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INTEGRATION OF UNMANNED AIRCRAFT SYSTEMS IN GENERAL AIR TRAFFIC IN PORTUGAL

INTEGRAÇÃO DE SISTEMAS DE AERONAVES NÃO TRIPULADAS NO TRÁFEGO AÉREO GERAL EM PORTUGAL

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Abstract

The integration of Unmanned Aircraft Systems (UAS) into General Air Traffic (GAT) presents complex regulatory, operational, and technological challenges. This study aims to design a conceptual ecosystem model to facilitate UAS integration into Portuguese airspace, ensuring alignment with international best practices. The research methodology combined documentary analysis of international and national literature and semi-structured interviews conducted with subject matter experts. The interviews focused on system, infrastructure, and airspace dimensions.

This analysis identified significant gaps in Portugal's current regulatory strategies, digital platforms, and airspace management, despite partial alignment with European Union Aviation Safety Agency regulations. Based on these findings, a phased ecosystem model is proposed, beginning with the implementation of test zones for U-Space implementation in Lisbon, Porto, Faro, and Funchal, and later expanding to support Urban Air Mobility services nationwide.

The study concludes that the successful integration of UAS into GAT requires a centralized, automated coordination system, strategic infrastructure investment, and formal airspace designation. The proposed model offers a pragmatic and scalable roadmap to overcome existing barriers, contributing to academic knowledge and providing actionable recommendations for policymakers and aviation stakeholders.

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Keywords: UAS Integration; General Air Traffic; Ecosystem Model; U-Space; Airspace Management.

Resumo

A integração de Aeronaves Não Tripuladas (UAS) no Tráfego Aéreo Geral (GAT) apresenta desafios regulatórios, operacionais e tecnológicos complexos. Este estudo visa conceber um modelo de ecossistema conceptual para facilitar a integração de UAS no espaço aéreo português, garantindo o alinhamento com as melhores práticas internacionais. A metodologia de investigação combinou a análise documental de legislação internacional e nacional, com entrevistas semiestruturadas com especialistas na área, estruturadas nas dimensões, sistema, infraestrutura e espaço aéreo.

A análise identificou lacunas significativas nas atuais estratégias regulatórias, plataformas digitais e gestão do espaço aéreo de Portugal, apesar do alinhamento parcial com os regulamentos da European Union Aviation Safety Agency. Com base nestas conclusões, propõe-se um modelo faseado, começando com implementações piloto do U-Space em Lisboa, Porto, Faro e Funchal e, posteriormente, expandindo-se a nível nacional para apoiar os serviços de Mobilidade Aérea Urbana.

O estudo conclui que a integração bem-sucedida de UAS no GAT requer um sistema de coordenação centralizado e automatizado, uma estratégia de investimento nas infraestruturas e formulação do espaço aéreo. O modelo propõe um roteiro pragmático e dimensionável para ultrapassar os constrangimentos existentes, contribuindo para o conhecimento académico e fornecendo recomendações para as autoridades aeronáuticas e para os utilizadores da aviação.

***Palavras-chave*:** *Integração de UAS Tráfego Aéreo Geral; Modelo de Ecossistema; U-Space, Gestão de Espaço Aéreo.*

1. Introduction

"Unmanned systems, particularly autonomous ones, have to be the new normal in ever-increasing areas."

(Sam LaGrone, 2015)

Unmanned Aircraft Systems (UAS) have evolved significantly in recent decades, expanding from military applications to a wide range of civilian and commercial uses. They were first exposed to the public during the Iraq and Afghanistan conflicts, where systems like the *Global Hawk* provided intelligence, surveillance and reconnaissance, while the *Predator* drone played a key role in ground attack missions (Kopardekar et al., 2016). Since then, UAS have increasingly been used in civilian operations, particularly in disaster response and environmental monitoring, and their market continues to grow. According to The Insight Partners (2023a), the compound annual growth rate of the global UAS industry is projected to reach 8.6% between 2023 and 2028. This rapid expansion aligns with broader trends in

automation and digitalization, enhancing operational capabilities across multiple industries (Rios et al., 2020).

The expansion of UAS into the civilian sector began with agricultural applications and quickly extended into industrial and commercial domains, including package delivery and infrastructure inspection (Jung & Craven, 2020). The market for civil UAS is expected to grow at three times the rate of the military sector (The Insight Partners, 2023b). However, the increased presence of UAS in controlled airspace presents challenges for Air Traffic Management (ATM), particularly near airports, where unauthorized drone incursions have disrupted operations (McTegg et al., 2022). The first mitigation efforts focused on countermeasures such as using trained birds of prey or electronic detection and disruption systems (European Authority for Aviation Safety [EASA], 2021a). Nevertheless, regulatory bodies have emphasized that, rather than restricting UAS operations near controlled airspace, they should be integrated into existing air traffic operations (EASA, 2024; Eurocontrol, 2018; Federal Aviation Administration [FAA], 2022d). Several studies have found that integrating UAS into general air traffic (GAT) requires robust technological frameworks and regulatory adaptations (Legros et al., 2019).

This will require the creation of an operational and technological framework to ensure interoperability between manned aviation and a dedicated Unmanned Traffic Management (UTM) system within the broader ATM environment. As noted by Jung & Craven (2020) and Kopardekar et al. (2016), successful UAS integration depends on UTM systems that guarantee safety and efficiency. While the United States (U.S.) of America and European Union (EU) have made progress through initiatives like Single European Sky (SES) ATM research project SESAR and U-Space (EASA, 2024; Eurocontrol, 2018), Portugal does not currently have a dedicated UTM system. The absence of such an infrastructure highlights the need for a national strategy aligned with European regulations and international best practices (Legros et al., 2019). Addressing these gaps is critical, as studies show that a well-designed ecosystem for UAS integration can significantly enhance operational efficiency and safety in national airspace (Rios et al., 2020).

This study proposes a model for an ecosystem that supports the integration of Unmanned Aircraft Systems (UAS) into General Air Traffic (GAT). The study falls under the domain of Military Sciences and addresses a topic in the field of Military Techniques and Technologies, and, more specifically, within the subfield of Command, Control, Communications, Computers, and Information (C4I).

The study is structured around a general objective (GO) and two specific objectives. The main goal is: to develop a tailored ecosystem model for integrating UAS into GAT in Portugal, drawing comparative insights from both the U.S. and European best practices frameworks. The first specific objective (SO1) is: to analyze and compare the ecosystem models for UAS integration in GAT developed in the U.S. and Europe. SO2 is: to assess the current regulatory, operational, and infrastructural conditions for UAS integration in Portugal.

The research question driving this study is: How can a tailored ecosystem model for integrating UAS into GAT in Portugal be developed by drawing comparative insights from the United States and European best practices frameworks?

To define the scope of the research, temporal, geographical, and subject delimitations were established. Temporally, the study focuses on the period from 2017 to the present (the U-Space concept was introduced in 2017 and should be fully implemented by 2040) (Eurocontrol, 2018). The topic is analyzed in a specific geographical area: the Portuguese airspace. However, due to differing interpretations of what constitutes national airspace jurisdiction (Dempsey & Manoli, 2017), relevant legal frameworks and conventions were consulted to delineate these boundaries within the scope of the study. In terms of subject, the study focuses on both aerial and ground-based systems, identifies necessary changes to existing infrastructure – both interoperable and stand-alone – and addresses the conditions required for the safe and efficient integration of UAS into GAT (EASA, 2024; Rios et al., 2020).

This comprehensive analysis aims to contribute to the creation of a structured and effective integration model for UAS that enhances safety, security, and operational efficiency in Portuguese airspace. At the same time, it seeks to align national efforts with broader European and international initiatives. Building on existing literature on air traffic management and unmanned aviation, the study offers insights that hold value for both military and civilian applications (Jung & Craven, 2020; Legros et al., 2019).

2. Theoretical and conceptual framework

2.1. Literature review

The evolution of ATM has been driven by key historical events and growing aviation demands. The Wright brothers' first powered flight in 1903 marked the beginning of modern aerospace development (Crouch, 2023). As aviation expanded, the need for organized airspace became evident, leading to the establishment of the world's first air traffic control (ATC) body at Croydon Airport in the 1920s (Hooks, 1997). This initiative set a precedent for structured air traffic management worldwide (*One Hundred Years of Flight Service*, 2020). However, it was not until the tragic 1956 mid-air collision over the Grand Canyon, which claimed 128 lives, that a standardized air traffic management system was recognized as essential. The incident highlighted the need to integrate ATC, airspace management, and traffic flow regulation to ensure safer and more efficient air travel (Kopardekar et al., 2016).

As traditional aviation systems matured and expanded, the emergence of innovative platforms such as UAS began to reshape the aerospace landscape. Initially designed for agricultural applications, civilian UAS soon found use in industrial and commercial domains, including tasks like package delivery and collection. This rapid growth in civilian UAS operations represents a significant shift in aviation trends, with their expansion expected to outpace that of military UAS by a considerable margin (The Insight Partners, 2023b).

With this growth in global UAS, UAS incidents have also increased (Leslie, 2023). And, in the same way that it was necessary to implement an ATM service for piloted air traffic, the

unmanned aviation sector would also require an air traffic management service for unmanned aircraft, or UTM service.

Nations all over the world expressed concerns for safety and called for the creation of legislation for using UAS. The International Civil Aviation Organization (ICAO), the FAA, the EASA, and the Joint Authorities for Rulemaking on Unmanned Systems are the main organizations that have begun to develop legislation on UAS and its integration into GAT, in addition to the national Civil Aviation Authorities (CAA).

Like with manned aviation, the ICAO developed the "UAS Model" regulations, parts 101, 102, and 149 (ICAO, 2020a, 2020b, 2020c), as well as Advisory Circulars (AC) and the UTM-A Common Framework with Core Principles for Global Harmonization (ICAO, 2020d), to guide and assist the CAA in implementing and supervising UAS operations. Also worth mentioning is Circular 328 on UAS and their operations, which are being considered for implementation in the U.S. National Airspace System, and Doc. 10019 on Remotely Piloted Aircraft System (RPAS) (ICAO, 2011, 2015, 2017b).

The FAA (2022a), through Part 107-Small Unmanned Aircraft Systems of Regulation 14 "Aeronautics and Space" (of the Code of Federal Regulations), set down rules for the use of small UAS and, together with the National Aeronautics and Space Administration (NASA), defined the UTM (FAA & NASA, 2017) and its concept of operations (FAA, 2020).

After the conception of the UTM, it collaborated with industries from the sector to develop the Low Altitude Authorization and Notification Capability (LAANC) to regulate UAS traffic in the vicinity of airports and prevent airspace violations. This system is currently in use at 732 U.S. airports, allowing users to obtain real-time UAS flight clearance (FAA, 2019, 2022c).

Lieb and Sievers (2024) provide a comparative analysis of the European U-space framework and the U.S. UTM system, highlighting regulatory differences and operational challenges. Similarly, Aposporis (2024) offers a global perspective on the regional frameworks that govern UAS integration into ATM, emphasizing the importance of harmonization efforts. Jepsen et al. (2024) introduce the Airspace Advisory Service, which supports detect-and-avoid capabilities for UAS operators utilizing traffic information systems, a crucial development for operational safety.

Current research on automation and artificial intelligence (AI) is significantly influencing the development of UAS integration frameworks. Schwoch et al. (2024) examine the interactions between ATM and UAS operators in U-space operations, highlighting the role of automation in improving coordination. Kalyanam (2023) investigates the application of AI/ML (machine learning) and natural language processing to optimize ATM and UTM operations. Similarly, Von Mengden et al. (2025) present an automated air traffic control interface concept for advanced air mobility aircraft, in an example of the ongoing efforts to enhance human-machine collaboration in airspace management.

Safety remains a critical consideration in UAS integration. Garcia et al. (2023) propose a safety and security technology ontology for UAS operations, while Teutsch et al. (2023) analyze the impact of UAS contingencies on ATC operations in shared airspace. Additionally,

Hashemi et al. (2023) introduce a novel ATM and control methodology that leverages fault-tolerant autoencoders and blockchain applications for UAS operations. G. Singh et al. (2024) highlight recent trends in the UAS-UTM ecosystem, focusing on key integration challenges, including airspace coordination and risk mitigation strategies.

In Europe, the SESAR Joint Undertaking identified the need for an ecosystem (dubbed U-Space) with a high level of digitalization and automation to allow the safe integration of a large number of UAS in the airspace, especially at low altitudes (SESAR Joint Undertaking, n.d.-b). Several research projects have been, and are being, developed to test various technologies to be applied in U-space (SESAR Joint Undertaking, n.d.-a).

One of them is the CORUS (Concept of Operations for EuROpean UTM Systems) consortia, which proposed three new classes of airspace, X, Y, and Z, based on the risk of the operation. These new airspace volumes are based on the existence of separation services and the access requirements of small UAS (sUAS – weighing less than 55 pounds) (CORUS, 2019a).

In turn, the EASA published Regulation (EU) 2019/945 (2019), which defines the categories of UAS, and, soon after, Regulation (UE) 2019/947 (2019), which establishes rules and procedures for the operation of UAS. With the publication of a package of three Implementing Regulations (EU) (2021/664, 2021; 2021/665, 2021; 2021/666, 2021) that would enter into force on January 26, 2023, the EASA identified the regulatory framework for U-Space.

Like other nations, Portugal has been adapting its regulatory landscape to accommodate UAS operations. Neto et al. (2024) discuss software training platforms aimed at bridging the gap between UAS, air traffic controllers (ATCo) and the national airspace system. Portugal has implemented ICAO, NATO (North Atlantic Treaty Organization), EASA, and Eurocontrol regulations, publishing specific amendments as needed (Autoridade Nacional da Aviação Civil [ANAC], 2022a). The country is still in the process of defining a National Strategy for U-space implementation to encourage industry investment and engagement.

To improve the safety and coordination of UAS operations in Portugal, the ANAC (ANAC 2020) launched the "Voa na Boa" application. This mobile platform provides real-time UAS flight authorization, interactive airspace maps, and compliance guidance for drone operators. Similar to the U.S. LAANC system, "Voa na Boa" serves as a digital tool to ensure adherence to airspace regulations and to prevent unauthorized UAS activity near sensitive areas (ANAC, 2023). While this represents progress in operational oversight, challenges remain in integrating Portugal's U-Space infrastructure with broader European frameworks and existing ATM systems.

To overcome those challenges and improve the existing ATM systems, the Portuguese Air Force (PrtAF) and NAV Portugal are exploring shared wide area multilateration (WAM) systems to improve surveillance capabilities (NAV Portugal, 2015; Rodrigues, 2010), but the complexity of integrating UAS into controlled airspace requires further automation and interoperability solutions (Schwoch et al., 2024). However, interoperability concerns remain, as the density of U-space operations could strain ATM infrastructure (Jadhav et al., 2021). Schwoch et al. (2024) highlight potential automation benefits that could address some of these challenges.

One of the main advantages of using and sharing the WAM system is that both organizations already have protocols in place for radar information sharing, facilitating rapid radar visualization of the territory. However, this system has a significant limitation: it is not compatible with other radar systems. This would require the acquisition of additional sensors, making it unfeasible to share the visualization of NAV's existing sensors, leading to higher costs and operational challenges.

Regarding airspace, some challenges must be considered, namely, the capacity of each sector, the necessary routes and approaches, the existing ATC and ATM systems, and the traffic management processes. Furthermore, geographic areas where U-Space can be developed is yet to be defined (Decree-Law no. 87/2021, 2021, p. 8). Airspace classes must be created for U-Space to distinguish the type of operation and services provided, in addition to the mandatory services prescribed by the Implementing Regulation (EU) 2021/664 (2021) and other Regulations.

It is still early to understand the level of interoperability that will be reached, as the sudden integration of the U-Space infrastructure, which will have to support a much higher density of devices than that of manned aviation, could overload the ATM infrastructure to such an extent that it would be impossible to use both (J. Pereira, Head of CNS Coordination Unit at Eurocontrol, online interview, June 2, 2022 and F. Camacho, Head of the Unmanned Aircraft Department at ANAC, online interview, July 18, 2022). However, with the introduction of U-Space airspace in the vicinity of airports, a certain level of interoperability will be required to keep both infrastructures safe.

The analysis of existing literature underscores the ongoing global efforts to integrate UAS into general air traffic (GAT) while balancing safety, efficiency, and regulatory compliance. A comparison between Europe and the U.S. reveals fundamental differences in regulatory structures, technological implementations, and integration strategies. Lieb & Sievers (2024) highlight the divergence between the European U-space framework, which emphasizes structured airspace segmentation, and the U.S. UTM system, which focuses on flexible, demand-driven solutions. Additionally, Aposporis (2024) identifies the need for harmonized frameworks to ensure interoperability across regions.

Portugal's approach to UAS integration reflects broader European regulatory trends, but faces specific national challenges. Neto et al. (2024) highlight the role of software training platforms in bridging gaps between UAS operators and air traffic controllers, but Portugal still lacks a fully defined national U-space strategy. While regulations based on ICAO, NATO, EASA, and Eurocontrol guidelines have been adopted, key challenges persist, particularly in surveillance, airspace management, and industry engagement.

Given these insights, there is a clear need for a comprehensive ecosystem model to facilitate the integration of UAS into GAT in Portugal. Such a model must address regulatory alignment, automation advancements, and operational frameworks to ensure the safe and efficient coexistence of manned and unmanned aviation. Current literature identifies the importance of refining Portugal's U-Space strategy (Kalyanam, 2023), leveraging automation

technologies, and implementing innovative safety solutions (Garcia et al., 2023), as well as enhancing digital platforms such as "Voa na Boa" to streamline UAS operations and regulatory compliance. The development of an adaptable and scalable ecosystem is therefore critical to support the sustainable growth of UAS operations in Portuguese airspace.

2.2. Concepts

This section defines the core concepts relevant to UAS integration into GAT and presents the analysis model guiding the study.

U-Space: refers to a set of new digital services and procedures designed to safely and efficiently integrate UAS into controlled and uncontrolled airspace. Defined primarily by the EASA and operationalized through the SESAR initiatives, U-Space includes services such as network identification, geo-awareness, flight authorization, and dynamic airspace management. The purpose of U-Space is to enable large-scale UAS operations while ensuring safety, security, and respect for existing manned aviation and airspace users (Implementing Regulation [EU] 2021/664, 2021).

Ecosystem: according to the biological definition, an ecosystem is the "set formed by an environment and the living beings that, in normal mutual relationships, occupy that environment; ecological system." (Porto Editora, n.d.). By analogy, in this study, an ecosystem is understood as the set of systems, infrastructures, and airspace in which UAS will be integrated, as well as how they relate.

System: a set of interdependent components that interact to achieve a common purpose (Chiavenato, 2003, p. 492). This study addresses various aerial and ground systems. For example, an aerial system includes the Communication, Navigation, and Surveillance (CNS) equipment on a UAS that forms a system to keep the UAS in flight. A ground system consists of the operator and Ground Control System, which provide C2 for the UAS.

Infrastructure: the set of elements or services that are considered necessary for an organization to function or for an activity to be developed effectively (Editora Conceitos.com, 2014). In the case of ATM infrastructure, it comprises the integrated air traffic of manned aviation and airspace, including air traffic services, airspace management, and air traffic flow management, ensuring continuous facilities and services in collaboration with all parties involved (ICAO, 2016). In this study, it refers to the equipment and services necessary for the integration of UAS into general air traffic.

Airspace: the mass of air surrounding the Earth's surface, including land and maritime areas, and the lower boundary of space. The upper boundary is not clearly defined due to various legal and physical considerations (Dempsey et al., 2017). To define the upper boundary in this study, the operational limits of manned and unmanned aircraft are considered: manned aircraft (Concorde) at FL600 (FAA, 1979) and unmanned aircraft (Global Hawk) at FL600 (Northrop Grumman, 2013). The Chicago Convention and the United Nations Convention on the Law of the Sea establish that sovereign airspace corresponds to the land areas and territorial waters of a state (Law no. 34/2006, 2006). Therefore, in this study, national airspace is defined as:

- The lateral limits coincide with the outer boundaries of the Lisbon and Santa Maria Flight Information Regions.
- The ground surface and mean sea level define the lower limit.
- The upper limit is set at FL600 altitude.

2.3. Analysis model

To focus and organize the research, key concepts, dimensions, and indicators were defined, which helped to design the questions used in the semi-structured interviews and guided the documentary analysis. The central research problem addresses the creation of an ecosystem model for integrating UAS into GAT in Portugal, aiming to ensure safety, regulatory compliance, and operational efficiency. The complexity of this task lies in harmonizing technological innovation, infrastructure development, and legal frameworks to enable the safe coexistence of manned and unmanned aviation.

To explore this issue, the main research question was formulated: "How can a tailored ecosystem model for integrating UAS into GAT in Portugal be developed by drawing comparative insights from the United States and European best practices frameworks?"

This question frames the investigation, directing the analysis toward identifying the systems, infrastructures, and regulatory adaptations required for effective UAS integration. The GO of this research is "to develop a tailored ecosystem model for integrating UAS into GAT in Portugal, drawing comparative insights from both the U.S. and European best practices frameworks". To achieve this GO, the following analysis model was created.

Table 1 – Analysis model.

Specific Objectives	SO1	To analyze and compare the ecosystem models for UAS integration in General Air Traffic developed in the U.S. and Europe		SO2	To assess the current regulatory, operational, and infrastructural conditions for UAS integration in Portugal
Subsidiary Questions (SQ)	SQ1	What are the key similarities and differences between the U.S. and European approaches to UAS integration into GAT, and what lessons can be drawn from them?		SQ2	What is the current state of UAS integration into GAT in Portugal, and what gaps or opportunities exist in the national context?
Concepts	System		Infrastructure		Airspace
Dimensions	Terrestrial	Aerial	Interoperable	Independent	Classification
Indicators	Requirements		Structure		Rules
Data collection techniques	Document analysis Semi-structured interviews				

The analysis model provides the conceptual foundation for developing a comprehensive ecosystem that integrates UAS with manned aircraft within shared airspace classes, including the necessary stakeholders, systems, infrastructures, and regulatory frameworks.

3. Methodology

The study methodology follows the rules and standards established by the Military University Institute (IUM) (Fachada et al., 2022).

The research field analyzed in this paper is UAS, which encompasses the study and development of various aspects related to unmanned aircraft, including design, control, navigation, communication, and sensing technologies, among others, and applications in civil and military domains (Valavanis & Vachtsevanos, 2015).

Considering the research object and objectives, an objectivist approach is deemed the most suitable methodology for studying this topic. Since the objective of this study is to propose a concrete model for the integration of UAS into the GAT, an ontological stance directed towards the study of reality as a concrete and objective structure is required (Santos & Lima, 2019).

The research approach was a deductive reasoning process, which progresses from general ideas to specific conclusions, in this case, by analyzing the situation in the U.S. and the prospects for Europe. Lessons learned from these analyses were then adapted to incorporate best practices for Portugal.

A qualitative research strategy was adopted, utilizing the following data collection methods:

- Semi-structured interviews (Flick, 2005) with recognized experts and specialists to obtain expert knowledge, contribute, and validate the ecosystem model proposed; and
- Reference documentation, including scientific articles and various legislative documents.

A case study research design was employed, as it allows for a thorough analysis of the national case study, aiming to provide a rigorous description of the observation unit (Santos & Lima, 2019).

In the first phase, a literature review (e.g., scholarly articles, legislation, projects, and case studies) was conducted to define the research object, establish objectives, delineate the topic, formulate the research problem, research questions, and the methodological procedure described. The search terms included concepts such as UAS, RPAS, U-Space, UTM, ATM, DAA, and regulations from the FAA and EASA. The initial search returned hundreds to thousands of documents, depending on the database used. Approximately 50 to 100 documents were analyzed in detail, and about 30 to 50 were ultimately used. The selection criteria prioritized documents published within the last 10 years, focusing on peer-reviewed academic articles, official regulatory publications, and technical project reports directly related to UAS integration, U-Space development, or airspace management innovations.

In the second phase, answers to the research questions were obtained through a analysis of documentation issued by the FAA, the EU (European Defense Agency, SESAR, EASA, and Eurocontrol), NATO, and Portugal, complemented by semi-structured interviews.

To enrich the bibliographic research and ensure the relevance of the findings, semi-structured interviews were conducted with 13 key stakeholders from regulatory authorities (Table 2), air navigation service providers, and UAS-related organizations. These interviews were carried out through videoconference, email, and in-person meetings, and served to collect detailed qualitative insights on the practical, regulatory, and technological dimensions of UAS integration into Portuguese airspace. This method enabled a flexible yet structured exploration of expert perspectives, contributing both to the validation of the proposed ecosystem model and to the identification of context-specific challenges that were not evident in the documentary analysis.

Table 2 – List of interviewees.

Name	Function	Affiliation
Rui Silva	Air Traffic Controller	NAV Portugal
Marcos Costa	Head of the Strategy, Planning, and External Relations Office / Strategic Development and External Relations	NAV Portugal
Clélio Ferreira Leite	President	APANT[1]
Fábio Camacho	Head of the Unmanned Aircraft Department	ANAC
Maj Coelho da Silva	Commander of Squadron 991 (Unmanned Aircraft)	PrtAF
Nathalie Hasevoets	EDA Project Officer UAS Certification and ATM Research	EDA
Ross McKenzie	Staff Officer Joint Capability Group UAS	NATO
Stephen Hanson	Secretary of Air Traffic Management Communications, Navigation & Surveillance Advisory Group	NATO
Jorge Pereira	Head of CNS Coordination Unit	Eurocontrol
Edgar Reuber	Head of Civil-Military ATM Coordination	Eurocontrol
Manu Lubrano	CEO and Co-Founder	INVOLI
Joseph Rios	Chief Technologist Aviation Systems Division	NASA
Jessica Ann Orquina	Acting Manager UAS Integration Office / FAA Aviation Safety	FAA

Interview responses were analyzed using Bardin's (2016) content analysis approach, focusing initially on airspace classification and UAS typology to identify key indicators aligned with the analysis model.

The qualitative data obtained from the semi-structured interviews were analyzed through thematic coding. Interview responses were manually organized according to the three analytical dimensions defined in the analysis model: system, infrastructure, and airspace. Key themes and insights were identified by systematically grouping similar responses and aligning them with the predefined indicators outlined in Table 1. This coding process enabled the consistent interpretation of expert opinions and facilitated the validation and enrichment of the conceptual ecosystem model.

[1] Associação Portuguesa de Aeronaves Não Tripuladas (in English, Portuguese Association of Unmanned Aircraft).

4. Presentation of data and analysis of results

This section presents the study's results, based on two primary sources: documentary analysis of international and national regulatory frameworks, technical studies, and institutional publications; and qualitative data obtained through semi-structured interviews with subject matter experts, including representatives from regulatory authorities, air navigation service providers, and UAS operators. The findings are organized according to the dimensions and indicators defined in the analysis model (Table 1): system, infrastructure, and airspace. This approach ensures a systematic interpretation of the data and facilitates answering the subsidiary research questions (SQ1 and SQ2).

4.1. System

The "system" dimension concerns the technological and regulatory platforms supporting UAS integration.

In the U.S., the integration of UAS into GAT has been driven largely by defense-related technological advancements and operational experience in conflict zones such as Iraq and Afghanistan (Bole, 2020; Gross, 2022). This context fostered a proactive regulatory environment where initiatives such as the LAANC system and UTM pilot programs were developed to automate flight authorizations and enable scalable operations (FAA, 2022d). Interviews confirmed that the centralization and automation achieved through the LAANC significantly accelerated UAS access to controlled airspace.

In contrast, Europe has followed a more research-oriented pathway, investing heavily in programs such as ERICA and CORUS to establish comprehensive regulatory and operational frameworks for UAS integration (CORUS, 2019b; SESAR Joint Undertaking, 2019). The European model is set out in a U-Space regulatory package that will be implemented in phases (U1–U4 phases), aiming to achieve high levels of digitalization and automation across the continent (EASA, 2021b). However, interviewees pointed out that the lack of uniform implementation among Member States remains a significant challenge, hindering cross-border drone operations.

In Portugal, national regulations largely align with EASA directives, ensuring mutual recognition of UAS certifications, pilot competencies, and operational authorizations within the EU (ANAC, n.d.). Nevertheless, the interviews revealed that the absence of a comprehensive National UAS Strategy has delayed the proactive development of supporting systems such as a centralized UTM or U-Space platform. Currently, Portugal relies on basic platforms like "Voa na Boa" (ANAC, 2020), which fall short of providing the dynamic flight planning and real-time coordination necessary for advanced UAS operations.

4.2. Infrastructure

The infrastructure dimension refers to the physical and digital networks required for safe UAS operations.

In the U.S., robust investments in communication, navigation, and surveillance infrastructures were made early to support UAS operations, enabling the reliable execution of BVLOS (Beyond Visual Line of Sight) missions (FAA, 2022b). The systematic integration of these technologies into existing ATM frameworks provided a solid foundation for scaling operations.

Europe, by contrast, adopted a phased and fragmented approach to infrastructure development linked to the U-Space implementation stages (EASA, 2021b). Research projects such as CORUS highlighted the need for scalable, interoperable ground infrastructures, but also revealed that Member States vary considerably in terms of readiness (CORUS, 2019b).

Portugal has also adopted this fragmented approach. Interviews with national stakeholders highlighted that, beyond regulatory compliance, there is a substantial gap in physical infrastructures, such as ground-based DAA systems, interoperable C2 networks, and dynamic airspace management tools. Unlike Spain, which has adopted a proactive, public-service-oriented U-Space deployment strategy (Ministerio de Transportes, 2018, 2022), Portugal has so far taken a reactive stance, implementing services only in response to operator demands rather than through a strategic infrastructure plan. Similar cautious approaches are found in France, Germany, and Italy, reflecting a broader European trend (Martín-Lammerding et al., 2022).

4.3. Airspace

The airspace dimension concerns the legal and operational structures that manage risk and define access for UAS.

In the U.S., airspace access for UAS was enabled primarily through standardized national rules supported by the LAANC, which made it possible to conduct low-risk drone operations in controlled airspace below 400 feet (FAA, 2022d). This approach simplified operator procedures and created a predictable operational environment.

In Europe, airspace is structured by establishing U-Space zones based on operational complexity and risk management criteria (EASA, 2021b). However, as noted by interviewees, inconsistencies between Member States in defining these zones present serious challenges to operational predictability and cross-border interoperability.

In Portugal, although legally aligned with EASA's framework, no official U-Space zones have been designated. National regulatory authorities maintain a reactive approach to airspace segmentation, pending operational demand. This has created uncertainty for UAS operators seeking to engage in more complex operations, such as BVLOS missions and Urban Air Mobility (UAM) initiatives. The case study of Squadron 991 (E991) of the PrtAF reflects this limitation: while operationally ready and equipped with UAS capabilities, its missions are constrained by the absence of clearly defined airspace structures for unmanned operations, which increases mission planning complexity and administrative burden.

4.4. Brief overview: lessons learned

This section addresses the two subsidiary questions:

– SQ1: What are the key similarities and differences between the U.S. and European

approaches to UAS integration into GAT, and what lessons can be drawn from them?
- SQ2: What is the current state of UAS integration into GAT in Portugal, and what gaps or opportunities exist in the national context?

Regarding SQ1, the findings presented in Sections 4.1 to 4.3 show that Portugal is still in an early phase of UAS integration into GAT. While national regulations are harmonized with the EASA framework, key structural gaps remain:

- System-level gaps include the absence of a comprehensive National UAS Strategy and the lack of a centralized UTM/U-Space platform, limiting automation and dynamic airspace coordination;
- Infrastructure gaps are evident in the lack of interoperable communication, surveillance, and ground-based detect-and-avoid systems required for BVLOS and Urban Air Mobility operations;
- Airspace management remains reactive, with no designated U-Space zones, increasing uncertainty as well as the administrative burden of complex missions.
- Nonetheless, Portugal has opportunities to leapfrog ahead by:
- Learning from more mature UAS implementations in Europe (e.g., Spain) and the U.S;
- Leveraging existing regulatory alignment with the EASA;
- Taking a proactive stance in infrastructure and digital service development to enable scalable, safe UAS operations.

As for SQ2, a comparative analysis of the U.S. and European frameworks revealed key insights:

- The U.S. model is centralized, regulator-driven, and focused on automation and national standardization, with operational tools such as the LAANC enabling low-friction airspace access;
- Europe uses a phased, research-led model (U-Space U1–U4) aimed at harmonizing across diverse national systems, but implementation varies significantly across countries;
- Both regions emphasize automation, interoperability, and digital services, but Europe must deal with challenges due to institutional fragmentation.

The Portuguese ecosystem can benefit from both (the U.S. focus on centralized services and Europe's structured regulatory roadmap) by adapting these strategies to its institutional and operational realities.

These insights underpin the following strategic priorities for Portugal:

- Establish a centralized, automated digital platform (System dimension);
- Invest in interoperable infrastructure to support BVLOS and UAM operations (Infrastructure dimension);
- Designate U-Space zones with a clear, risk-based operational framework (Airspace dimension).

These findings serve as the foundation for the ecosystem model proposed in the next chapter, ensuring that the identified gaps, opportunities, and international best practices inform the proposed solution.

5. Ecosystem proposal for Portugal

Building on the analysis of the system, infrastructure, and airspace dimensions presented in the previous section, this chapter proposes a conceptual ecosystem model designed to address the critical challenges identified for UAS integration into GAT in Portugal.

5.1. Current state vs implementation needs

To facilitate the implementation of the proposed ecosystem model, it is essential to distinguish between the components that already exist in Portugal and those that must still be developed.

Table 3 summarizes the current implementation status of each key component of the proposed ecosystem model, highlighting what is already operational in Portugal and what remains to be developed to ensure full integration of UAS into GAT.

Table 3 – Current Status and Implementation Needs for the Portuguese UAS Ecosystem.

Aspect	Status	Action Needed
Regulatory Alignment with EASA	In place	Strengthen U-Space regulation with national strategy
"Voa na Boa" UAS Registration Platform	Exists	Upgrade to real-time U-Space coordination
WAM, SSR	Partially exists	Integrate UAS visibility into ATM systems
UAS Operations (e.g., Squadron 991)	Exists (limited)	Expand to BVLOS and integrate with civil ATM
UACS Platform	Not yet implemented	Develop and deploy UACS nationwide
U-Space Airspace Designation	Not yet implemented	Define U-Space zones and airspace classes
Public Reporting and Conspicuity Standards	Incomplete	Publish standards for public involvement and mandatory conspicuity
Mobile Network Support for UAS	Urban areas	Assess and expand capacity for dense UAS operations

5.2. Model components

The proposed ecosystem model is composed of several key entities whose coordinated interactions are essential to ensure the safe and efficient integration of UAS into GAT in Portugal. Table 4 outlines the main stakeholders and their respective responsibilities within the model, including regulatory bodies, service providers, infrastructures, and UAS operators.

Table 4 – Model Components.

Entities	Systems	Infrastructures	Airspace
ANAC	Conspicuity	Mobile networks	ATM
AAN			
NAV			
PrtAF		SSR[2]/WAM	
SFS[3]	DAA		U-Space
CISP[4]		USSP architecture	
USSP[5]			
USS[6]	UACS		
UAS operators			
Population			

Figure 1 illustrates the proposal for U-Space Authorization and Coordination System (UACS), a digital platform that forms the technological backbone of the proposed ecosystem model. It supports real-time data sharing, flight coordination, and communication between UAS operators and air traffic stakeholders, contributing directly to the development of the operational UAS ecosystem in Portugal.

[2] Secondary Surveillance Radar.
[3] Security Forces and Services.
[4] Common Information Services Provider.
[5] U-Space Service Provider.
[6] UAS Service Suppliers.

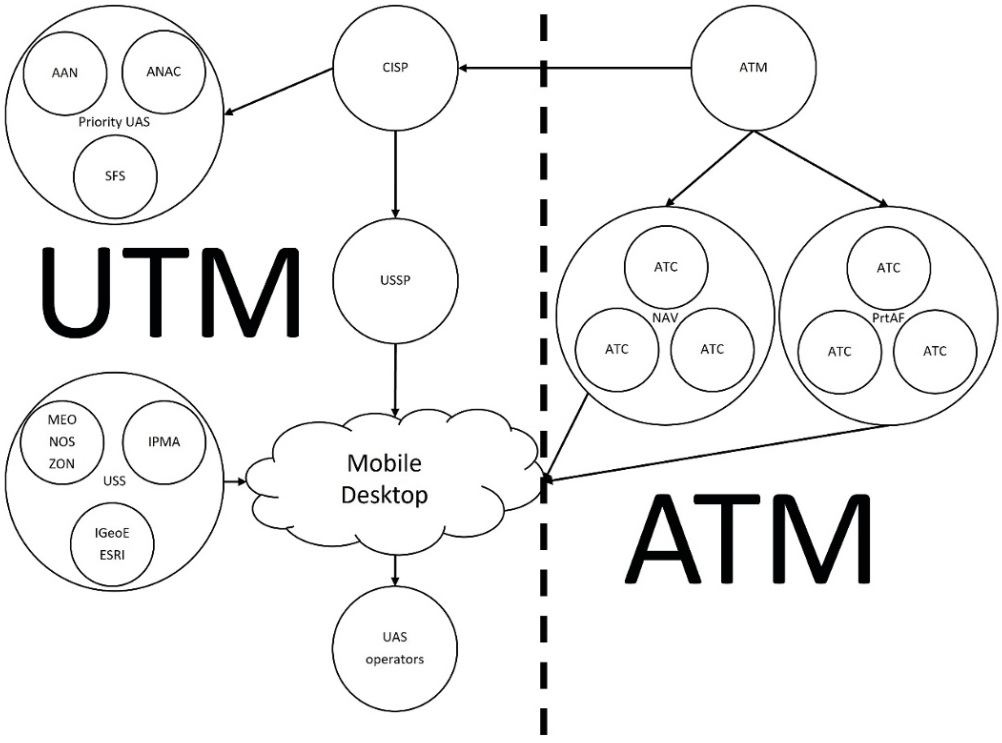

Figure 1 – Proposal for U-Space Authorization and Coordination System (UACS).
Source: (Lourenço, 2023).

As the use of UAS continues to expand, integrating drones safely into shared airspace has become a critical challenge. The proposed ecosystem model offers a blueprint for managing this integration in a structured way, facilitating coordination between unmanned and manned aviation. Its digital foundation, particularly the UACS, enhances adaptability and scalability, allowing the model to evolve into a mature UAS operational ecosystem over time.

Building on the regulatory framework characterized in Section 4.2, the proposed ecosystem model defines the roles and interactions of key entities essential for the safe integration of UAS into Portuguese airspace.

Regulatory bodies such as the AAN, the ANAC, and the SFS are some of the most influential entities in this ecosystem. These organizations define the legal framework governing both manned and unmanned aviation. Their responsibilities range from certifying UAS operators and enforcing safety protocols to monitoring compliance and managing airspace restrictions. Without these regulatory bodies, the integration of drones into controlled airspace would lack the necessary oversight to prevent risks and conflicts.

To facilitate real-time coordination and data sharing within the proposed ecosystem model, the CISP is envisioned as a central hub for exchanging critical airspace information.

The CISP would act as an intermediary between UAS operators, USSPs, and air traffic management authorities in this framework. The CISP would ensure that all stakeholders operate with the most accurate and up-to-date information by continuously updating airspace restrictions, traffic conditions, and other operational data. This seamless exchange is essential for maintaining situational awareness, reducing conflicts, and enhancing the overall safety of drone operations.

A key component of the U-Space system is the USSP, which offers specialized air traffic management services tailored to drones. These providers enable safe and automated UAS operations by handling flight authorization, conflict detection, and real-time tracking of unmanned aircraft. By working closely with the CISP, USSPs integrate drone activity into the broader airspace management system, ensuring that UAS missions are conducted in compliance with regulations and in harmony with manned aviation.

Directly supporting drone operators is the UAS Service Supplier (USS), which includes organizations such as telecommunications providers (e.g., MEO, NOS, and ZON), meteorological services (e.g., IPMA), and georeferencing companies (e.g., ESRI and CIGeoE). Mobile telecommunications networks are another key infrastructure for sUAS, as they provide connectivity that covers most urban areas – where drone operations are expected to be most concentrated (F. Camacho, op. cit.). However, with the increase in sUAS operations in urban environments and the expansion of U-Space, USSPs must assess whether existing telecommunications networks can handle the increased demand in urban airspace (C. F. Leite, Chairman of the Portuguese Unmanned Aircraft Association, online interview, June 18, 2022, op. cit.). If network capacity proves insufficient, alternative solutions such as strengthened signal coverage or Global Navigation Satellite Systems (GNSS) must be implemented (Koumaras et al., 2021; Modi et al., 2021).

These entities provide essential operational services such as flight planning, compliance verification, and communication with ATC. Acting as a bridge between UAS operators and the U-Space infrastructure, USSs play a vital role in ensuring that drones operate safely, efficiently, and within legal boundaries.

Additionally, sUAS capable of interacting with the manned aviation CNS infrastructure – including SSR and WAM surveillance assets – should integrate with these systems to enhance visibility and situational awareness for ATC (M. Costa, Head of Strategy, Planning and External Relations Office of NAV Portugal, online interview, June 14, 2022). This will allow ATC to track and manage drone operations more effectively, ensuring safer interactions between manned and unmanned aircraft.

Meanwhile, the ATM system, along with ATC service providers (NAV Portugal and the PrtAF), oversees the coordination of both manned and unmanned flights. NAV Portugal is responsible for general air traffic control, while the PrtAF manages operations in military airspace. These entities work together to prevent conflicts, enforce regulations, and ensure smooth operations for all airspace users.

At the core of this system are the UAS operators, who rely on these interconnected services to conduct their missions safely. Whether flying for commercial, industrial, or recreational purposes, operators must adhere to airspace regulations, coordinate with service providers, and maintain situational awareness to avoid conflicts with other airspace users. Their ability to access real-time data, obtain the necessary authorizations, and integrate with ATC services is crucial to ensure safe and efficient UAS operations.

Based on the model presented by the CORUS (CORUS, 2019a), new classes of airspace should be proposed for U-Space, namely, to disentangle the types of operations and services provided, classified by level of risk, as shown in Table 5, in addition to the mandatory services prescribed by the Implementing Regulation (EU) 2021/664 (2021) and other Regulations.

Table 5 – Proposed U-Space airspace classes.

Class	Category	Operation type	Separation	Service provided	Mandatory flight plan
UA	Certified	Autonomous	Strategic and autonomous separation		Yes
UB		BVLOS and IFR	Yes	Strategic and tactical separation	Yes
UC		BVLOS and IFR	Yes	Strategic and tactical separation and traffic information	Yes
		VLOS[7] and VFR	Yes		Yes
UD	Specific	BVLOS and IFR	Yes	Strategic and tactical separation between (btn) BVLOS/BVLOS and btn BVLOS/VLOS and traffic information	Yes
		VLOS and VFR	No		Yes
UE	Open	BVLOS and IFR	Yes	Strategic and tactical separation btn BVLOS/ BVLOS and traffic information when possible	Yes
		VLOS and VFR	No		No
UF	Open	BVLOS and IFR	No	Traffic information when possible	Yes
		VLOS and VFR	No		No
UG	Open	VLOS and VFR	No		No

Source: (Lourenço, 2023).

Manned air traffic that needs to use U-Space will have to be conspicuous and obtain the same authorizations that are required for UAS. In addition, separations will also be made between manned and unmanned aviation, as in the existing airspace classes (F. Camacho, *op. cit.*).[7]

According to the North American model, the creation of U-Space in the vicinity of airports must account for the limits of conical surfaces, prohibited flight areas (through geofences), and the upper limits permitted in each flight sector (Figure 2), and this information must be synchronized with the entire USSP infrastructure with the UACS.

[7] Visual Line-Of-Sight.

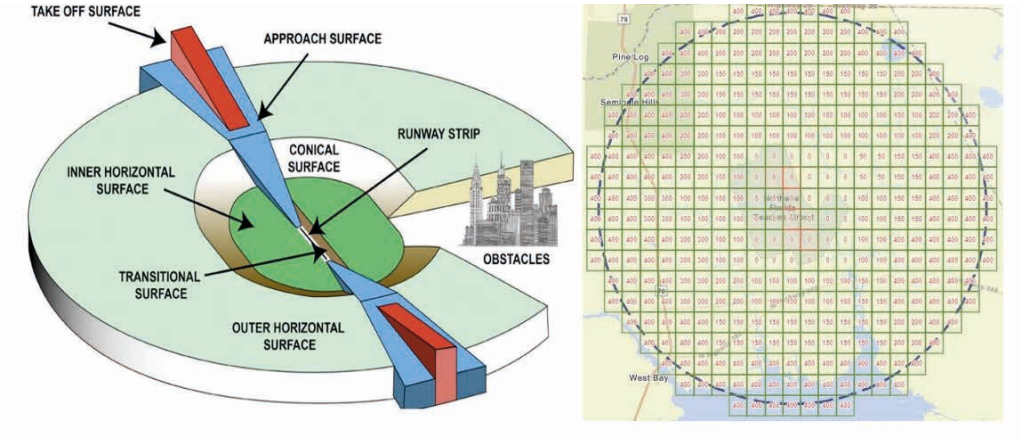

Figure 2 – Clearance area and flight sectors in the vicinity of an airport.
Source: (FAA & ESRI, n.d.; ICAO, 2017a)

Taking Spain as a reference, the U-Space framework incorporates multiple regulatory and operational stakeholders. In the Spanish model, aeronautical authorities such as the AAN (Law no. 28/2013, 2013) and the ANAC (2022b) are responsible for issuing SAL and OA, respectively. These authorizations are essential for UAS operations in GAT, enabling incident recording, investigation, and airspace classification.

Supporting these regulatory bodies, the SFS system plays a critical role in monitoring UAS activities. Drawing from the North American model, the SFS is tasked with reporting unauthorized or hazardous drone operations to the aeronautical authorities, ensuring regulatory enforcement through UA identification. Additionally, the public is encouraged to report any incidents or potential privacy infringements caused by UAS.

A parallel structure is envisioned for Portugal. NAV Portugal, as the designated provider of civil air traffic services (NAV Portugal, 2024, p. GEN 3.3-1), is recognized by ANAC as the "single common information services provider" (R. Silva, *op. cit.*) under Implementing Regulation (EU) 2021/665, 2021. Consequently, the Common Information Services Provider (CISP) model should adopt a centralized approach (Figure 3), at least in the initial phase, to ensure a streamlined transition to the new infrastructure while maintaining operational continuity (Martin et al., 2022).

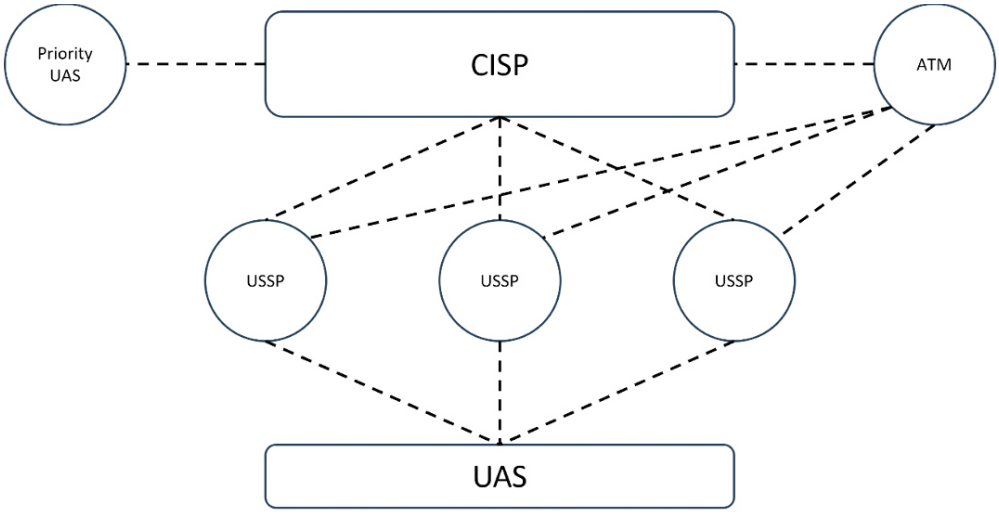

Figure 3 – Centralized CISP model.
Source: (Lourenço, 2023).

NAV Portugal, (2022b) also plays a dual role as a USSP, extending some of its existing services from manned aviation to unmanned operations. These services include aeronautical information through Notices to Airmen (NOTAMs), airspace reservation management, flight plan (FPL) reception, and UAS Volume Reservation (UVR) dissemination.

Similar to other international models, USSPs are responsible for both providing and overseeing the services delivered to UAS operators. They also facilitate coordination between UAS operators and ATC, whether managed by NAV Portugal or the PrtAF. Based on the LAANC model, USS functionalities may be provided either by USSPs or by existing service providers. This includes organizations such as the IPMA for meteorological services, telecommunications operators (MEO, NOS, and Vodafone) for network coverage, and cartographic service providers like CIGeoE and ESRI.

UAS operators form the core user base of this ecosystem, requiring access to various services, including:

Registration of the UAS with the AAN or the ANAC, depending on whether it is a military or civilian platform;

- Aeronautical information for pre-flight and in-flight planning;
- Submission of flight plans or operation plans;
- USSP authorization to enter designated airspace;
- Access to flight information, control, and meteorological services.

For manned aircraft requiring transit through U-Space, coordination is managed via ATC authorities, which in turn liaise with USSPs. Similarly, UAS operators seeking to exit U-Space must coordinate their flight plans through the USSPs, ensuring seamless integration with conventional ATC services.

Although military and state aircraft operations are exempt from U-Space regulations, any entry into this airspace necessitates compliance with GAT protocols. The only exception occurs during priority missions, in which these aircraft have precedence over other traffic.

This entire ecosystem is underpinned by the UACS, which enables real-time operational management. Figure 4 graphically represents the interactions among all entities within the conceptual framework. It maps how stakeholders interact and how services are coordinated to maintain safe and effective UAS operations. It also highlights the relationship between various U-Space airspaces, both contiguous and separate, as well as their characteristics, such as altitudes, classifications, and service provisions.

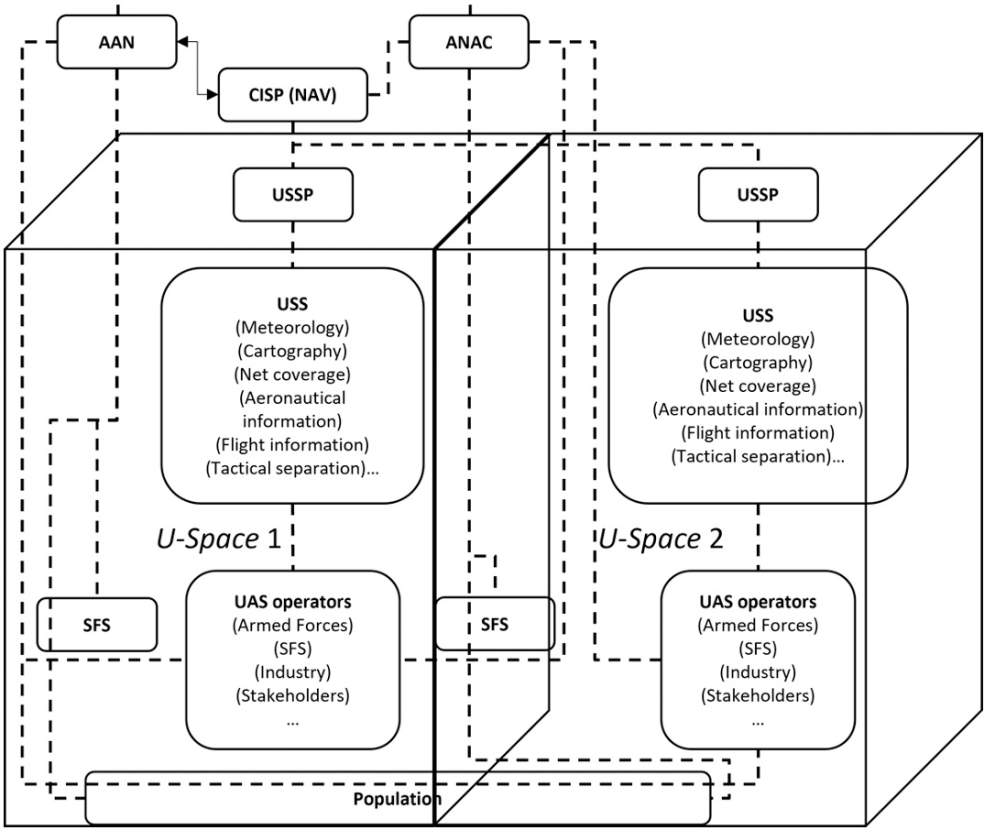

Figure 4 – Proposed U-Space ecosystem model.
Source: (Lourenço, 2023).

By clarifying the roles of each stakeholder and the infrastructure requirements, the proposed ecosystem model serves not only as a planning tool but also as a foundation for implementing a real-world UAS integration ecosystem that aligns with international best practices and Portuguese regulatory needs.

The flowchart in Figure 5 outlines the procedural flow for UAS operators, based on the ecosystem model, showing, step-by-step, how missions should be authorized, coordinated, and integrated into existing ATM systems.

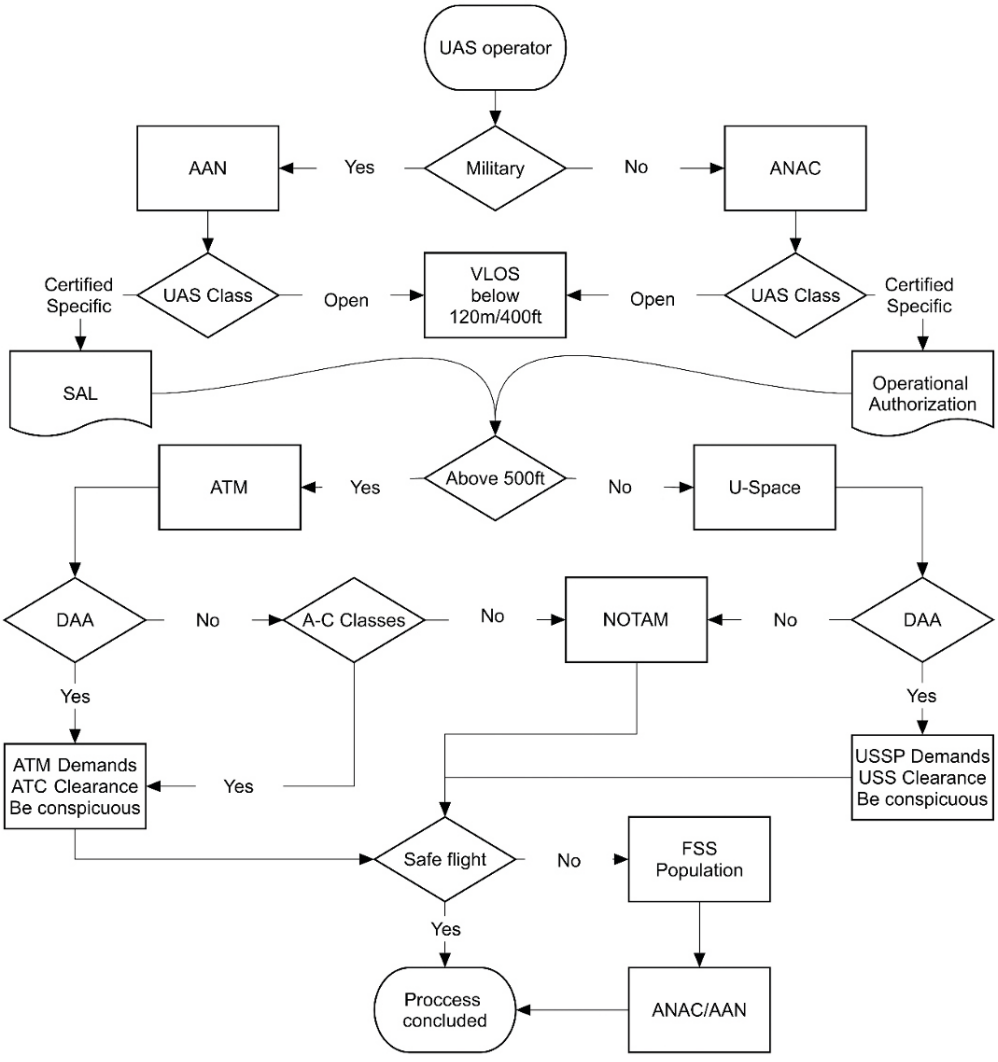

Figure 5 – Proposed Integration of UAS in GAT.
Source: (Lourenço, 2023).

5.3. Phased implementation strategy

To facilitate the effective adoption of the ecosystem model, a phased implementation strategy is proposed. This approach allows for initial operational validation in selected U-Space zones, beginning with trial locations, as explained by R. Silva, ATCo at NAV Portugal

(online interview, June 5, 2022), which would later be expanded to other regions to support the development of UAM, following the North American example.

The key stages of this phased deployment are summarized in Table 6, illustrating the operational scope and objectives of each phase.

Table 6 – Phase 1 and Phase 2 summary.

Phase	Location	Action	Objective
1	Lisbon, Porto, Faro and Funchal	Implement initial U-Space services and validate operational procedures	Test interoperability, stakeholder coordination, and technology in a controlled environment
2	Nationwide (all Portuguese airspace)	Expand U-Space services across the country	Achieve full integration of UAS into GAT, enabling BVLOS and UAM operations

Phased implementation mitigates operational and regulatory risks by allowing new procedures and technologies to be validated in a controlled environment before national deployment. Initial U-Space operations in Lisbon, Porto, Faro, and Funchal provide diverse operational scenarios, including urban density, airport proximity, and maritime contexts, enabling comprehensive testing of interoperability, communication reliability, and safety protocols.

The initial phase is expected to reveal critical technical and regulatory challenges, informing necessary adaptations before expanding the ecosystem nationwide. This strategy enables incremental capacity building among regulatory authorities, service providers, and UAS operators, reducing the risk of systemic failures and increasing acceptance from manned aviation stakeholders.

As for the study's main research question, this phased strategy operationalizes a tailored ecosystem model for Portugal by synthesizing best practices from the United States – such as centralized automation and phased airspace access (e.g., LAANC) – and Europe – such as the U-Space framework and the definition of zones based on risk. By combining centralized digital coordination, investment in interoperable infrastructure, and gradual U-Space deployment, the model provides a scalable, safe, and context-sensitive pathway to UAS integration into GAT.

The proposed ecosystem model offers a structured, phased approach to the integration of UAS into GAT in Portugal. By clearly defining stakeholder responsibilities and establishing a realistic implementation roadmap, the model addresses current operational, infrastructural, and regulatory gaps. The phased strategy ensures that integration progresses incrementally, allowing for continuous validation, adaptation, and alignment with international best practices.

6. Conclusions

This study set out to answer the main research question: "How can a tailored ecosystem model for integrating UAS into GAT in Portugal be developed by drawing comparative insights from the United States and European best practices frameworks?" To answer this question, the study used a qualitative strategy combining documentary analysis and semi-

structured interviews with key stakeholders and industry experts. Using this approach, a conceptual ecosystem model was developed with three critical dimensions: system, infrastructure, and airspace.

Grounded in an objectivist perspective and guided by deductive reasoning, the study critically assessed regulatory and operational approaches in both the U.S. and Europe. From the U.S., the model draws lessons on automation, scalability, and phased implementation – particularly the use of systems like the LAANC and the emphasis on BVLOS operations. From the European framework, it incorporates structured regulatory oversight, the definition of U-Space zones, and digital coordination systems. These comparative insights were synthesized to propose a model tailored to Portugal's unique operational and regulatory environment.

The resulting ecosystem model addresses key national gaps and proposes a phased implementation strategy. Phase 1 prioritizes operational validation within designated U-Space zones in Lisbon, Porto, Faro, and Funchal, enabling localized testing and stakeholder coordination. Phase 2 expands the model nationwide, enabling broader deployment of UAS operations, including BVLOS and potential UAM services. By clarifying stakeholder responsibilities, infrastructure requirements, and operational frameworks, the model provides a structured, adaptive roadmap for the integration of UAS into Portuguese GAT, aligned with international best practices.

This research contributes to the academic and operational discourse by offering a pragmatic model that balances regulatory feasibility with technological readiness. While it is tailored to Portugal, the underlying principles – phased deployment, risk-based airspace management, and collaborative governance – are broadly applicable to similar regulatory contexts.

Nonetheless, the study presents limitations. The proposed model has not yet been validated through live operational trials, and it relies on assumptions regarding regulatory responsiveness and interagency collaboration that must be empirically tested. Furthermore, the economic feasibility of implementing the ecosystem model was beyond the scope of this research and should be explored in future studies that focus on cost structures, funding mechanisms, and return on investment.

Future research should focus on the operational testing of U-Space test zones, the integration of BVLOS and UAM services, and the certification of critical support technologies such as DAA systems. Additionally, economic modeling and stakeholder engagement strategies will be essential for moving from conceptual design to operational deployment.

As the aviation landscape continues to evolve, the integration of UAS into national airspace will require not only technological innovation but also regulatory adaptability and stakeholder alignment. The model proposed in this study offers a structured, phased path forward for Portugal – one that is informed by international best practices yet responsive to local needs. With continued research, stakeholder engagement, and regulatory commitment, Portugal can lead a safe and scalable transformation toward integrated, future-ready airspace operations.

Portugal now stands at a pivotal moment: by embracing a phased, collaborative, and innovation-driven approach to UAS integration, it can become a benchmark for safe, scalable, and future-ready airspace transformation, not just nationally, but across Europe.

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