of the requirements for UAM technologies identified during the discussions between Safran and ADP. The gathering of requirements from ADP took place between April and October 2024, both in the form of meetings and using a survey. These discussions were interrupted by the intensive period of preparation for the demonstrations planned during the 2024 Olympic Games. The availability of ADP remained limited after the Olympic Games until the dismounting of the Austerlitz floating barge at the end of December 2024, but the overall requirements needed for the execution of Di-PEGASUS technical developments have been gathered.

4.4.1. Business requirements

As shown in Figure 12, several areas need to be simultaneously addressed in order to ensure the successful development of the UAM market.

The main requirement contributing to the acceptability and development of the UAM service is the travel price. The precommercial flights which have been studied by ADP in order to initiate the business case, planned a flight volume of 2,000 to 2,500 flights between July and December 2024 (for comparison, there were 6,000



Figure 12 Areas contributing to the UAM market

helicopter flights around the Paris ring road in 2022). The price of the UAM trip is “roughly twice that of a car taxi”, or “around €110” for a 31-kilometre trip from Roissy to Paris, which costs 55 to 65 euros by taxi.

In the case of medical or emergency transport, the comparison needs to be done between eVTOL and conventional road transport. Three specific use cases are considered: transport of grafts, transport of persons suffering minor injuries, and travel of doctors to accident sites. Based on works led by Volocopter with the German Emergency medical assistance service, ADP will define specific requirements with Public Assistance for Paris Hospitals. The flights intended for simulation of medical use cases will be mainly deployed from vertiports based on Le Bourget (first health airport of France), on the Paris-Issy-les Moulineaux heliport (near the Georges Pompidou European hospital) and from the vertiport of Paris-Austerlitz (near Pitié-Salpêtrière University Hospital). The goal is to test the time saving of an eVTOL compared to transportation by land ambulance in a dense urban environment and its agility compared to a helicopter.

An essential factor in the success of the UAM business case is also the overall optimisation of dwell time for ground procedures and the journey (typically 20 minutes to reach a city center). The design of a vertiport must integrate the passenger experience and optimisation of waiting times (“no-wait no-touch” vertiport concept). The passenger buys a ticket via a mobile application then checks in quickly and paper-free. A facial recognition scan confirms their identity and a sensor measures the weight of the passenger and their luggage. This makes it possible to calculate the carrying payload of the air vehicle, to determine the energy required for the trip and to anticipate the reloading of the batteries. Optimisation of the round trip time has an impact on the time of flight operations near the vertiport (take-off, approach, landing).

4.4.2. Technical requirements

A set of requirements have been identified as key drivers to the successful development of UAM air platforms and services:

- The acoustic impacts of the project, around the vertiport but also near the entire flyover road. There is no standard quantified requirement, but ADP provided first figures based on low acoustic impact measures from the Volocity aircraft (powered by a fully-electric propulsion distributed via 18 electric rotors, which reduces the noise footprint). The sound measurements carried out at the Pontoise airfield by the RATP laboratory and the Buitparif institute, taking into account the lowest flight altitude (150 meters), showed an emission level of 65 decibels, below the emission level of a conventional bus and 4 times less noisy than a helicopter. A survey carried out among visitors to Pontoise showed that 86% of them expected a louder perception of the noise impact than that experienced in a real situation.
- The energy consumption and greenhouse gas emissions. ADP gave preliminary figures: eVTOL operation will not induce local emissions, but indirect emissions taking into account the life cycle and an average energy consumption of 190kWh/100 km, bring total emissions to 110g of CO₂/km, less than an average hybrid car (118g of CO₂/km).
- Simple and sustainable infrastructure for eVTOL operations: requirements are on compact infrastructures, with little footprint, including a single take-off and landing zone, a passenger reception area and a maintenance and recharge area.
- Safety of flight and security for the populations flown over in a very dense urban context. Unprecedented requirements are defined on levels of safety in order to authorise urban flight operations.
- Safe and secure procedures on the landing of eVTOLs in vertiports. Requirements include the dimensions of landing surface (final Approach and take-off Area and Safe Area), landing distance and approach envelope, conditions of operations, markings and lightings, timeline of each phase of take-off and landing, nominal and degraded procedures. These requirements will form the baseline input to Task 2.4 "Safe automatic landing".

4.4.3. Vertiport requirements

ADP provided answers to the specific subject of vertiport design requirements:

- Vertiport design should follow the EASA specifications (PTS-VPT-DSN)
- Whenever EASA guidelines are unsuitable or insufficient, helicopter regulations should be taken as guidance (in France: TAC heliports decree)

The authority responsible for the approval of a vertiport is the national Civil Aviation Authority (CAA). They refer to national regulation on to helipad and heliport.

It should be noted that the regulations applicable to operations from prototype vertiports are still directly derived from those applicable to helicopters because the first VTOL experiments are carried out with a pilot on board and flight controls identical to those of a conventional rotorcraft. For example, the approach or take-off trajectories remain the same. This is also the reason why, to date, there are no new landing aid equipment solutions on prototype vertiports (no new marking or beacon).

As such, vertiports are currently regulated in the same way as heliports (according to current regulation, VTOLs must be able to land on a heliport). The FATO of a vertiport is the same as that of a heliport. Due to the footprint of multi-rotor VTOLS on the ground, it is simply necessary to select the largest FATO dimension (D-Value).

Several requirements and procedures are under the responsibility of the VTOL operator, including: approach and traffic management procedures, maintenance and repair operations, energy and fluid easements (electricity, fuels, other fluids, etc.).

5. CONCLUSIONS

This deliverable provided a review of the state-of-the-art and practice related to the new digital technologies that will be developed in WP2 - Aircraft and Airspace digital technologies and WP3 - Digital innovative ground maintenance technologies. Thus, it sets the knowledge baseline upon which the new digital technologies that will be developed as part of Di-PEGASUS will build. Furthermore, D1.1 identifies the stakeholder requirements that relate to the new digital technologies, which will help shape the outputs of WP2 and WP3, as well as the business models that will be developed as part of T1.5.

LIST OF REFERENCES

- Abbott, A. et al. (2000) 'Cost–benefit analysis of the use of TBT: the case for a treatment approach', *TBT Costs and Benefits- A*, 258(1), pp. 5–19. Available at: [https://doi.org/10.1016/S0048-9697\(00\)00505-2](https://doi.org/10.1016/S0048-9697(00)00505-2).
- Aghapour Aktij, S. et al. (2020) 'A critical review on ultrasonic-assisted fouling control and cleaning of fouled membranes', *Ultrasonics*, 108, p. 106228. Available at: <https://doi.org/10.1016/j.ultras.2020.106228>.
- Ahmad, A.L. et al. (2012) 'Membrane Antifouling Methods and Alternatives: Ultrasound Approach', *Separation & Purification Reviews*, 41(4), pp. 318–346. Available at: <https://doi.org/10.1080/15422119.2011.617804>.
- Ahn, C.-Y. et al. (2003) 'Growth inhibition of cyanobacteria by ultrasonic radiation: laboratory and enclosure studies', *Environmental science & technology*, 37(13), pp. 3031–3037.
- Almeida, E., Diamantino, T.C. and de Sousa, O. (2007) 'Marine paints: The particular case of antifouling paints', *Progress in Organic Coatings*, 59(1), pp. 2–20. Available at: <https://doi.org/10.1016/j.porgcoat.2007.01.017>.
- Alvarez-Montoya, J., Carvajal-Castrillón, A. and Sierra-Pérez, J. (2020) 'In-flight and wireless damage detection in a UAV composite wing using fiber optic sensors and strain field pattern recognition', *Mechanical Systems and Signal Processing*, 136, p. 106526. Available at: <https://doi.org/10.1016/j.ymssp.2019.106526>.
- Arnold, R.D., Yamaguchi, H. and Tanaka, T. (2018) 'Search and rescue with autonomous flying robots through behavior-based cooperative intelligence', *Journal of International Humanitarian Action*, 3(1), p. 18. Available at: <https://doi.org/10.1186/s41018-018-0045-4>.
- Beniaminy, I. et al. (2009) 'When the rubber meets the road: Bio-inspired Field Service Scheduling in the real world', *Bio-inspired Algorithms for the Vehicle Routing Problem*, pp. 191–213. Available at: https://doi.org/10.1007/978-3-540-85152-3_9
- Boat Dock Systems (2024) RGC marine. Available at: <https://rgcmarine.com/product-category/dock-systems/>.
- Breedveld, G.D. et al. (2003) 'Persistence of the de-icing additive benzotriazole at an abandoned airport', *Water, Air and Soil Pollution: Focus*, 3, pp. 91–101.
- Brittain, M. and Wei, P. (2019) 'Autonomous Separation Assurance in An High-Density En Route Sector: A Deep Multi-Agent Reinforcement Learning Approach', in *2019 IEEE Intelligent Transportation Systems Conference (ITSC)*. 2019 IEEE Intelligent Transportation Systems Conference (ITSC), pp. 3256–3262. Available at: <https://doi.org/10.1109/ITSC.2019.8917217>.
- Brittain, M. and Wei, P. (2022) 'Scalable Autonomous Separation Assurance With Heterogeneous Multi-Agent Reinforcement Learning', *IEEE Transactions on Automation Science and Engineering*, 19(4), pp. 2837–2848. Available at: <https://doi.org/10.1109/TASE.2022.3151607>.
- Brittain, M., Yang, X. and Wei, P. (2020) 'A Deep Multi-Agent Reinforcement Learning Approach to Autonomous Separation Assurance'. *arXiv*. Available at: <http://arxiv.org/abs/2003.08353> (Accessed: 14 March 2024).
- Brittain, M.W. and Wei, P. (2021) 'One to Any: Distributed Conflict Resolution with Deep Multi-Agent Reinforcement Learning and Long Short-Term Memory', in *AIAA Scitech 2021 Forum*. American Institute of Aeronautics and Astronautics. Available at: <https://doi.org/10.2514/6.2021-1952>.

Camur, M.C. et al. (2021) 'Optimizing the response for arctic mass rescue events', *Transportation Research Part E: Logistics and Transportation Review*, 152, p. 102368. Available at: <https://doi.org/10.1016/j.tre.2021.102368>.

Camur, M.C. et al. (2023) 'An integrated system dynamics and Discrete Event Supply Chain Simulation Framework for supply chain resilience with non-stationary pandemic demand', *arXiv.org*. Available at: <https://arxiv.org/abs/2305.00086> (Accessed: 15 July 2024).

Cao, S. et al. (2011) 'Progress of marine biofouling and antifouling technologies', *Chinese Science Bulletin*, 56(7), pp. 598–612. Available at: <https://doi.org/10.1007/s11434-010-4158-4>.

Carellan, I. et al. (2014) 'Characterization of ultrasonic wave propagation in the application of prevention of fouling on a ship's hull', *Proceedings of the ICMT2014, Glasgow, Scotland*, pp. 7–9.

Champ, M.A. (2000) 'A review of organotin regulatory strategies, pending actions, related costs and benefits', *TBT Costs and Benefits- A*, 258(1), pp. 21–71. Available at: [https://doi.org/10.1016/S0048-9697\(00\)00506-4](https://doi.org/10.1016/S0048-9697(00)00506-4).

Chen, H. et al. (2018) 'Review of ice-pavement adhesion study and development of hydrophobic surface in pavement deicing', *Journal of Traffic and Transportation Engineering (English Edition)*, 5(3), pp. 224–238. Available at: <https://doi.org/10.1016/j.jtte.2018.03.002>.

Civil Aviation Safety Authority (2024) Guide to vertiport design. Available at: <https://www.casa.gov.au/sites/default/files/2024-05/guide-to-vertiport-design.pdf>.

Cui, Y. et al. (2024) 'Anti-icing properties and application of superhydrophobic coatings on asphalt pavement', *Construction and Building Materials*, 419, p. 135452. Available at: <https://doi.org/10.1016/j.conbuildmat.2024.135452>.

Daniliuk, V. et al. (2020) 'Ultrasonic de-icing of wind turbine blades: Performance comparison of perspective transducers', *Renewable Energy*, 145, pp. 2005–2018. Available at: <https://doi.org/10.1016/j.renene.2019.07.102>.

Design Guide for Marinas (2022) EZ DOCK. Available at: <https://www.ez-dock.com/blog/design-guide-for-marinas/>.

Du, Y. et al. (2023) 'A Review of Cooperation in Multi-agent Learning'. *arXiv*. Available at: <https://doi.org/10.48550/arXiv.2312.05162>.

EASA (2022) Prototype Technical Specifications for the Design of VFR Vertiports for Operation with Manned VTOL-Capable Aircraft Certified in the Enhanced Category (PTS-VPT-DSN). Cologne, Germany. Available at: <https://www.easa.europa.eu/en/document-library/general-publications/prototype-technical-design-specifications-vertiports>.

Estévez-Calvar, N. et al. (2018) 'Potential use of an ultrasound antifouling technology as a ballast water treatment system', *Recent Advances in Ballast Water Research*, 133, pp. 115–123. Available at: <https://doi.org/10.1016/j.seares.2017.04.007>.

European Union Aviation Safety Agency (2024) 'Commission Implementing Regulation (EU) 2024/1109', *Official Journal of the European Union [Preprint]*, (1109). Available at: <https://www.easa.europa.eu/en/document-library/regulations/commission-implementing-regulation-eu-20241109>.

FAA Airports (2024) ENGINEERING BRIEF No. 105, Vertiport Design. FAA. Available at: https://www.faa.gov/airports/engineering/engineering_briefs/eb_105a_vertiports.

Fatemi-Anaraki, S. et al. (2023) 'Scheduling of multi-robot job shop systems in dynamic environments: Mixed-integer linear programming and constraint programming approaches', *Omega*, 115, p. 102770. Available at: <https://doi.org/10.1016/j.omega.2022.102770>.

Federal Aviation Administration (2020) 'UAS Traffic Management (UTM) Concept of Operations'. FAA. Available at: https://www.faa.gov/sites/faa.gov/files/2022-08/UTM_ConOps_v2.pdf.

Feng, T. et al. (2023) 'An ADMM-based dual decomposition mechanism for integrating crew scheduling and rostering in an urban rail transit line', *Transportation Research Part C: Emerging Technologies*, 149, p. 104081. Available at: <https://doi.org/10.1016/j.omega.2022.102770>.

Frazzon, E.M. et al. (2017) 'Hybrid approach for the integrated scheduling of production and transport processes along supply chains', *International Journal of Production Research*, 56(5), pp. 2019–2035. Available at: <https://doi.org/10.1080/00207543.2017.1355118>.

Geng, S. et al. (2021) 'Experimental study on antifouling performance of ultrasonic/electronic compound treatment in heat transfer', *Experimental Heat Transfer*, 34(7), pp. 605–619. Available at: <https://doi.org/10.1080/08916152.2020.1797929>.

Geurtsen, M. et al. (2023) 'Production, maintenance and Resource Scheduling: A Review', *European Journal of Operational Research*, 305(2), pp. 501–529. Available at: <https://doi.org/10.1016/j.ejor.2022.03.045>.

Guo, S., Lee, H.P. and Khoo, B.C. (2011) 'Inhibitory effect of ultrasound on barnacle (*Amphibalanus amphitrite*) cyprid settlement', *Journal of Experimental Marine Biology and Ecology*, 409(1), pp. 253–258. Available at: <https://doi.org/10.1016/j.jembe.2011.09.006>.

Guo, W., Brittain, M. and Wei, P. (2021) 'Safety Enhancement for Deep Reinforcement Learning in Autonomous Separation Assurance', in 2021 IEEE International Intelligent Transportation Systems Conference (ITSC). 2021 IEEE International Intelligent Transportation Systems Conference (ITSC), pp. 348–354. Available at: <https://doi.org/10.1109/ITSC48978.2021.9564466>.

Habibi, H. and Gan, T.-H. (2016) 'An acoustic antifouling study in sea environment for ship hulls using ultrasonic guided waves', *International Journal of Engineering Technologies and Management Research*, 3(4), pp. 14–30.

Habibi, H. et al. (2015) 'A dual de-icing system for wind turbine blades combining high-power ultrasonic guided waves and low-frequency forced vibrations', *Renewable Energy*, 83, pp. 859–870. Available at: <https://doi.org/10.1016/j.renene.2015.05.025>.

Harman, W.H. (1989) 'TCAS: a system for preventing midair collisions', *Citeseer*, 2, pp. 437–457.

Hasytec (2024) HASYTEC group. Available at: <https://hasytec.com/>.

He, Y., Liu, Z. and Song, Z. (2020) 'Optimal charging scheduling and management for a fast-charging battery electric bus system', *Transportation Research Part E: Logistics and Transportation Review*, 142, p. 102056. Available at: <https://doi.org/10.1016/j.tre.2020.102056>.

Hou, T. et al. (2018) 'Experimental study of fouling process and antifouling effect in convective heat transfer under ultrasonic treatment', *Applied Thermal Engineering*, 140, pp. 671–678. Available at: <https://doi.org/10.1016/j.applthermaleng.2018.04.021>.

Huang, X. et al. (2024) 'Application of Ultrasonic Cavitation in Ship and Marine Engineering', *Journal of Marine Science and Application*, 23(1), pp. 23–38. Available at: <https://doi.org/10.1007/s11804-024-00393-7>.

Jeannin, J.-B. et al. (2015) 'Formal verification of ACAS X, an industrial airborne collision avoidance system', in 2015 International Conference on Embedded Software (EMSOFT). 2015 International Conference on Embedded Software (EMSOFT), pp. 127–136. Available at: <https://doi.org/10.1109/EMSOFT.2015.7318268>.

Joris Mollinga et al. (2020) 'An Autonomous Free Airspace En-route Controller using Deep Reinforcement Learning Techniques.', arXiv.org [Preprint].

Khare, A. and Agrawal, S. (2020) 'Effective heuristics and metaheuristics to minimise total tardiness for the distributed permutation flowshop scheduling problem', *International Journal of Production Research*, 59(23), pp. 7266–7282. Available at: <https://doi.org/10.1080/00207543.2020.1837982>.

Kochenderfer, M.J., Holland, J.E. and Chryssanthacopoulos, J.P. (no date) 'Next-Generation Airborne Collision Avoidance System'.

Kohn, R. (2013) *Tovatech Blog, TOVATECH*. Available at: <https://tovatech.com/blog>. Accessed: 04/12/2025

Koschlik, A., Meyer, H., & Raddatz, F. (2023). Linking digital twins to use time series for predictive maintenance at component level. NATO AVT-369 Research Symposium, Båstad

Kozuba, J. and Pil'a, J. (2019) 'Impact of de-icing substances on runway and aircraft structure', in. 2019 International Conference on Military Technologies (ICMT), IEEE, pp. 1–6.

Leung, J.Y. (2004). 'Handbook of scheduling: algorithms, models, and performance analysis'. Chapman and Hall/CRC.

LG Sonic (2024) LG sonic. Available at: <https://www.lgsonic.com/>.

Lindholdt, A. et al. (2015) 'Effects of biofouling development on drag forces of hull coatings for ocean-going ships: a review', *Journal of Coatings Technology and Research*, 12(3), pp. 415–444. Available at: <https://doi.org/10.1007/s11998-014-9651-2>.

Lowe, R. et al. (2020) 'Multi-Agent Actor-Critic for Mixed Cooperative-Competitive Environments'. arXiv. Available at: <https://doi.org/10.48550/arXiv.1706.02275>.

Marinas, Harbours and Fishing Docks' (2023). Lindley. Available at: https://www.lindley.pt/docs/content/catalogo_marinas_eng.pdf.

Meng, Y. et al. (2022) 'Deicing characteristics and pavement performance of eco-friendly de-icing asphalt mixture', *Construction and Building Materials*, 360, p. 129565. Available at: <https://doi.org/10.1016/j.conbuildmat.2022.129565>.

Moerland, T.M. et al. (2022) 'A unifying framework for reinforcement learning and planning', *Frontiers in Artificial Intelligence*, 5. Available at: <https://doi.org/10.3389/frai.2022.908353>.

Nautix EXPO (2024) Marina equipment, Nautix EXPO. Available at: <https://www.nauticexpo.com/cat/marina-equipment-YA.html>.

Neumann, A. et al. (2023) 'Genetic algorithms for planning and Scheduling Engineer-to-order production: A systematic review', *International Journal of Production Research*, 62(8), pp. 2888–2917. Available at: <https://doi.org/10.1080/00207543.2023.2237122>.

Nicolas Heess et al. (2017) 'Emergence of Locomotion Behaviours in Rich Environments', arXiv: Artificial Intelligence [Preprint].

OroojlooyJadid, A. and Hajinezhad, D. (2021) 'A Review of Cooperative Multi-Agent Deep Reinforcement Learning'. arXiv. Available at: <https://doi.org/10.48550/arXiv.1908.03963>.

Øvstedal, J. and Wejden, B. (2007) Dispersion of de-icing chemicals to the areas along the runways at Oslo Airport Gardermoen. 0148–7191. SAE Technical Paper.

Paduraru, C. and Dimitrakopoulos, R. (2019) 'Responding to new information in a mining complex: Fast mechanisms using machine learning', *Mining Technology*, 128(3), pp. 129–142. Available at: <https://doi.org/10.1080/25726668.2019.1577596>.

Park, J.-S. and Lee, J.-H. (2018) 'Sea-trial verification of ultrasonic antifouling control', *Biofouling*, 34(1), pp. 98–110. Available at: <https://doi.org/10.1080/08927014.2017.1409347>.

Pu, Y. et al. (2021) 'Decomposed soft actor-critic method for Cooperative Multi-Agent Reinforcement Learning', arXiv.org. Available at: <https://arxiv.org/abs/2104.06655> (Accessed: 15 July 2024).

Razzaghi, P. et al. (2022) 'A Survey on Reinforcement Learning in Aviation Applications'. arXiv. Available at: <http://arxiv.org/abs/2211.02147> (Accessed: 10 April 2024).

Rekuvienė, R. et al. (2024) 'A review on passive and active anti-icing and de-icing technologies', *Applied Thermal Engineering*, 250, p. 123474. Available at: <https://doi.org/10.1016/j.applthermaleng.2024.123474>.

Relini, G. et al. (1998) 'The macrofouling on offshore platforms at Ravenna', *International Biodeterioration & Biodegradation*, 41(1), pp. 41–55. Available at: [https://doi.org/10.1016/S0964-8305\(98\)80007-3](https://doi.org/10.1016/S0964-8305(98)80007-3).

Ribeiro, M., Ellerbroek, J. and Hoekstra, J. (2020) 'Review of Conflict Resolution Methods for Manned and Unmanned Aviation', *Aerospace*, 7(6), p. 79. Available at: <https://doi.org/10.3390/aerospace7060079>.

Salta, M. et al. (2016) 'Bubbles versus biofilms: a novel method for the removal of marine biofilms attached on antifouling coatings using an ultrasonically activated water stream', *Surface Topography: Metrology and Properties*, 4(3), p. 034009. Available at: <https://doi.org/10.1088/2051-672X/4/3/034009>.

Samaey, G., Holvoet, T. & Wolf, T. (2008). 'Using Equation-Free Macroscopic Analysis for Studying Self-Organising Emergent Solutions'. *Proceedings - 2nd IEEE International Conference on Self-Adaptive and Self-Organizing Systems, SASO 2008*. 425-434. 10.1109/SASO.2008.30.

Schulman, J. et al. (2017) 'Proximal Policy Optimization Algorithms'. arXiv. Available at: <https://doi.org/10.48550/arXiv.1707.06347>.

SESAR Joint Undertaking (2019) CORUS-XUAM Project - Urban Air Mobility for Europe, CORUS-XUAM - Concept of Operations for Urban Air Mobility in Europe. Available at: <https://corus-xuam.eu/> (Accessed: 28 March 2024).

SESAR Joint Undertaking (2022a) BUBBLES - Defining the BUilding Basic BLocks for a U-Space SEparation Management Service, BUBBLES - Defining the BUilding Basic BLocks for a U-Space SEparation Management Service. Available at: <https://www.sesarju.eu/projects/bubbles> (Accessed: 14 August 2024).

SESAR Joint Undertaking (2022b) URClearED - A Unified Integrated Remain Well Clear Concept in Airspace D-G Class. Available at: <https://www.sesarju.eu/projects/urcleared> (Accessed: 14 August 2024).

SESAR Joint Undertaking (2023) SPATIO- U-Space Separation Management. Available at: <https://www.sesarju.eu/projects/SPATIO> (Accessed: 14 August 2024).

SESAR, J.U. (2017) U-space and urban air mobility. Available at: <https://www.sesarju.eu/U-space> (Accessed: 28 March 2024).

Simões, D., Lau, N. and Paulo Reis, L. (2020) 'Multi-agent actor centralized-critic with communication', *Neurocomputing*, 390, pp. 40–56. Available at: <https://doi.org/10.1016/j.neucom.2020.01.079>.

Sonihull (2024) SONIHULL - ultrasonic anti-fouling system. Available at: <https://sonihull.com/>.

Tan, H. et al. (2016) 'Investigation on the ultrasonic propagation mechanism and its application on air-source heat pump defrosting', *Applied Thermal Engineering*, 107, pp. 479–492. Available at: <https://doi.org/10.1016/j.applthermaleng.2016.06.185>.

UK Civil Aviation Authority (2023) Considerations for Aerodromes and Vertiports planning to operate Vertical Take-off and Landing Aircraft (VTOL). Available at: <https://www.caa.co.uk/our-work/publications/documents/content/cap2538/>.

Vehlhaber, F. & Salazar, M. (2024) A Model Predictive Control Scheme for Flight Scheduling and Energy Management of Electric Aviation Networks. DOI: 10.48550/arXiv.2404.09282

Videla, H.A. (2003) 'Biocorrosion and biofouling of metals and alloys of industrial usage. Present state of the art at the beginning of the new millennium', *Revista de Metalurgia*, 1, pp. 256–264.

WALCON (2024) steel pontoons, WALCON. Available at: <https://www.walconmarine.com/products>.

Wang, R.E., Everett, M. and How, J.P. (2020) 'R-MADDPG for Partially Observable Environments and Limited Communication'. arXiv. Available at: <https://doi.org/10.48550/arXiv.2002.06684>.

Wang, Y., Xu, Y. and Huang, Q. (2017) 'Progress on ultrasonic guided waves de-icing techniques in improving aviation energy efficiency', *Renewable and Sustainable Energy Reviews*, 79, pp. 638–645. Available at: <https://doi.org/10.1016/j.rser.2017.05.129>.

Wang, Y., Xu, Y. and Su, F. (2020) 'Damage accumulation model of ice detach behavior in ultrasonic de-icing technology', *Renewable Energy*, 153, pp. 1396–1405. Available at: <https://doi.org/10.1016/j.renene.2020.02.069>.

Xu, P. et al. (2024) 'Hybrid de-icing method combining electrothermal system and ultrasonic guided waves', *Applied Acoustics*, 217, p. 109804. Available at: <https://doi.org/10.1016/j.apacoust.2023.109804>.

APPENDIX A - SEAPLANE DATA COLLECTION MATERIALS

INFORMATION SHEET

The project

Di-PEGASUS (Digital compETitive next Generation Aviation technologies for SUStainable business models, products and services) is a European Commission-funded research project aiming to enable fully autonomous cost-effective and environmentally friendly operations for seaplanes, Vertical Take Off and Landing (VTOL) aircraft, and drones.

This will be achieved by developing several enabling technologies targeting both the air and the ground side. In addition, Di-PEGASUS proposes to develop a digital platform to evaluate the viability of specific business models at different locations, according to the digital technologies available, and Key Performance Indicators (including cost-effectiveness, job creation, emissions savings, investment costs), in order to make recommendations to policy makers and relevant stakeholders that will host these services. This platform should also support the assessment of regulatory compliance to identify the safety assurance process that the technologies will need to follow, as well as the gaps in existing regulations that will need to be addressed.

Di-PEGASUS includes three use cases (Greece – seaplanes, Italy – drones, France -Urban Air Mobility). In the case of Greece, the University of the Aegean examines the current conditions in the seaplane market and the challenges that operators and authorities face in their efforts to establish an operational network of seaports and seaplane services.

Your participation

We are inviting you to participate in Di-PEGASUS because of your extensive experience in relation to seaplanes and/or water airports. Your participation will be invaluable to Di-PEGASUS and the research carried out by the University of the Aegean.

The purpose of interview is to draw from your experience and add to one of the project's three use cases that focuses on Greece. The interview is expected to last approximately 45 minutes. If you agree to participate, we will send you in advance of the interview a consent form and the list of questions that we will be using.

We note that your participation is completely voluntary and you do not have to answer any questions you do not want.

Anonymity and data protection

We will use the information that you will give us during the interview in the Di-PEGASUS reports, and in any academic papers or conference presentations that we will deliver as part of this project.

The interviews will be recorded, while any written notes taken during the interviews will not refer to your name. Nobody outside the research team will have access to the interview recording or to interview notes. In order to protect your anonymity, we will not make reference to your name or to your personal details in any of our reports, papers or presentations. Instead, we will use pseudonyms (for example, Participant A from seaplane company A).

Di-PEGASUS is fully compliant with the European General Data Protection Regulation. All digital files will be saved in encrypted locations and will be deleted after the project end (30 November 2026).

Please take the time to carefully read this document. If you have any questions regarding the project or your participation, please contact us using the following details.

Dr Ioanna Pagoni – tel: 6956033737, email: ipagoni@aegean.gr

Dr Ioanna Moscholidou – tel: 6975712690, email: imoscholidou@aegean.gr

Kindest regards,

Professor Amalia Polydoropoulou

Dr Ioanna Pagoni, Assistant Professor

Dr Ioanna Moscholidou, Postdoctoral researcher

Di-Pegasus is funded by the European Commission under call number HORIZON-CL5-2022-D5-01, and has received approval under project number 101096000.

Participant consent form for the Di-PEGASUS project

Add your initials
next to the
statement if you
agree

I confirm that I have read and understood the Di-PEGASUS information sheet explaining the above project and that I have had the opportunity to ask questions about the project.	
I agree to participate in this interview. Should I not wish to answer any particular question or questions, I am free to decline.	
I understand that my participation is voluntary and that I am free to withdraw from this project within two weeks from the interview without having to give any reason, by contacting the lead researcher via email (imoscholidou@aegean.gr). If I request withdrawal all the recordings, notes and transcripts, and any other data I have provided will be deleted from all storage devices or will be destroyed.	
I understand that my name will not be linked with the project materials, and I will not be named in the report(s), presentation(s) or publication(s) that result from this project.	
I agree to be quoted anonymously in report(s), publication(s) and presentation(s) that result from the project.	
I understand that despite those protocols and because of the nature of my position, I might still be identifiable by others who are familiar with my organisation/ authority/ department in the report(s), presentation(s) or publication(s) that result from this project.	
I agree for the data collected from me to be stored safely online or at a secure location until the completion of this project and any relevant report(s), presentation(s) or publications(s) that result from the project.	

Name of participant	
Participant's signature	
Date	
Name of lead researcher	
Signature	
Date	

A copy of the signed and dated consent form will be stored in a secure location.

Di-Pegasus is funded by the European Commission under call number HORIZON-CL5-2022-D5-01, and has received approval under project number 101096000.

Project title	Document type	Version	Date
Di-PEGASUS	Participant consent form	2	April 2024

Di- PEGASUS interview questions

Interviewee group: private sector stakeholders

Introduction

The goal of Di-PEGASUS is to enable fully autonomous, cost-effective and environmentally friendly operations for seaplanes, VTOL aircraft and drones. This objective will be achieved by developing several enabling technologies targeting both the air and the ground side. In addition, Di-PEGASUS will make recommendations to policy makers and relevant stakeholders that will host these services. To do so, the project includes the development of a digital platform that will evaluate the viability of different business models for the developed enabling technologies at particular locations, using Key Performance Indicators (including cost-effectiveness, job creation, emissions savings, investment costs). This platform will also assess the regulatory compliance of the technologies in each location, identify the safety assurance processes that they will need to follow, as well as the gaps in existing regulations that will need to be addressed.

General information

1. **Organisation:**
2. **Role:**
3. **In a couple of sentences, describe what your role entails:**
4. **Years of experience in the industry:**

The seaplane business

5. **What is the fleet size of the organisation you represent?**
 - Small (0-5)
 - Medium (5-15)
 - Large (15+)
6. **Where do you currently operate?**
7. **How are you currently funded?**
 - Equity financing
 - Debt financing
 - Government funding
 - Other (*please specify*)
8. **From the following list, prioritise the costs that apply to your business from the biggest to the smallest:**
 - General and administrative
 - Commercial/ marketing
 - Pilot/ crew salaries

- Fuel
- Landing/ water airport fees
- Passenger tariffs/ taxes
- Maintenance (airframe, engine etc.)
- Ground support equipment
- Aircraft insurance
- Aircraft lease rates/ financing rates

9. From the following list, prioritise the sources of revenue that apply to your business from the biggest to the smallest:

- (A) Luxury hotels
- (B) Cruise ship arrivals
- (C) Scheduled routes
- (D) Sightseeing/thematic flights
- (E) Charter flights

10. Who is your typical customer?

- Tourists
- Tour operators
- Tourist businesses (hotels, resorts)
- Business travellers
- People travelling for their daily needs
- Other (*please specify*)

11. Looking at the global seaplane market, what are the success of a commercial seaplane business? Please rate your agreement with the following on a scale from 1 (I completely disagree) to 5 (I fully agree). Elaborate on each of the following that you think apply.

- Low operating and maintenance costs
- Consistent demand year-round
- Geographic characteristics of the area served
- Monopoly/ oligopoly operations
- A strong focus on technological innovation
- Sufficient commercial revenue
- A favourable regulatory framework
- Supportive governments at the national/ regional/ local level

Seaplanes in Greece

- 12. Do you have any experience in the Greek seaplane market?**
- 13. How attractive do you consider the Greek seaplane market on a scale from 1 (completely unattractive) to 5 (fully attractive)?**
- 14. What are the reasons that the Greek market is not attractive for your business? Please rate your agreement with the following on a scale from 1 (I completely disagree) to 5 (I fully agree). Elaborate on each of the following that you think apply.**
- Lack of demand
 - High operating and maintenance costs
 - Seasonal variations in demand
 - Geographic spread/ location of destinations
 - Competition from other modes
 - Lack of infrastructure
 - Lack of willing operators
 - Lack of government support and regulatory barriers at the national/ regional/ local level
 - Business models deployed by operators

Focus on the role of the Greek public sector

Only for those who answered yes to 12/ have experience in the Greek market.

- 15. What do you believe is the Greek government's and regulators' perception on commercial seaplane operations?**
- Seaplanes need to be supported by the government
 - Seaplane operators need to act on their own to establish the services
 - Seaplanes do not have a place in the Greek market
 - Indifferent
- 16. More specifically, what do you think the Greek government and regulators need to do to accelerate the development of the local seaplane market?**
- 17. Does the private sector have a role in supporting the Greek government? If so, prioritise the following methods from the most to the least important.**
- Provide technical and advisory services for legislation development
 - Commit to operating in the Greek market for a sustained period of time, to establish trust and stability
 - Help disseminate global best practice
 - Invest in water airport planning and infrastructure
 - Other (please specify)

18. What do you believe is the Greek public's perception on commercial seaplanes in Greece?

- Overall positive
- Overall negative
- Indifferent
- The public do not have enough information.



Focus on sustainability

19. Which of the following sentences apply to your business currently, and which reflect your future goals? What are the barriers to achieving these goals?

If applicable, respond in relation to the Greek context.

	CURRENT CONDITIONS	FUTURE GOALS
Our operations are net zero carbon.		
Our seaplanes are fully accessible.		
We offer subsidised fares for low income groups.		
We will focus on employing local people.		
We follow Corporate Social Responsibility principles and give back to the local communities.		
We work with other operators to facilitate multimodal travel and increase access options for remote communities.		

The role of Di-PEGASUS

As part of Di-PEGASUS, we will develop two innovative technologies for seaplane and water airports operations:

- Innovative de-icing and biofouling mitigation strategies in water airports
- Flexible fleet and operations management methods

For investigating the stakeholders' requirements for these technologies, two separate questionnaires have been developed (attached). Please forward them to your technical team to complete.

Closing

20. Based on this discussion, is there any other way you think Di-PEGASUS could help you? Is there anything to add?



APPENDIX B - CONSORTIUM WORKSHOP OUTPUTS

Use cases workshop at Consortium meeting in Thessaloniki 4th June 2024

Workshop preparation: Sara Molinari (EUSC), Claudia Iasillo (DBL)

Facilitator: Claudia Iasillo (DBL)

Workshop duration: 1h 30

Participants: all members participating to Consortium Meeting


N.	Name	Organization	Short Name
1	Marco Ducci Sara Molinari	EUROUSC ITALIA SRL	EUSC
2	Ioanna Pagoni Ioanna Moscholidou	PANEPISTIMIO AIGAIU	UAEGEAN
3	Claudia Iasillo Paris Vaiopoulos	DEEP BLUE	DBL
4	Vassilis Kappatos Evangelos Spyrou Nikolaos Aggelopoulos Athanasia Maria Moustaka	ETHNIKO KENTRO EREVNAS KAI TECHNOLOGIKIS ANAPTYXIS	CERTH
5	Giovanni Franzini	COLLINS AEROSPACE	ART
6	Olivier Reichert	SAFRAN ELECTRONICS & DEFENCE	SED
7	Filipa Grosso João Silva	CAPGEMINI PORTUGAL	CAP-PT
8	Vivienne Kraeter Stefano Chiocca	RINA CONSULTING SPA	RINA-C
9	Constantin Tzembelicos Alexander Vaizoglou	MEDITERRA HOLDINGS CYPRUS	MH
10	Angelica Mazzina	FONDAZIONE ISTITUTO SUI TRASPORTI E LA LOGISTICA	ITL
11	Komsun Tamanakijprasart Antonios Tsourdos Nico Avdelidis	CRANFIELD UNIVERSITY	CRA

Material: posters (one for each use case), markers and sticky notes

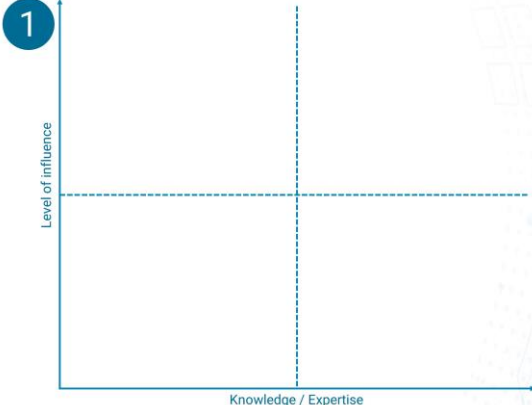
1. Posters

USE CASE 1 - ITALY

Delivery of goods through drones and swarms in the Emilia Romagna Region



1



TECHNOLOGIES TO BE DEVELOPED


1. Innovative swarm-based collision avoidance algorithms for autonomous decision making in-flight
2. New generation control station HMI for handling AI tasked UAS
3. Software for efficient and flexible fleet and operation management (together with Greece)

2

Challenges and obstacles	Resources

3


Activity	Responsible partner	Deadline	Stakeholders involved



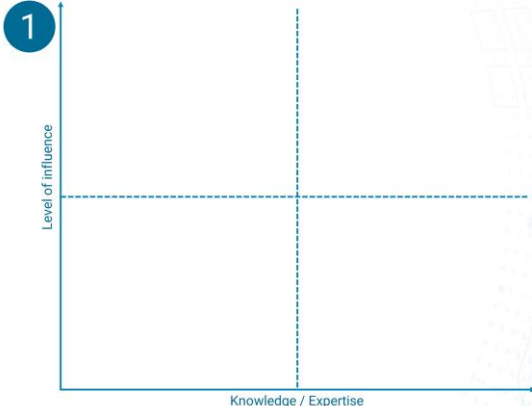
Funded by the European Union

USE CASE 2 - GREECE

Environmentally sustainable transport solutions at water airports in Ionian Islands



1



TECHNOLOGIES TO BE DEVELOPED


1. Software for efficient and flexible fleet and operation management (together with Italy)
2. Tool for automated health status monitoring and health management of aircraft and vertiports/ water airports (together with France)
3. High power ultrasonic technologies for icing and biofouling mitigation strategies at vertiports/water airports (together with France)
4. Sustainable Circular Economy technological framework in aircraft and vertiports/water airports (together with France)

2

Challenges and obstacles	Resources

3

Activity	Responsible partner	Deadline	Stakeholders involved

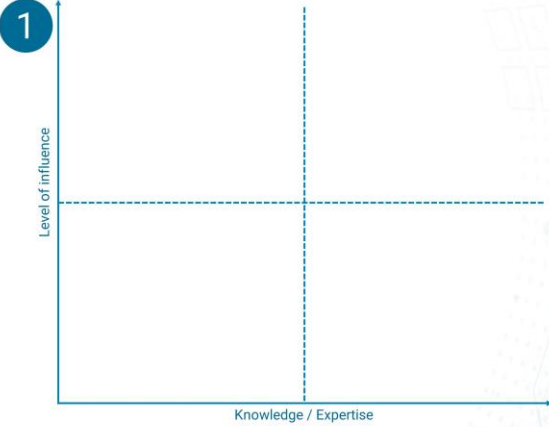


Funded by the European Union

USE CASE 3 - FRANCE

Paris Region AAM (Advanced Air Mobility) Alliance

1



2

TECHNOLOGIES TO BE DEVELOPED

1. Safe and secure, all-weather auto-landing aid at vertiports
2. Tool for automated health status monitoring and health management of aircraft and vertiports/ water airports (together with Greece)
3. High power ultrasonic technologies for icing and biofouling mitigation strategies at vertiports/water airports (together with Greece)
4. Sustainable Circular Economy technological framework in aircraft and vertiports/water airports (together with Greece)

Challenges and obstacles	Resources

3

Activity	Responsible partner	Deadline	Stakeholders involved



2. Workshop agenda

Step 0 | Introduction (5')

The facilitator explains the whole exercise to all participants and divide them in groups. Groups were previously set by EUSC and organized as follows:

	UC ITALY	UC GREECE	UC FRANCE
LEADERS	Paris Vaiopoulos (DBL)	Ioanna Pagoni (UAEGEAN)	Oliver Reichert (SED)
Other participants	Angelica Mazzina (ITL) Giovanni Franzini (ART) Vivienne Krater (RINA-BV) Sara Molinari (EUROUSC) João Silva (CAP-PT) Nikolaos Aggelopoulos (CERTH)	Antonios Tsourdos (CRA) Evangelos Spyrou (CERTH) Stefano Chiocca (RINA-BV) Alexander Vaizoglou (MH) Costantin Tzembelicos (MH) Athanasia Maria Moustaka (CERTH)	Vasilis Kappatos (CERTH) Nico Avdelidis (CRA) Filipa Grosso (CAP-PT) Marco Ducci (EUROUSC) Ioanna Moscholidou (UAEGAN) Komsun Tamanakijprasart (CRA)

Each use case was presented previously during the WP5 presentation ([Minutes](#)).

Each Use Case has a board to work on. The Use Case responsible leads the discussion and answers to possible questions about the Use Case coming from participants. Participants can add their contribution to the board, using markers and sticky notes.

Step 1 | Exercise 1: Stakeholders definition and change agents identification (20')

All participants think of stakeholders to be involved in the specific Use Case and place them according to their level of knowledge/expertise and influence.

Step 2 | Exercise 2: Challenges and resources (20')

The participants are asked to add their thoughts about possible challenges and obstacles of the specific Use Case. At the same time, they are also asked to work on the resources needed to successfully overcome the obstacles.

Step 3 | Exercise 3: Use Case Action plan (30')

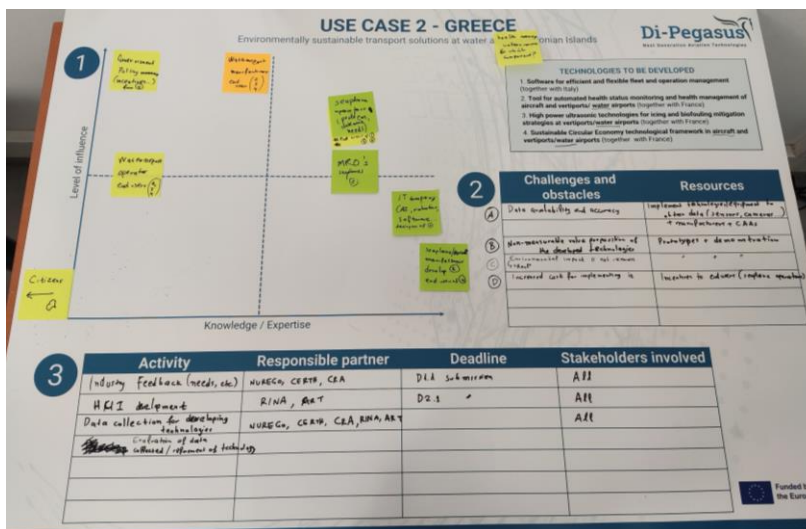
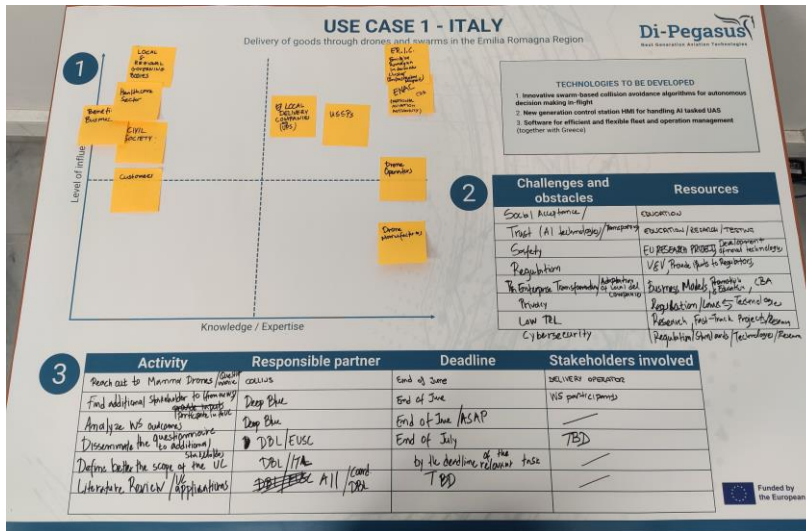
The aim of the exercise is to elaborate an action plan about the implementation of the Use Case, identifying actions, timing, responsibilities and stakeholders to be involved.

Step 4 | Wrap up (15')

Each Use Case responsible reports to all the participants an overview of the activity and of the action plan.

3. Workshop outcomes

All the participants actively took part in the workshops and the objectives of the activity have been achieved. Pictures of the posters are reported below.

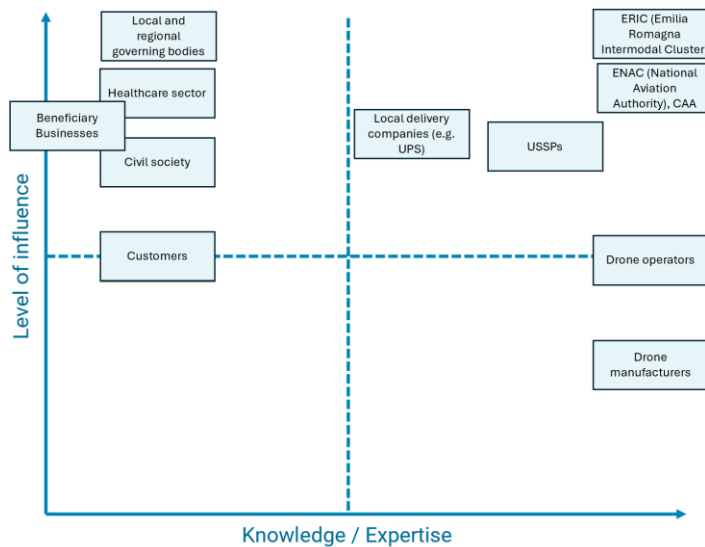


In the next sections, figures and tables faithfully reports what has been written on the posters. Then, in the Summary section the outcomes are analysed.

3.1. Exercise 1: Stakeholders definition and change agents identification

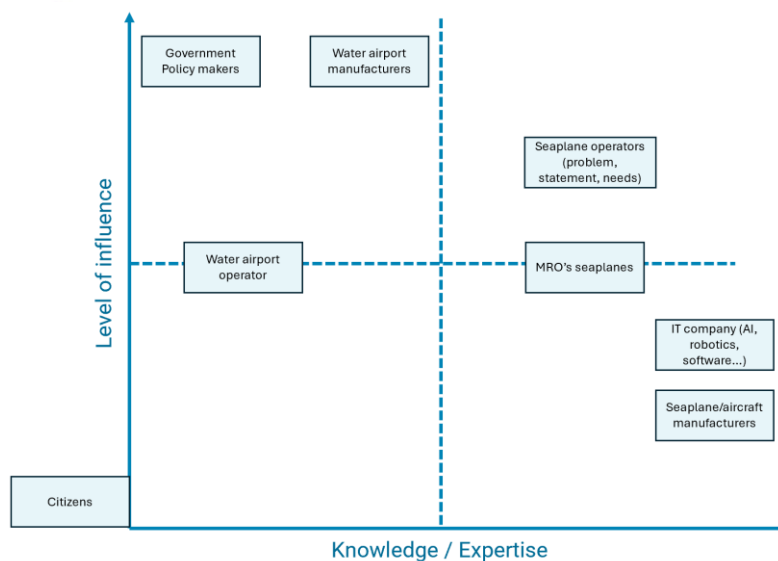
In the first exercise participants were asked to identify the stakeholders to be involved in the specific Use Case and to place them according to their level of knowledge/expertise and influence. The stakeholders collocated in the upper-right quadrant can be considered as the most relevant for the Use case, since they have the most knowledge and influence.

3.1.1. Use Case 1 – Italy

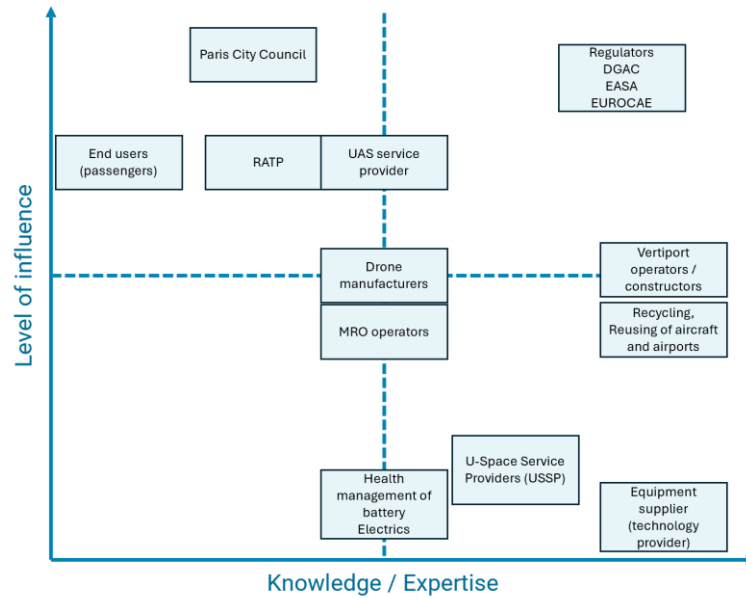


3.1.2. Use Case 2

– Greece



3.1.3. Use Case 1 – France



3.1.4. Summary

The analysis shows that citizen and passengers are the less important stakeholders for all the three use cases, whereas the regulatory bodies are the most important ones. Moreover, for the Italian Use Case, the involvement of the local delivery companies and the Emilia Romagna Intermodal Cluster (ERIC) seems crucial for the Use Case implementation. On the other hand, the seaplanes operators play a key role for the Greek Use Case.

The local and regional governing bodies are considered as stakeholders with a high level of influence but little expertise in the drone/seaplanes/aerotaxi sector. By contrast, manufacturers are considered very experienced but with little influence. Similarly, operators are considered as stakeholders with a high level of knowledge and with a medium level of influence, greater than the manufacturers but not as powerful as for the authorities.

3.2. Exercise 2: Challenges and resources

The participants were asked to add their thoughts about possible challenges and obstacles for the specific Use Case. At the same time, they were also asked to work on the resources needed to successfully overcome the obstacles.

3.2.1. Use Case 1 – Italy

Challenges and obstacles	Resources
Social acceptance	Education
Trust (AI technologies) / Transparency	Education, Research, Testing
Safety	EU research projects, Development of new technologies
Regulation	Verification and validation, Provide inputs to Regulators
Enterprise transformation, adaptation of local delivery companies	Business models, Promotion and education, CBA
Privacy	Regulation/laws ↔ Technologies
Low TRL	Research, Fast-track projects
Cybersecurity	Regulation, Standards, Technologies, Research

3.2.2. Use Case 2 – Greece

Challenges and obstacles	Resources
Data availability and accuracy	Implement technologies/equipment to obtain data (sensors, cameras ...) + manufacturers + CAAs
Non-measurable value proposition of the developed technologies	Prototypes + demonstrations
“Real” environmental impact is not known	Prototypes + demonstrations
Increased costs for implementing it	Incentives to end-users (seaplane operators)

3.2.3. Use Case 3 – France

Challenges and obstacles	Resources
Compliance to safety standard (challenge) Lack of standardisation (obstacle)	Strong relation between technologies providers and vertiport operators
Materials of different vertiports	Contact with ADP Literature, handbooks, construction specifications
Low interest in new technologies	Dissemination material to be distributed
Competing technologies (applies to all?)	Dissemination material to be distributed

What are the target weather conditions?	Consider reference requirements from regulators, OEM, technologies suppliers
---	--

3.2.4. Summary

From exercise 2, it emerges that each use case faces different challenges and obstacles.

For the Italian Use Case, the main obstacles are the social acceptance and the trust in technologies that can be achieved by educating people. The other gaps mainly concern topics such as safety, regulation, technology development, cybersecurity, privacy, which can be overcome through research.

On the other hand, the main challenges for the Greek Use Case are the data availability and the necessity to have test and demonstrations to have concrete values concerning the technologies and the environmental impact. Moreover, the economic aspect is also an obstacle to the development of the Use Case for which more incentives would be needed.

Finally, the obstacles for the French Use Case are the lack of standards and the difficulties to comply with the existing ones, the low interest in new technologies, the competing technologies and the definition of the target values for the weather conditions.

3.3. Exercise 3: Use Case Action plan

The aim of the exercise is to elaborate an action plan about the implementation of the Use Case, identifying actions, timing, responsibilities and stakeholders to be involved.

3.3.1. Use Case 1 - Italy

Activity	Responsible partner	Deadline	Stakeholders involved
Reach out to Manna drones, Questionnaire	ART	End of June 2024	Delivery operator
Find stakeholders (from the workshops) to participate in the Use Case	DBL	End of June 2024	Workshop participants
Analyse workshop outcomes	DBL	End of June 2024	N/A

Disseminate the questionnaire to additional stakeholders	DBL, EUSC	End of July 2024	TBD
Define better the scope of the Use Case	DBL, ITL	By the deadline of the relevant task	N/A
Literature review on Use Case application	All (coordinated by DBL)	TBD	N/A

3.3.2. Use Case 2 – Greece

Activity	Responsible partner	Deadline	Stakeholders involved
Industry feedback (needs, etc)	NUR, CERTH, CRA	D1.1 submission	All
HMI development	RINA, ART	D2.1 submission	All
Data collection for developing technologies	NUR, CERTH, CRA, RINA, ART		All
Evaluation of data collected, refinement of technologies			

3.3.3. Use Case 3 – France

Activity	Responsible partner	Deadline	Stakeholders involved
Gather information on: materials, operating conditions, reference safety standards	SED	End of September 2024	ADP, EASA, EUROCAE
Developing dissemination material	DBL, SED	June 2025	All
Validate technologies against requirements	SED	June 2026	ADP

3.3.4. Summary

From the Italian Use Case emerges the necessity to concretely define the activities to implement in the use case by involving the stakeholders. To this aim, a literature review is considered helpful for define better the use case.

Also in the Greek Use Case the stakeholder's involvement is considered fundamental and in particular it is essential to collect feedbacks from the industries and to gather and analyse the appropriate data for technology development.

Finally, for the French Use Case the next steps consist in gathering information on materials, operating conditions and safety standards, developing dissemination material and validate the technologies against the requirements.



APPENDIX C - ITALIAN WORKSHOP QUESTIONS AND RESPONSES

WORKSHOP 1 “Italian” Use Case

Mentimeter questions (30 min)

General Questions

1. **Have you ever used a drone delivery service before?**

Yes, No.

2. **How often do you require goods delivery services?**

Daily, Weekly, Monthly, Occasionally, Rarely.

3. **In your opinion, which kind of goods would be a good candidate for drone transportation?**

Food/Groceries Retail Products (e.g., electronics, clothing) Medical Supplies Documents/Parcels

Other

4. **Where would you typically require deliveries to be made?**

Residential Address, Workplace/Office Address, Public Location (e.g., park, beach), Industrial zones

Other

5. **What minimum time duration would be acceptable for your deliveries?**

Less than 30 minutes, 30 minutes to 1 hour, 1 to 2 hours, Within 12 hours, Within the day,

Other

6. **How would you prioritize between payload capacity, range, and delivery time when considering drone options for your deliveries?**

Payload capacity is the highest priority, Range is the highest priority, Flight time is the highest priority,

All factors are equally important.

7. **How important is it to you that drone delivery services are environmentally friendly?**

Extremely important, Very important, Somewhat important, Not important.

8. **How concerned are you about the safety of your deliveries?**

Extremely concerned, Moderately concerned, Slightly concerned, Not concerned.

9. **How concerned are you about the integrity of your deliveries?**

Extremely concerned, Moderately concerned, Slightly concerned, Not concerned.

10. **Do you have any privacy concerns related to drone deliveries?**

Yes, No, Maybe.

Fleet Composition

11. What types of drones would you prefer to operate?

- Single-rotor helicopters, Multi-rotor (e.g., quadrotors, excopters), Fixed-wing,
 Fixed-wing hybrid vertical take-off and lift (VTOL), No preference,
 Other (please specify): _____

12. Would you prefer a homogeneous fleet (drones of the same type) or a heterogeneous fleet (drones of varying types and sizes to address different types of scenarios and delivery requirements)?

- Homogeneous, Heterogeneous.

Drone Control and Monitoring

13. What is your preferred method for handling emergency situations (e.g., drone malfunction, adverse weather conditions)?

- Manual intervention, Automated emergency procedures, Both.

14. What is your preferred method for loading and unloading goods from the drones?

- Manual loading/unloading, Automated loading/unloading, No preference.

15. How frequently would you require the ability to reroute drones in real-time based on changing conditions?

- Yes, frequently, Occasionally, Not necessary.

Simultaneous Drone Operations

16. How comfortable are you with the idea of multiple autonomous drones operating simultaneously in your vicinity?

- Very comfortable, Somewhat comfortable, Neutral, Somewhat uncomfortable, Very uncomfortable.

Delivery Operations Automation and Simulation

17. What would be your preferred method for scheduling drone operations?

- Manual scheduling, Automated scheduling based on demand, Both.

18. In case of a failed delivery attempt, how would you prefer the issue to be resolved?

- Reschedule delivery, Pick up from a nearby location, Cancel the order,
 Other

19. How comfortable are you with implementing new innovative AI approaches in automating drone operations?

- Very comfortable, Somewhat comfortable, Neutral, Somewhat uncomfortable, Very uncomfortable.

Appendix : Results of the Mentimeter session in the Italian use case workshop

A total of 19 questions were asked to the participants¹ in the Italian language.

The majority of participants (69%) had never used drones for the delivery of goods, however they would use the service on occasion (38%) or monthly (38%).

Overall, there was a slight preference towards the use of the service to deliver drugs and medical devices, although other goods were also considered (Figure 1).

Secondo te, che tipo di beni/servizi potrebbero essere trasportati con i droni?

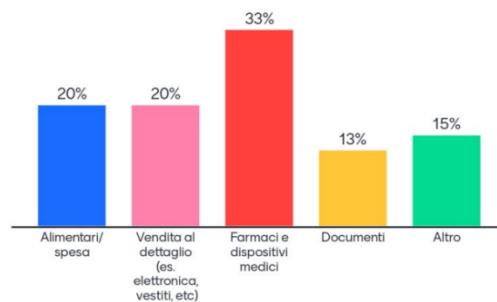


Figure 1 - Preferences of participants for goods to be delivered by drones²

The majority of participants would consider useful the service with a duration for delivery within the day or within 12 hours (Figure 2) and they consider delivery time as the most important option to be taken into consideration (Figure 3).

¹ Questions available on [SharePoint](#) and all results of the Mentimeter session are also available on [SharePoint](#).

² In English: "In your opinion, which kind of goods would be a good candidate for drone transportation?"

- Food/grocery shopping
- Retail (electronics, clothes)
- Medical devices, prescribed drugs
- Documents
- Other

Quale pensi che sia il tempo minimo di consegna accettabile?

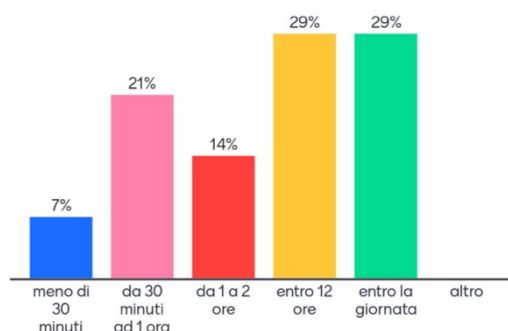


Figure 2 - Preferable delivery time³

Elenca in ordine di importanza le seguenti opzioni:

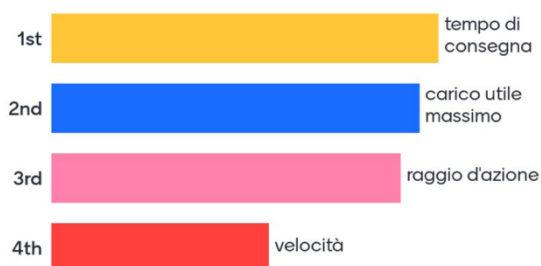


Figure 3 - Priority of options for the use of drones for goods delivery⁴

³ In English: "What is a delivery time you would consider acceptable once the service is established?"

- Less than 30 minutes
- 30 minutes to one hour
- One to two hours
- Within 12 hours
- By the day
- Other

⁴ In English: "List the following option by their importance"

- Delivery time
- Loading capacity
- Radius of action
- Speed

The sustainability of the service was considered as important by almost all participants as long as the security and safety of the service are guaranteed, while privacy was not considered a concern by 40% of participants.

The participants considered a heterogeneous fleet most useful, and 71% of participants indicated fixed-wing hybrid vertical take-off and landing (VTOL) drones as the most useful for logistics operations (Figure 4).

Che tipologia di droni pensi sia preferibile per le operazioni di logistica?

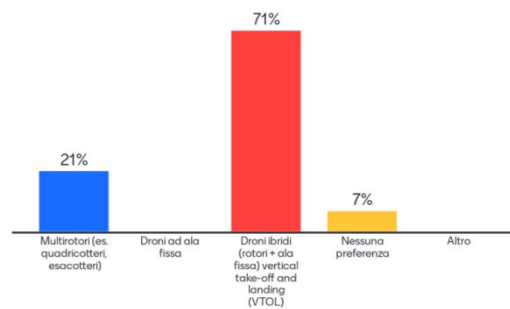


Figure 4 - Typologies of drones for logistics⁵

Regarding the control of operations in case of emergencies, the integration of both manual and automated emergency procedures is considered useful. 71% of participants considered very frequent the need to reroute drones in real-time based on changing conditions.

The level of comfort of participants with the idea of multiple drones operating simultaneously in their vicinity was spanning from very high (33%) to somewhat high (27%) (Figure 5), while the integration of manual and automated scheduling based on demand was considered the preferred method for scheduling drone operations (73%).

⁵ In English: "Which type of drones is preferable for logistics operations?"

- Multirotor (esa- quadri-copter)
- Fixed wing
- Hybrid (rotor+fixed wing) Vertical Take Off and Landing (VTOL)
- No preference

Quanto sei a tuo agio con l'idea di operazioni simultanee di droni autonomi?

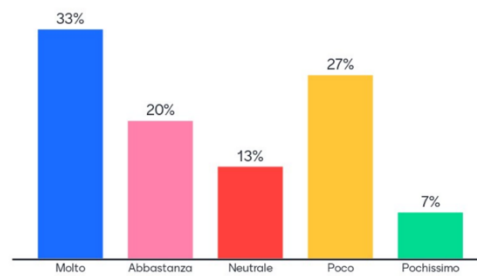


Figure 5 - Level of comfort with simultaneous drone operations⁶

None of the participants considered as alternative solution to failed delivery the order cancellation, but they indicated the rescheduling or pick up from a nearby location as favoured options. Finally, 60% of the participants was comfortable with the idea of implementing new innovative AI approaches in automating drone operations.

⁶ In English: "How much do you feel comfortable with the idea of simultaneous multi-drone autonomous operations?"

- Very comfortable
- Sufficiently comfortable
- Neutral
- Uncomfortable
- Very uncomfortable

APPENDIX D - TECHNICAL QUESTIONNAIRES

Di- PEGASUS technical questionnaire

Innovative de-icing and biofouling mitigation methods

Introduction

A key aim of Di-PEGASUS is to develop cost-effective and environmentally friendly technologies to improve ground operations for seaplanes, VTOL vehicles and drones. These include novel and cost-effective technologies to prevent ice and biofouling formation in water airports and vertiports.

In offshore and water airport infrastructures biofouling accumulation is usually removed using abrasive cleaning methods. The cleaning tools remove and abrade the protective coating from structural components, shortening their lifespan and increasing overall maintenance costs. In addition, the use of biocidal antifouling coating can harm marine life and enter the food chain. The usual method to address snow and ice buildup on vertiport aprons and runways involves the use of deicing chemicals. Such chemicals have been associated with damage to runway lights, ground support equipment and runway pavement, while they can be also hazardous to organic life.

To lower the risks arising from the current de-icing and anti-fouling cleaning methods, Di- PEGASUS will evaluate the use of high-power ultrasonic technologies for icing and biofouling mitigation at vertiports and water airports. These technologies produce bursts of ultrasonic waves at 20–40 kHz, which are transmitted through the materials that are attached to the surfaces affected by biofouling and ice. The ultrasound waves produce cycles of increasing and decreasing pressure on the surface of the material, creating cavitation micro-bubbles in the water. The collapse of micro-bubbles disrupts algae formation. Algae is the base layer of the food chain and its disruption prevents further bioaccumulation. In addition, ultrasonic systems, which are designed primarily for biofouling prevention, could also prevent or delaying ice formation in below freezing conditions. Through cavitation, the formation and collapse of micro-bubbles on the moisture condensation surface layer can disrupt ice nucleation and delay or prevent the subsequent formation of surface frost. As such, the use of novel and cost-effective ultrasonic methods can mitigate ice and biofouling formation on vertiport and water airport infrastructure, enabling safer operation, lower maintenance costs, and reduce the need for de-icing and antibiofouling liquids and coatings.

General information

1. **Organisation:**
2. **Role:**
3. **In a couple of sentences, describe what your role entails:**
4. **Years of experience in the industry:**

Water airports anti-fouling:

5. **Are biofouling issues commonly encountered at your water airports?**
6. **Which parts of your water airport structures are affected by biofouling?**

7. What methods are currently employed by your organisation for the removal of biofouling?
8. What is the frequency of biofouling maintenance on the affected structures?
9. What materials are commonly affected by biofouling in your water airport structures?
10. In which structures of water airports is biofouling cleaning necessary?
11. How are biofouling-prone structures assembled in terms of plates and beam arrangements?
12. How easy is it to access the structures where biofouling needs to be addressed?

Water airports de-icing:

1. Do the water airports you work with operate in sub-zero temperatures, and if so, in which structures is ice removal necessary?
2. In which water airport structures does ice removal prove to be more challenging?
3. What materials are used for the construction of the structures that require de-icing?
4. How are these structures assembled in terms of plates, pillars and beam arrangements?
5. What methods are currently deployed for the removal of ice from water airport infrastructure?
6. How much time is required to apply the current de-icing methods?
7. How often is de-icing required to prevent ice formation?
8. Are there specific areas where current de-icing methods are less effective?
9. How easy is the access to the structures where ultrasonic de-icing can be potentially applied?

Di- PEGASUS technical questionnaire

Flexible fleet and operations management services

Introduction

The goal of Di-PEGASUS is to enable fully autonomous, cost-effective and environmentally friendly operations for seaplanes, VTOL aircraft and drones. This objective will be achieved by developing several enabling technologies targeting both the air and the ground side. In addition, Di-PEGASUS will make recommendations to policy makers and relevant stakeholders that will host these services. To do so, the project includes the development of a digital platform that will evaluate the viability of different business models for the developed enabling technologies at particular locations, using Key Performance Indicators (including cost-effectiveness, job creation, emissions savings, investment costs). This platform will also assess the regulatory compliance of the technologies in each location, identify the safety assurance processes that they will need to follow, as well as the gaps in existing regulations that will need to be addressed.

One of the enabling technologies that will be developed is a set of software services to optimise resource allocation and use for seaplanes, VTOL aircraft and drones. This will include functions such as short-term scheduling and dispatching, short-to-medium-term allocation of aircraft based on forecasted demand, medium-term planning of maintenance activities to schedule vehicle downtime to times with low forecasted demand, ongoing situation reassessment, and flexible, human-accessible configuration of the set of constraints and objectives that dictate how the aircraft fleet and operations should be optimised. These services will be validated using a simulation-based environment.

To facilitate the development of the above services, this questionnaire aims to understand how the different stakeholders engaged manage their operations and what issues they face. The questions focus on the management processes, whether any relevant data is held, and if so, what format it has. In addition, the questions try to gauge the stakeholders' need for and interest in fleet and operations optimisation services.

General information

- 1. Organisation:**
- 2. Role:**
- 3. In a couple of sentences, describe what your role entails:**
- 4. Years of experience in the industry:**

Operations automation

5. To what extent are the following aspects of your operations automated?

Operations/ Level of automation	Manual (emails, post-it boards, personal files, white board, verbal directions)	Information kept in Excel spreadsheets	Information kept in databases	Other data format (please describe)	Automatic alerts generated from data	Optimisation algorithms run on data (please describe)	AI based prediction/ planning engine
Supply chain (parts, materials, equipment)							
Maintenance (scheduled)							
Repairs (unscheduled)							
Ordering							
Integration of new equipment/ parts							

Business objectives

6. Are there any improvements in the operational management that you would like to achieve for the above? For example: “automating repair scheduling”.
7. If you have several goals, how would you prioritise them?
8. Can you place an estimated monetary value for achieving each of these goals?

Data restrictions

9. If you worked with an organisation that can develop tools and methods to achieve the above goals, to what extent would you be willing to share your data with them?

- All data is open
- Some or all data anonymised only (please describe)
- Some or all data restricted (please describe)

10. To what extent is your data automated?

- Completely automated
- Data only available through file transfer (Excel or other)
- Data only available through hand written or other non-formal formats (MS Word for example)
- We have a functioning digital twin

Simulation

11. Do you already have a computerised simulation of segments of your operation?

12. If you do and you worked with an organisation that can develop tools and methods to achieve the above goals, would you allow them to access to the simulation for testing and development?

Actionable data/ feedback

13. To what extent can you provide members with a method for verification and testing of their algorithms?

- Theoretical against simulated data
- Theoretical against actual data
- In a testing environment (test site)
- In real operations

APPENDIX E - VERTIPOINTS AND UAM QUESTIONNAIRE

APPENDIX E

Vertiport design requirements

1. How is ADP organized to define the design of a vertiport? Which partners? What skills?
2. What are the reference documents to which ADP refers?
3. How did ADP use the EASA vertiport guidance document ?
 - For the adaptation of existing heliports into VTOL platforms (e.g. Issy-les-Moulineaux)
 - For the creation of a new, dedicated VTOL infrastructure
 - For the design of the Austerlitz floating barge
4. What are the gaps in the EASA spec (missing information, requirement to be updated)?
5. Is there any ongoing standardization of the specification of a vertiport (EUROCAE working group, etc.)? If yes, which type of information is subject to normalization (or standardization) ? Ex: size/surface of the pad, obstacles/clearances, etc
6. What are the main differences between a vertiport designed for eVTOLs and a helicopter pad?
7. Will the vertiports be reserved for VTOLs only or also authorized for helicopters?
8. Which regulatory entities are responsible for the approval/certification of a vertiport?
9. Who approved the sites used for the Olympic Games experimentation?
10. What additional infrastructure is needed?
 - Premises for ground operators (e.g. workstation for traffic management, separation and priorities management)?
 - Maintenance and servicing premises?
 - Ancillary electrical systems? fuel? other fluids?
 - Passenger reception areas?
 - Other infrastructure (security, roads, logistics, etc.)?
11. Will these vertiport management infrastructures be nearby or at a distance? If remotely, how are safety/maintenance/upkeep/refueling interventions envisaged?

VTOL autoland requirements

1. What are the general specifications for automatic VTOL landing on vertiports (accuracy, etc.)?
2. Is there a safety requirement associated with the function?
3. What are the operating conditions?
 - Day/night operations?
 - All-weather operations (visibility, weather conditions, etc.)?
 - Lighting conditions?
 - Management of restrictions according to equipment availability / operators / ...?
 - Integration of platforms into a connected network for management of availability / information / alerts, etc.?
4. What are the landing constraints?
 - Area dimensions
 - Obstacle clearances
 - EM constraints...?
 - Additional conditions in the case of a “multi-vertiport” hub?
5. What landing methods and principles have already been identified? What is their maturity level?
 - GNSS-based
 - Vision-based (ground markings on the vertiport or nearby, possible lighting, etc.)
 - Beacons-based (radio, laser, IR... passive or active beacons, specific pattern for communication with the aircraft...)
 - Other technologies
6. How will “active” landing aids be used?

- Will they be activated continuously or activated depending on operating conditions (poor weather, low visibility, heavy surrounding traffic, etc.)?
- Will they be automatic or managed by ground operators?
- In the event of proximity to several aircraft, how will the priorities or “directivity” of these aids be managed (if beacon, several aircraft can sensor it at the same time, etc.)?
- Will they be integrated into the AAM traffic management system or will they be managed locally?

