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Key features and applications of military drones: a case study from the Portuguese military ground forces

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Abstract

Purpose – The rapid advancement of new technologies necessitates the adaptation of existing resources to address the evolving demands of contemporary conflicts among nations. As exemplified by the emergence of Unmanned Aerial Systems (UAS) and Unmanned Aerial Vehicles (UAVs), these technologies have become indispensable components of military drone operations. This study investigates the role of innovation models in driving Portuguese Innovation and Development, focusing specifically on military drones.

Design/methodology/approach – Through an examination of existing scientific and doctrinal literature, this research establishes a connection between theoretical concepts and the practical deployment of drones within the Portuguese ground forces. Employing a qualitative approach, this study follows a case study, with data collection following the principle of triangulation.

Findings – The findings of this research reveal several attributes crucial to drone utilization, such as optronic capability and drone range. These attributes are vital for ensuring high-quality, real-time imagery transmission and operational effectiveness in military activities.

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Originality/value – This study contributes to the understanding of the implications of drone attributes for the Command, Control, Communications and Information Systems (C3IS) capabilities of the Portuguese ground forces. It highlights the importance of continued emphasis on drone development and innovation as a key priority for the Portuguese Army.

Keywords Military drones, Military operations, Portuguese army, Unmanned aerial systems, Unmanned aerial vehicles

Paper type Research paper

1. Introduction

Recent advancements in Unmanned Aerial Systems (UAS) and Unmanned Aerial Vehicles (UAVs) have revolutionized modern warfare, enabling more precise and efficient operations. In fiscal year 2017, the US Department of Defense allocated around $4.6 billion to drone technology (Gettinger, 2016). According to the 2022 report by the Stockholm International Peace Research Institute (SIPRI, 2022), global military spending reached a record high of $2.1 trillion, with significant investments in drone technology. This highlights the critical role that drones play in contemporary military strategy, from reconnaissance to targeted strikes. The doctrine of the Portuguese ground forces is documented in doctrinal publications, which serve as the foundation for the development of procedures and practices within the force (Reis *et al.*, 2022a). In recent years, there has been a renewal in these practices and procedures, mainly influenced by the employment of advanced technologies such as Artificial Intelligence (AI) and automation systems. The incorporation of these new technologies has compelled the adaptation of existing resources to meet the evolving requirements posed by emergent conflicts (Mohsan *et al.*, 2023). However, the development of novel practices and procedures hinges upon formal validation and documentation, impelling the modernization efforts of the Portuguese ground forces. Furthermore, the innovation development within the Portuguese Army is constrained by regulatory frameworks dictating resource acquisition and innovative model approaches. For example, technological advancements are subject to inclusion in the Military Programming Law, which undergoes revision every 12 years, with the latest revision affecting the period from 2023 to 2034. These hurdles hamper the forces' ability to effectively respond to contemporary conflict scenarios. Despite these challenges, the Portuguese armed forces adhere to the Triple Helix (TH) innovation model, pioneered by Etzkowitz and Leydesdorff (1995). This model has evolved to encompass the "Society" player, leading to the Quadruple Helix innovation model, and subsequently integrating the "Environment" player, resulting in the Quintuple Helix (QiH) innovation model (Leydesdorff, 2012). The QiH model significantly influences the "techniques, tactics, and procedures" employed by the Portuguese armed forces, particularly within the ground forces (Reis *et al.*, 2021), involving the Defense Industry and higher education institutions (i.e. research centers or universities) in the production of knowledge.

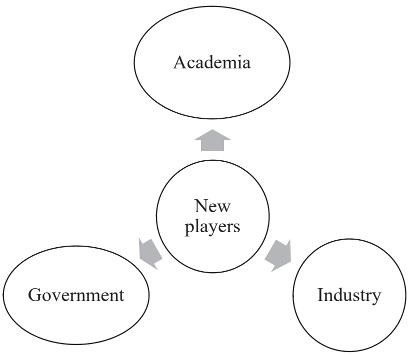
In the context of the QiH model, there is an increased development and use of electronic systems and equipment within the scope of Portuguese National Defense (Mohsan *et al.*, 2023). Commanders who lead military forces, regardless of the size or type of unit under their command, rely on comprehensive information to make effective decisions. As a result, the utilization of electronic systems and equipment to support commanders in decision-making has become increasingly valued (Reis *et al.*, 2020; Papa, 2018). Therefore, the study of these systems and equipment, particularly military drones applicable in military operations, emerges as a relevant asset. From this perspective, Barros *et al.* (2024) highlighted the lack of a comprehensive approach to understanding the main attributes of military drones, especially concerning the Portuguese ground forces. Building upon this observation, this study aims to establish a relationship between existing scientific and doctrinal literature on drones and their practical deployment, considering their key attributes and potential applications within the context of the Portuguese ground forces.

The research questions (RQ) of this research are formulated as follows: (1) How are drones utilized by the Portuguese military ground forces? and (2) What attributes are required for the development of military drones? The secondary objectives (SO) of this study include: (1) describing the use of drones according to doctrinal publications; (2) identifying the use of military drones through the application of case study methodology; (3) presenting the military drones attributes in the context of Portuguese Army. Utilizing a qualitative approach and case study methodology (Creswell and Creswell, 2017; Yin, 2018), this research draws upon official documents of the Portuguese Army, direct observation, and semi-structured interviews to ensure the reliability and consistency of the results. The study identifies several attributes concerning the utilization of drones by the Portuguese Army and advocates for the inclusion of two additional attributes: optronic capability and drone range, emphasizing the importance of high-quality, real-time imagery transmission and operational range in military operations. This study is structured with an introduction, followed by the conceptual background, materials and methods, results presentation, and a conclusion, which includes the theoretical and practical contributions as well as research limitations and suggestions for future research.

2. Conceptual background

2.1 Triple Helix (TH), Quadruple Helix (QaH), and Quintuple Helix (QiH) innovation models

The innovation development within the Portuguese National Defense Industry is based on the Triple Helix (TH) model (Leydesdorff and Ivanova, 2016), which serves as the foundational framework for economic growth (Cai and Lattu, 2022). This model is structured around three key pillars: Education, Economy, and Politics (Leydesdorff and Ivanova, 2016 and Cai and Lattu, 2022), each represented by distinct players: Academia, Industry, and Government (Carayannis *et al.*, 2022). The “Academia” player, encompassing research centers, researchers, and universities, conducts studies and research, while the “Industry” player focuses on manufacturing, and the “Government” procures the products (Cai and Etzkowitz, 2020). The relationship among these three players is dynamic, facilitating trilateral coordination and innovation development (Carayannis and Campbell, 2009). In recent years there has been a pronounced development of the industry–academia relationship and the emergence of new international players (Reis *et al.*, 2022b). The trilateral relationship should be represented as shown in Figure 1.



Source(s): Own elaboration

Figure 1. New players to the Triple-Helix model

While the knowledge generated by the "Academia" player is primarily theoretical, with limited practical application (Reis *et al.*, 2021), empirical scientific knowledge generation within the Triple Helix framework emphasizes interaction among different players (Aken, 2001; MacLean *et al.*, 2002) to foster technology development, integrating public perspectives such as media and culture (Cai and Lattu, 2022). The Triple Helix Model's correlation among Academia, Industry, and Government aims to bolster innovation, encouraging knowledge-generating institutions to contribute more effectively to the economy and society. Efforts include clearly defining institutional roles, enhancing communication and collaboration, and fostering hybrid organizations that incorporate elements from all three institutions to promote collaborative innovation (Arnkil *et al.*, 2010).

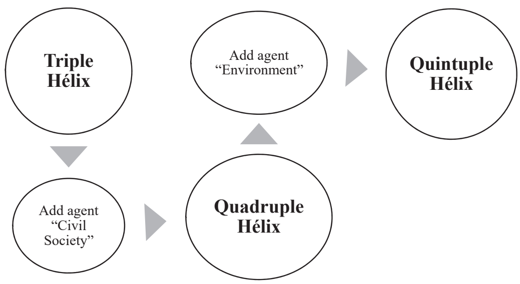
The Quadruple Helix innovation model introduces a fourth player, "Society" (Leydesdorff, 2012), emphasizing the need to address social concerns in technology development, particularly within the Portuguese National Defense Industry (Carayannis and Rakhmatullin, 2014). Research and innovation concepts are intrinsic to knowledge generation (Carayannis and Campbell, 2009; Carayannis and Rakhmatullin, 2014), aggregating diverse forms of knowledge for practical application (Carayannis and Campbell, 2009). This forms the foundation for the Quintuple Helix (QiH) innovation model (Carayannis and Campbell, 2009), incorporating a fifth player, "Environment." This addition addresses environmental concerns and global warming resulting from rapid technological development (Carayannis *et al.*, 2012).

The original TH innovation model underwent several transformations and resulted in the QiH model, which is sensitive to environmental and ecological impacts and addresses social issues arising from Portuguese National Defense Industry activities (Carayannis and Rakhmatullin, 2014). The evolution of innovation models is illustrated in Figure 2.

The integration of the QiH innovation model within the Portuguese National Defense Industry has led to increased technology adoption and greater involvement of the "Government" and "Academia" sectors in its advancement (Reis *et al.*, 2022b). Additionally, cooperation has been identified between the Portuguese Defense Industry and civil society, which heightened stability and prosperity within the Portuguese National Defense Industry (Reis *et al.*, 2021). Meanwhile, there is a need for military institutions, particularly higher education institutions like research centers or universities, to take on a more proactive and interventionist role in knowledge generation, replicating the practices of civilian institutions (Reis *et al.*, 2021; Simões *et al.*, 2020).

2.2 Portuguese perspective of innovation and development

Portugal underwent a period of political dictatorship during the 1960 and 1970s, marked by significant development in its National Defense Industry due to conflicts with its colonies



Source(s): Adapted from Reis *et al.* (2022)

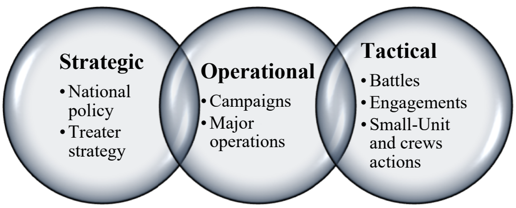
Figure 2. Evolution of innovation models

(Barros, 2002). However, the conclusion of these conflicts and the subsequent revolution led to a decline in investment in Portugal's defense sector (Barros, 2002). Despite efforts to match the advancements seen in the defense industries of other European countries like the United Kingdom and France (Avadikyan and Cohendet, 2009; Lazaric *et al.*, 2011), Portugal has struggled to establish a substantial presence in this sector, mainly due to the longer industrial traditions of these nations in aligning their capacities with defense needs (Barros, 2002; Simões *et al.*, 2020). The disparity in investment and economic returns between countries with robust defense industrial policies and those with weaker capacities presents challenges for Portugal in adapting its defense industry to emerging needs (Barros, 2002; Fernandes *et al.*, 2020; Simões *et al.*, 2020). Hence, in Portugal, the creation of the Defense Technological and Industrial Base (DTIB) has aimed to reposition the National Defense Industry within a competitive European framework and drive advancements in technological domains within the defense sector (Bellais, 2013; Carayannis and Campbell, 2009; Reis, 2021). Therefore, the success of I&D projects has been reliant on a combination of internal and external investments, as well as extensive collaboration among the players in the TH model.

2.3 UAS, UAV and drones

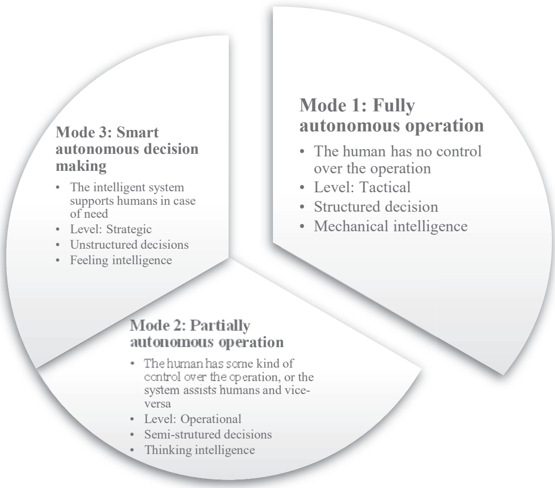
In recent decades there has been a growing interest in Intelligent Autonomous Systems (IAS), which aim to reduce human intervention (Mohsan *et al.*, 2023; Reis *et al.*, 2021; Zhang *et al.*, 2017). These systems are employed by the Portuguese defense across air, land, and sea (Reis *et al.*, 2021) with a significant focus on aerial operations. In this regard, Unmanned Aerial Systems (UAS) (Klimkowska *et al.*, 2016) have been developed to meet specific mission requirements, particularly for military missions and operations (Prisacariu and Muraru, 2016). A key component of UAS is the Unmanned Aerial Vehicle (UAV), which carries out assigned tasks and enhances information-gathering capabilities with attributes and parameters tailored to mission requirements (Fatima *et al.*, 2023; Solomentsev *et al.*, 2015; Reis *et al.*, 2021). In the context of the Portuguese defense, military operations are categorized into three levels: Strategic, Operational, and Tactical (Harvey, 2021). These levels are interconnected, regulating national defense activities and military operations as illustrated in Figure 3.

Moreover, the IAS is integrated within these levels, establishing three distinct modes of automation, as depicted in Figure 4 (Reis *et al.*, 2021). For example, "Mode 1" pertains to the Tactical level of military operations, characterized by no human intervention, structured decision-making, and mechanical artificial intelligence (Reis *et al.*, 2021). In light of Figure 4, this article primarily focuses on "Mode 1" operations, which are characterized by tactical operations involving structured decision-making and mechanical intelligence. This mode is particularly relevant for the deployment of drones, as their utilization is most predictable and prevalent at the tactical level. The ongoing conflict in Ukraine exemplifies the rapid growth and



Source(s): Harvey (2021)

Figure 3.
The levels of war



Source(s): Adapted from Reis *et al*. (2021)

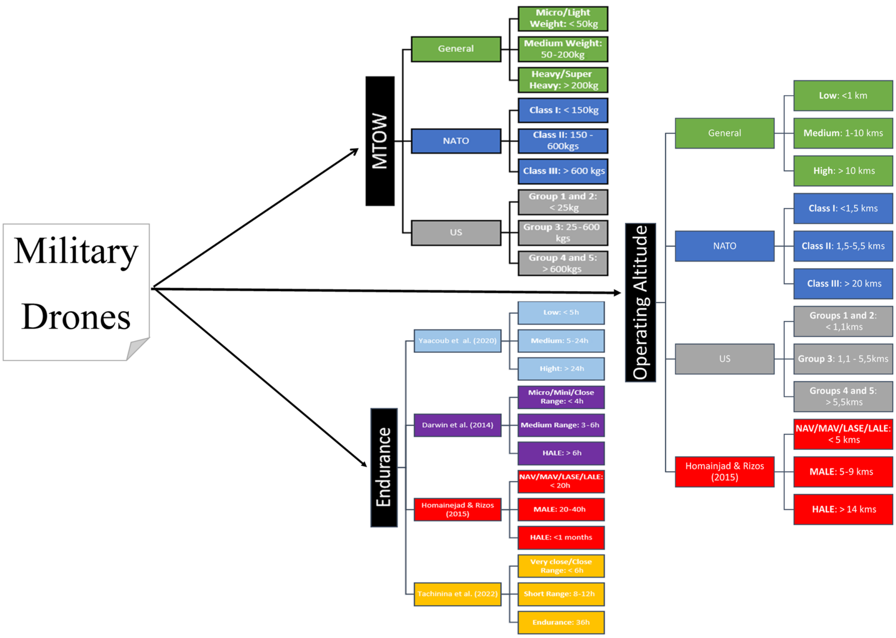
Figure 4.
Modes of autonomous intelligent systems

significant impact of drones in tactical military operations. This occurs because both operational and especially strategic levels are already highly automated. A prime example of this is the use of strategic drones such as the North American MQ-9 Reaper. In Portugal, the deployment of drones similarly emphasizes tactical applications rather than operational (Mode 2) or strategic (Mode 3) levels. This trend highlights the increasing reliance on drones for tasks requiring immediate and precise responses, which are hallmarks of tactical operations.

The integration of IAS with Artificial Intelligence (AI) represents a shift of paradigm in military operations (Huang and Rust, 2018), enhancing the operational efficiency and decision-making processes, particularly when combined with machine learning (Huang and Rust, 2018; Reis *et al.*, 2021; Vergouw *et al.*, 2016). The automation levels of IAS are classified into eight distinct levels, which denote their ability to perform tasks autonomously using robotics and AI technologies (Reis *et al.*, 2021). Drones, a key subset of IAS, have evolved significantly from basic Unmanned Aerial Vehicles (UAVs) to sophisticated systems featuring high levels of automation (Levels 6, 7, or 8) (Reis *et al.*, 2021; Vergouw *et al.*, 2016). These advanced drones operate through a human-machine interface and can be controlled automatically, remotely, or through AI-driven functionalities, reducing the need for direct human intervention (Vergouw *et al.*, 2016; Kardasz *et al.*, 2016). This autonomy allows drones to execute complex missions with precision and efficiency, whether they are controlled by specialized technicians or operators, or functioning independently based on pre-programmed parameters or real-time AI decision-making. In conclusion, the integration of IAS with AI in drone technology heralds a new era of operational capabilities across the military domain. These systems have been enhancing the efficiency of various operations, from tactical military missions to environmental monitoring and commercial logistics. As the technology continues to evolve, ongoing advancements will be crucial in harnessing the full potential of drones while mitigating associated risks.

2.4 Military drones: parameters and functional characteristics

The categorization of military drones based on their parameters and functional characteristics is a critical necessity. This classification aids in understanding their applicability in both civil and military contexts (Barros *et al.*, 2024; Ramesh and Jeyan, 2020). Figure 5 (Barros *et al.*, 2024) offers a comprehensive overview of drone classification as documented in existing literature, highlighting three primary parameters: Operational Altitude (OA), Maximum Takeoff Weight (MTOW), and Endurance (Barros *et al.*, 2024, p. 89). Scholarly consensus on OA and MTOW is marked in green, while the Endurance attribute is highlighted in light blue. The characteristics of drones must align with the specific operational needs and requirements of military forces (Barros *et al.*, 2024; Yaacoub *et al.*, 2020). In the context of the Portuguese Army, the focus is on tactical drones. These drones are characterized by the following technical parameters: (1) MTOW: Micro/Light Weight (less than 50 kg), (2) OA: Low (less than 1 km), (3) Endurance: Low (less than 5 h) (Barros *et al.*, 2024; Yaacoub *et al.*, 2020). The units responsible for missions involving the tactical drones in Portugal are dependent on the ISTAR Battalion (Intelligence, Surveillance, Targeting Acquisition, and Reconnaissance). This unit's primary objective is to collect data on threats and environmental conditions, which is crucial for decision-making processes within the General Staff. The Portuguese ground forces utilize military drones in international missions, exemplified by their deployment in the Central African Republic (CAR) as part of the United Nations Multidimensional Integrated Stabilization Mission in the Central African Republic (UNMISMCAR). In this operation, the UAV RQ-11B Raven was employed, featuring the following technical specifications: (1) Maximum Takeoff Weight (MTOW): 1.9–2.7 kg (depending on payload), (2) Operational Altitude (OA): 30–152 meters, (3) Endurance: 60–90 min (AeroVironment, 2022). This drone has a range of 10 km and is launched manually (AeroVironment, 2022). This drone is classified as a tactical drone with (1) MTOW: Micro/Light Weight, (2) OA: Low, and (3) Endurance: Low (Barros *et al.*, 2024; Yaacoub *et al.*, 2020).



Source(s): Barros *et al.* (2024)

Figure 5.
Characteristics of drones according to literature

2.5 Comparative perspectives on the use of drones and innovation models in global armed forces

Using drones and adapting innovation models like the TH, QaH, and QiH vary significantly across different countries. This shows each nation's strategic needs, technological capabilities, and defense priorities. For instance, the U.S. military has been at the front of integrating drones into its defense strategy, leveraging the TH model to foster collaboration between military institutions, private defense contractors, and government agencies such as DARPA (Defense Advanced Research Projects Agency) (Durmaz, 2016). The U.S. has developed a comprehensive ecosystem where academia, represented by leading research universities, works closely with industry and government to innovate and develop advanced drone technologies. These collaborations have led to the developing of high-end UAVs like the MQ-9 Reaper (Rinehart, 2017), which are extensively used for intelligence, surveillance, reconnaissance (ISR), and targeted strikes (Doyle, 2018). The U.S. model emphasizes robust public-private partnerships and a strong governmental role in funding and regulating drone innovation, highlighting the effectiveness of the TH model in achieving military technological superiority.

In contrast, the People's Republic of China (PRC) has employed a state-centric approach to drone development, integrating aspects of the TH and QaH/QiH models within its defense strategy (Akhter, 2019). The Chinese government heavily invests in both state-owned enterprises and private companies to foster innovation in drone technologies, which are used for a wide range of purposes, from surveillance to electronic warfare (Anand, 2006). PRC's model reflects a top-down approach where the government not only funds and regulates but also directs research and development efforts to align with national defense objectives (Chou, 2009). This approach has enabled the PRC to rapidly advance its capabilities in drone technology, focusing on mass production and strategic applications, such as the deployment of swarming drones that can overwhelm enemy defenses (Lachow, 2017).

Israel's defense sector provides another distinct perspective, characterized by a highly integrated TH model that includes a close-knit collaboration between military, academic institutions, and the private sector (Vaivode *et al.*, 2016). Israel's focus has been on developing drones for tactical intelligence gathering, border security, and targeted operations, as evidenced by the widespread use of UAVs like the Heron and Hermes series (Chaturvedi *et al.*, 2019). The unique security challenges faced by Israel have driven innovation towards more agile and versatile drone technologies, optimized for real-time intelligence and rapid response (Borg, 2021). This has been facilitated by a strong innovation culture within its armed forces, supported by government policies that encourage military-civilian technology transfer and rapid prototyping, aspects that align with both the TH and QaH/QiH models.

The defense strategies across various EU member states also offer diverse insights into the adoption of drones and innovation models. Countries like Portugal or France have leveraged the TH and QaH/QiH models to develop their defense industries with a strong emphasis on joint ventures and international collaborations (Reis *et al.*, 2022a). For instance, the Portuguese's approach has been to foster partnerships between defense companies, universities, and research institutes under government guidance, leading to the development of drones like the ones from TEKEVER. France, on the other hand, has focused on enhancing its indigenous drone capabilities through its defense research agency, DGA, while also being a part of the European MALE (Medium Altitude Long Endurance) drone project (Lavallée and Zubeldia, 2018). Both countries reflect a balanced application of the TH model, with increasing attention to societal impacts and environmental sustainability as mandated by the QiH framework.

Lastly, Russia's approach to drone innovation combines elements of the TH and a more centralized, state-controlled model. The Russian military-industrial complex, heavily influenced by government priorities, focuses on drones for reconnaissance, electronic warfare, and recently, tactical offensive operations, such as those seen in conflicts in Syria and Ukraine (Chávez and Swed, 2023; Kunertova, 2023). The Russian model has traditionally underutilized the role of academia in innovation but is increasingly seeking to integrate academic research more effectively, as demonstrated by recent collaborations between state defense companies and Russian technical universities (Blank, 2012; Roffey, 2013). This shift indicates a growing recognition of the need for a more comprehensive innovation ecosystem akin to the TH model, albeit within a highly state-regulated environment.

These varied approaches illustrate that while the foundational principles of the TH, QaH, and QiH models provide a useful framework for fostering innovation in military technology, their implementation and evolution are highly context-dependent. Each country adapts these models according to its specific strategic needs, cultural context, regulatory environment, and defense priorities.

3. Materials and methods

This research employs a qualitative case study research design, well-known for its in-depth exploration of specific cases within their real-life contexts (Yin, 2018). Such methodology ensures accuracy in data collection and analysis, endeavoring for both reliability and validity. To improve this analysis, this research adhered to triangulation and corroboration principles, leveraging multiple data sources concurrently for cross-validation (Yin, 2018).

The primary data sources comprised semi-structured interviews, conducted with members of the Portuguese Army military, and complemented by secondary sources such as official documents and direct observation. By employing multiple data sources, the study not only broadened the scope of information but also deepened the understanding of the phenomenon being investigated (Creswell and Creswell, 2017; Yin, 2018). This information can be summarized in Table 1:

The data collection process unfolded systematically across three delineated phases: exploratory, analytical, and conclusive. In the exploratory phase, a literature review laid the groundwork by establishing a theoretical framework and guiding subsequent data collection endeavors. The literature review process began by conducting a comprehensive search for relevant scholarly articles and books using several academic databases and tools. Specifically, Scopus and Web of Science (WoS) were utilized to retrieve peer-reviewed articles that were most relevant to the study's focus on military drone usage and qualitative research methodologies. These databases were chosen due to their extensive coverage of high-quality academic publications across a range of disciplines, ensuring a robust foundation for the theoretical framework. The search strategy involved using a combination of keywords and Boolean operators to refine the search results, targeting terms such as "military drones", "qualitative research" and "Portuguese Army". Additionally, the "Publish or Perish" software was employed to identify and select articles from Google Scholar that were most closely related to the research theme. This tool allowed for an examination of literature beyond the scope of traditional databases, including grey literature, which can provide insights and complement more formal sources. Articles were selected based on their relevance, citation count, and recency to ensure that the literature review reflected the most current and impactful research in the field. Following the identification of relevant sources, a screening process was undertaken. This involved reading abstracts and, where necessary, full texts to determine the suitability of each source for inclusion in the literature review. The selected literature was then categorized into thematic areas that informed the development of the interview protocol and the overall research design. This approach ensured that the literature review was comprehensive and aligned with the study's research objectives. Concurrently, fieldwork activities provided firsthand insights

Duty	Rank (military)	Quantity	Interview date
Military intelligence analyst	Lieutenant Colonel (OF-5)	1	March 2024
Commanders of tactical units	Captain (OF-2)	3	February–April 2024
	Lieutenant (OF-1)	1	February 2024
UAV Operators	Staff Sergeant (OR-7)	1	February 2024
	Sergeant First Class (OR-6)	1	March 2024
Military ground forces planning managers	Major (OF-4)	1	March 2024
	Captain (OF-2)	2	December 2023–April 2024
Activity	**Place**	**Quantity**	**Direct observation**
Informal Conversation	Abrantes, Mechanized Brigade	1	December 2023
Seminar	Lisbon, Military Academy	1	February 2024
Informal Conversation	Lisbon, Army Joint Chief of Staff	1	March 2024
Informal Conversation	Lisbon, Army Center for Technological Experimentation and Modernization	1	March 2024
Tour	Tekever	1	May 2024
Type	**Title**	**Quantity**	**Official documents (publication date)**
Doctrinal publication	Mini-UAV Section employment	1	2013
Doctrinal publication	Use of Unmanned Aerial Systems (UAS)	1	2017
Doctrinal publication	Joint Unmanned Aerial Systems Capability in the Portuguese Armed Forces: A Concept	1	2022
Report, Portuguese Army	Activities Plan 2024	1	2024

Source(s): Own elaboration

Table 1. Sources of data collection

into the research context. This literature review, following the methodological framework outlined by Barros *et al.* (2024, p. 89), informed the development of an interview protocol, ensuring alignment with research objectives and guiding subsequent fieldwork (Erlingsson and Brysiewicz, 2017; Leavy, 2022; Yin, 2018). A total of ten semi-structured interviews were conducted, utilizing a combination of in-person and videoconference formats to accommodate logistical constraints without compromising data quality. Each interview lasted between 30 and 45 min, except for the first one, which extended to 71 min due to its exploratory nature.

Moreover, the snowball sampling method facilitated the identification of additional interviewees, a common technique in qualitative research aimed at reaching saturation, where new information ceases to emerge (Leavy, 2022). In that regard, we only initiated contact with the first interviewee; all subsequent interviewees were recommended by previous participants. Saturation was reached when the interviewees' recommendations included military personnel with similar functions (*vide* Table 1), and no new information was provided (Nascimento *et al.*, 2018). The direct observation activities encompassed attending military lectures, examining drone equipment and resources, and engaging in informal conversations with military drone experts and operators. These observations supplemented and validated information obtained from interviews and official documentation, thus enhancing the reliability of the findings.

In the analytical phase, collected data underwent synthesis and interpretation to disclose key themes and patterns. This involved transcription and validation of interview data, followed by the creation of a summary table to organize pertinent information related to each interview question. Hence, the coding process ensued, comprising multiple phases such as text review, category creation, and organization, aimed at identifying and elucidating key themes aligned with research objectives (Reis, 2023). In more detail, the coding process began with the verbatim transcription of all interview recordings, followed by a detailed line-by-line analysis to identify initial codes. These initial codes were generated based on recurrent words, phrases, and concepts mentioned by the interviewees. To enhance the reliability of the coding process, the article co-authors independently reviewed the transcripts and assigned codes, which were then compared and refined through iterative discussions. This collaborative approach helped ensure that the coding was both consistent and reflective of the data. The coding mechanism was structured around three main phases: open coding, axial coding, and selective coding. During the open coding phase (Holton, 2007), we identified discrete pieces of information relevant to the study's objectives. This process resulted in a preliminary set of codes that captured various aspects of drone usage, doctrinal gaps, and innovation practices within the military context. In the axial coding phase (Williams and Moser, 2019), we examined the relationships between the initial codes, grouping them into broader categories that represented significant themes emerging from the data. This phase involved constant comparison techniques, where codes were continuously compared across different interviews to identify patterns and linkages. Finally, in the selective coding phase (Benaquisto and Given, 2008), we synthesized the categories into core themes that provided a deeper understanding of the research question. Five major themes emerged from this analysis: operational challenges with current drone technology (internal and external factors), gaps in doctrinal guidance, innovation and modernization needs, human factors in drone operations, and the role of Triple Helix collaborations.

To ensure data saturation—where no new themes or insights were emerging from the interviews—several measures were taken. First, we conducted interviews until redundancy was observed, meaning that subsequent interviews did not reveal new information. We also utilized a saturation grid to track themes and determine when saturation was achieved across different stakeholder groups. A tabular representation of the coding framework, including the codes, categories, and themes that emerged from the interviews was used to provide a clear overview of the analytical process. For instance, in the table of topics related to operational challenges with current drone technology, we identified two categories: internal and external factors. Under external factors, we included codes related to weather conditions, such as temperature, wind, and precipitation, which directly affect flight parameters like distance, altitude, and payload capacity. We determined that we had reached theoretical saturation when no new codes were mentioned by the interviewees, and any new codes aligned with existing ones.

Lastly, the conclusive phase entailed a comparative analysis of operational drone characteristics, juxtaposing study findings with existing literature. This phase facilitated a comprehensive understanding of the contemporary phenomenon under investigation and facilitated the identification of key insights and implications for practice and future research endeavors (Hancock *et al.*, 2021; Mills *et al.*, 2009; Yin, 2018). In summation, the phased approach adopted in this study ensures a systematic investigation, yielding relevant insights into the utilization and implications of military drones in the context of the Portuguese Army.

4. Results and discussion

4.1 The QiH innovation model in the Portuguese ground forces – the case of TEKEVER company

In response to the escalating tensions stemming from the Russia-Ukraine conflict that commenced in February 2022, European nations, including Portugal, have embarked on robust initiatives to strengthen their national defense capabilities by amplifying investments in defense industries. Portugal has allocated substantial resources totaling 42 billion euros until 2034 across twelve strategic sectors, prominently featuring Intelligence, Surveillance, Target Acquisition, and Reconnaissance (ISTAR) capabilities.

Following the above discourse, which was collected from official documents, the Portuguese Army has embraced a collaborative ethos by fostering partnerships with a diverse array of industrial sectors to spur innovation in its operational systems, equipment, and logistical resources, thereby fortifying the national defense industry. Functioning as a pivotal liaison within the QiH innovation model, the Army has been serving as a conduit for dynamic interactions among stakeholders, notably engaging with manufacturing entities. A relevant instance of this collaborative endeavor was evidenced during the "II Army Innovation Seminar", convened at the Portuguese Military Academy on February 29, 2024, which highlighted the significance of research, development, and innovation within the military institution. The symbiotic relationship between the Portuguese Army and TEKEVER exemplifies the relationship between diverse stakeholders within the QiH innovation model. TEKEVER, a focal point in this context, stands as Portugal's preeminent developer and producer of UAS and UAVs, playing a pivotal role in advancing the nation's defense industry.

Primarily oriented towards civilian operations on a global scale, TEKEVER endeavors to innovate, manufacture, and distribute UAS and UAVs. However, the company has also lent its expertise to military endeavors, including its involvement in a Portuguese NATO mission in Kosovo back in 2014. The collaboration between TEKEVER and the Portuguese Army dates to 2011, commencing with the deployment of the AR4 UAV, subsequently succeeded by the Raven Mini-UAV RQ-11 in 2016. Presently, TEKEVER is actively engaged in the development of the AR3 and AR5 UAVs, tailored to address the diverse operational exigencies of both civilian and military clientele, thereby augmenting the versatility of their equipment and associated systems. Figure 6 shows the TEKEVER UAV AR3 alongside other components of the UAS (TEKEVER, 2024).

International civilian entities such as TEKEVER, offer a spectrum of equipment and services, encompassing technical support, system enhancements, and modernization. These enterprises provide customized services to the specific requirements of clients, a level of flexibility rarely achievable in military contexts constrained by the imperative of operational secrecy. Consequently, their endeavors to augment the intelligence capabilities of UAS and UAVs ensure the customization of critical components, such as payloads and datalinks, to align with client specifications.

Figure 6. TEKEVER UAV AR3 and other components of UAS

Source(s): TEKEVER (2024)

The persistent state of armed conflicts, exemplified by the ongoing Russia-Ukraine conflict, shows the dynamic nature of the Portuguese Defense Industry, necessitating a continuous cycle of technological refinement and modernization. In this vein, the innovation process within the Portuguese Army is predicated upon delineating strategic, operational, and tactical objectives, with a keen emphasis on prioritization at each phase. These priorities crystallize in response to identified capability gaps, particularly within the ground forces domain. To articulate the operational requisites for equipment procurement, the Portuguese Army collaborates closely with various entities, particularly with civilian firms such as TEKEVER. The effective delineation of these requirements hinges upon transparent communication between ground force units tasked with equipment operation and the project teams entrusted with defining and executing "use cases", which elucidate the practical application of the equipment. Adhering to this framework ensures the fulfillment of preconditions for equipment acquisition. One of the respondents argued that the acquisition of the Mini-UAV RQ-11B Raven entailed the definition of operational prerequisites based on Army-specified "use cases", culminating in the identification of 120 operational requirements. Certain units within the Portuguese ground forces, especially those deployed in military missions, currently operate with equipment such as the Matrice 300 RTK or Dragon Fish, which inadequately fulfill the operational imperatives of military missions, including camouflage and deception. To redress this capability gap, the Army has initiated a procurement process for military drones, aimed at acquiring cost-effective, high-performance equipment for lower echelons of the Army, including units up to the company level. Furthermore, leveraging the Army's 3D printing capabilities, certain components of this equipment can be manufactured in-house, thereby mitigating production costs and fostering flexibility in design iterations and expedited component replacement, as demonstrated by TEKEVER.

4.2 The use and relevance of operational military drones in the Portuguese Ground Forces

The interviews outlined the influence of operational considerations on drone deployment, categorized into internal and external factors. Externally, factors such as weather conditions, encompassing temperature, wind, and precipitation, directly influence flight parameters, including distance, altitude, and payload capacity. The respondents argued that the missions in regions like the Central African Republic (CAR) or Romania demand adherence to stringent operational constraints due to climatic exigencies. They also stress that in these contexts "drones are limited to a flight distance of 10 kilometers and an altitude ceiling of 3 kilometers, albeit offering clandestine observation capabilities up to 300 meters altitude". Furthermore, operational feasibility mandates wind speeds below 20 knots and precludes flights in heavy rainfall. Other external factors encompass the requisite dimensions of takeoff and landing areas (10 by 10 meters) and uninterrupted electronic line-of-sight connectivity, though this can be circumvented by employing secondary drones as relays.

Concerning the internal drone operations, we identified factors related to communication security and quality. According to the interviewed drone operators, these factors are fundamental to protecting confidential information. In this regard, the respondents stressed that encrypting communications and strengthening the fidelity of communication between drones and operators have increasingly been recognized as vital measures. In other words, they guarantee data integrity even if the drone is compromised or destroyed, thus preventing hostile access to classified information. Furthermore, attention must be directed towards the integration of drones with the existing communication and protection systems of military vehicles, such as the Threat Detection System (TDS) deployed with vehicles like the Pandur II armored wheeled vehicles (Figure 7). TDSs, while improving vehicle safety, can inadvertently impede drone operations. Consequently, we identified it as critical to include drone experts in command structures to optimize operational effectiveness and spread awareness among unit commanders regarding operational constraints and considerations.

Figure 7. Portuguese Pandur II armored wheeled vehicle – Portuguese Army official website(s)

Source(s): Portuguese Army (2023)

The conflict dynamics observed in Ukraine have precipitated adaptations in the certification process for remote drone pilot operators, streamlining bureaucratic hurdles and minimizing training requirements. This shift underlines the perceived simplicity of drone operations and the consequential impact on modern battlefield dynamics, as articulated in interviews. The training and readiness of military personnel play a pivotal role in facilitating the operational effectiveness of drone deployment within the Portuguese Ground Forces. Pre-deployment training, particularly for missions in regions like the Central African Republic and Romania, highlights the importance of familiarizing ground forces with UAS and UAVs. This has come to require coordination between support units responsible for drone operations and maneuver units tasked with operational responsibilities. According to the respondents, certification as a military drone operator in Portugal entails the completion of two training courses: general aeronautical training and an equipment-specific operational qualification course. This certification is a prerequisite for deployment within support units of the national force, with a requisite accumulation of over 60 h of flight experience before operational deployment and has been vital for the smooth running of operations.

4.3 Defining the characteristics of operational military drones

All interviewees concurred on the utility of drones within the Portuguese Army, albeit differing on the prioritization of attributes for categorizing military drones. In that regard, a consensus emerged on certain characteristics, as delineated in Figure 8. The attributes identified by Barros *et al.* (2024) (MTOW, OA, and Endurance) were widely acknowledged for drone categorization, with suggestions for incorporating two additional parameters, as depicted by dashed lines in Figure 8.

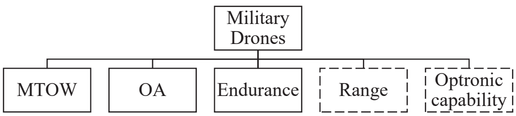


Figure 8. Military operational drone attributes

Source(s): Own elaboration

To our knowledge, optronic capability and range constitute operational requisites not extensively addressed in existing literature, particularly concerning the metric capacity for data transmission to the operator. The operating altitude (OA) necessitates reduction to ensure continuous electronic line-of-sight connectivity between the operator and the equipment. Additionally, the metric range of communication and data transmission systems should be accessible to the operator, as emphasized by a drone specialist during the interview. According to the specialist, the inclusion of two additional parameters, namely Range and Optronic Capability, is warranted. The Range attribute is justified by the significance of an aircraft's ability to record and transmit video, notwithstanding its endurance, especially in Electronic Warfare scenarios where spectrum influence on military operations is pivotal. This pertains to telemetric capabilities, ensuring robust ground station-aircraft connectivity. Moreover, for surveillance missions, optimal imaging capability is imperative, necessitating features such as thermal or infrared cameras and optical cameras with magnification, aligning with payload characteristics essential for real-time, high-quality image acquisition. For long-range surveillance missions, drones offer significant advantages by reducing the need for a large number of vehicles. This enhances the security of military personnel and mitigates environmental impact (QiH), as many drones used by the Portuguese military are electric. Although these drones are often charged using generators, they are still far more energy-efficient than deploying an entire military convoy.

4.4 Summary

The classification of attributes of military drones (Alimpiev *et al.*, 2017; Arjomandi *et al.*, 2006; Bekešienė, 2017; Chaturvedi *et al.*, 2019; Darwin *et al.*, 2014; Homainejad and Rizos, 2015; Klimkowska *et al.*, 2016; Tachinina *et al.*, 2022) lacks consensus within academic discourse, as highlighted by Barros *et al.* (2024, p. 89). This ambiguity extends to the Portuguese military, particularly the Army, which has yet to delineate the specific drones utilized in operations or define their requisite attributes. Addressing these knowledge gaps, this study formulated two primary research questions (RQ): (1) How are drones integrated into the operational framework of the Portuguese military ground forces? and (2) What attributes are required for the development of military drones? In response to these questions, this article pursued several secondary objectives (SO), including (1) describing the use of drones according to doctrinal publications; (2) identifying the use of military drones through the application of case study methodology; (3) presenting the military drones attributes in the context of Portuguese Army.

Through expert insights and input from military drone operators, five pivotal attributes for drone classification emerged, namely: Maximum Takeoff Weight (MTOW), Operational Altitude (OA), Endurance, Range, and Optronic Capability. While the Portuguese ground forces currently employ available drones, certain units utilize drones not officially provided by the organization. Particularly, the Raven Mini-UAV is extensively employed to support units up to the battalion level, mainly in operations within the Central African Republic (CAR). Furthermore, the Army's strategic intent to procure drones tailored to support units down to the company level signifies a proactive approach toward enhancing tactical capabilities and adaptability.

Overall, in our view, this research bears significance for both the academic community and the Portuguese ground forces as it contributes with empirical insights into issues delineated by Barros *et al.* (2024). While also affirming the evolving alignment of Portuguese military doctrine with contemporary operational realities. This alignment fosters effective collaboration among stakeholders within the Triple Helix (TH) model, particularly enhancing synergy between the military, industry, and research sectors. Within this framework, the military, as the “Government” sector, is tasked with acquiring components and equipment developed by industry to meet operational needs, while researchers focus on developing innovative technologies to address these requirements.

5. Conclusion

This research undertook a literature review of innovation models within both national and international defense industries. It prominently highlights the Triple Helix (TH) innovation model developed by Etzkowitz and Leydesdorff (1995) and Cai and Etzkowitz (2020). This model’s evolution includes the Quadruple Helix model, which adds the “society” dimension, and the Quintuple Helix (QiH) model, which further incorporates the “environment” dimension. The study demonstrates how the QiH model influences the Techniques, Tactics, and Procedures (TTPs) of the Portuguese armed forces, especially the ground forces. By comparing these doctrinal procedures with the missions and operational practices of Portuguese Army sections and platoons, the research identifies a significant need for advancements in the components and equipment used by the Portuguese ground forces. This necessity is driven by a disparity between current capabilities and the demands of contemporary operational environments. To address these shortcomings, the Portuguese Ministry of National Defense, in collaboration with other ministries, has initiated research efforts. These efforts aimed to integrate doctrinal principles, scientific advancements documented in peer-reviewed literature, and empirical investigations of military forces. Building upon previous research by Barros *et al.* (2024), this study extends the exploration of concepts related to Intelligence, Surveillance, and Reconnaissance (ISR), Unmanned Aircraft Systems (UAS), Unmanned Aerial Vehicles (UAVs), and drones. It specifically examines the attributes of operational drones within the Portuguese ground forces, identifying a gap between documented literature and current practices. Five critical attributes of military drones were identified, acknowledging the rapid development and technological advancements in these systems. Overall, the research highlights the importance of continuous innovation and technological integration within military operations to meet the evolving challenges of modern warfare.

5.1 Practical and theoretical contributions

This article addressed the issues within the contracting process for acquiring drones for the Portuguese land forces. Our recommendations include involving specialized military from the Portuguese Armed Forces in the acquisition process of modern equipment. Additionally, we suggest implementing knowledge exchange initiatives with civilian companies to accelerate modernization efforts, ensuring they align more closely with military needs. The study also highlights the importance of integrating military expertise in Unmanned Aerial Vehicles (UAVs) and drones into the command structure of operational units. To achieve this, we recommend prioritizing these subjects in the curricula of military education institutions, such as the Military Academy and the Army Sergeants School, ensuring this knowledge is widespread and acquired early in military careers. From a theoretical perspective, this research makes a significant contribution to the existing body of knowledge. It introduces a more comprehensive discussion of military drones and their opportunities and challenges for integration into the armed forces. Additionally, this research establishes a foundation for future investigations into the effectiveness of Command, Control, Communications, and Information Systems (C4I) across different units of the Portuguese Army Land Forces. It proposes incorporating the five identified attributes relevant to military drones, aligning them with the specific needs of the units they are designed to serve.

5.2 Strengthening the connection between findings and implications

The findings of this study, derived from interviews, document analysis, and site visits, have direct implications for both the practical implementation of drone technology in the Portuguese military and the theoretical understanding of innovation frameworks. For instance, the interviews provided knowledge of the current operational challenges faced by the Portuguese military in integrating drone technology, including gaps in doctrinal guidance and the need for specialized training. Quotes from interviewees, such as a military operator stating "We often lack the clear directives needed to effectively deploy drones in dynamic environments" highlight the urgency for updated and precise doctrinal frameworks. These statements show the practical implications of our research by identifying specific areas where policy and training must evolve to meet contemporary operational needs. Informal conversations and document analysis further corroborated these findings by revealing a lack of comprehensive guidelines in existing military manuals and training documents. For example, a respondent explicitly noted that "Current manuals do not cover advanced drone tactics or integration into combined arms operations", which reinforces the need for doctrinal development. Similarly, site visits allowed us to observe firsthand the operational deployment of drones, revealing discrepancies between documented practices and actual field usage. These discrepancies suggest a significant gap between theory and practice, emphasizing the necessity for continuous updates to military doctrine to reflect technological advancements and changing operational contexts.

5.3 Clarifying theoretical contributions and extending the Quintuple Helix framework

While our study utilized the Quintuple Helix (QiH) framework as a foundational model, it went beyond applying this framework to analyze innovation in military contexts. The Quintuple Helix framework, which incorporates the dimensions of academia, industry, government, society, and the environment, provides a comprehensive lens for examining complex innovation ecosystems. Our research contributes to this theoretical framework by integrating empirical data from a military setting—a context often underrepresented in innovation studies.

Through our interviews, documents, and site visits, we were able to identify unique interactions among the helix components, particularly how societal and environmental factors influence military innovation. For instance, one significant finding was the role of environmental perception in shaping ground military operations, especially concerning the implications of drone use. A key quote from an expert highlights this: "For long-range surveillance missions, electric drones offer significant advantages by reducing the need for a large number of vehicles". This insight extends the Quintuple Helix framework by demonstrating how the environmental dimensions, such as green energy can actively shape military operations.

5.4 Advancing the Triple Helix framework through empirical insights

Our research not only extends the Quintuple Helix model but also refines the original Triple Helix model, which traditionally examines the interactions between academia, industry, and government. Our case study data highlighted specific dynamics in these interactions, particularly concerning the development and deployment of drone technologies. For instance, while academia and industry were actively collaborating on drone innovation and, at times, the industry itself drives innovation, we identified significant bottlenecks in the innovation process, especially in the interface between military forces and industry. A military respondent remark illustrates this issue: "Some of the equipment, such as the Matrice 300 RTK or the Dragon Fish, does not fully meet our military operational needs". This feedback shows the necessity for more agile and close collaboration between government and industry, suggesting an extension of the Triple Helix model to incorporate adaptive governance for rapidly evolving technologies.

Our study contributes to theoretical frameworks by enhancing the Quintuple Helix model with insights from the military sector, advancing our understanding of environmental and social factors in defense innovation, and highlighting the need for more dynamic governance models within the Triple Helix framework. These contributions provide a deeper perspective on innovation processes in complex, high-risk environments like the military, enriching the existing body of literature with new understandings.

5.5 Limitations and recommendations for future contributions

The primary limitation of this study is the absence of contemporary military doctrine within the Portuguese Land Forces specifically addressing drone usage. While drones have been actively deployed by the Portuguese military in regions such as the Central African Republic (CAR) and Romania, there remains a significant gap in documented literature and official guidelines that reflect these experiences and lessons learned. This lack of comprehensive doctrinal guidance hinders the ability to standardize and optimize drone operations across different military units and missions. Future research should, therefore, prioritize the development and integration of updated doctrinal frameworks that incorporate the latest Techniques, Tactics, and Procedures (TTPs) to enhance the operational capabilities and effectiveness of the Portuguese military forces.

Moreover, addressing this doctrinal gap from a scientific perspective is central. There is a need to systematically document and analyze drone usage, drawing on empirical data and experiences from the field. This will help to create strong frameworks that can be adapted not only within the Portuguese military but also in a broader European context. Such an approach would facilitate the standardization of drone operations across European armed forces, promoting interoperability and shared understanding in multinational operations.

Future research should also critically examine the use of the Triple Helix (TH) and Quintuple Helix (QiH) innovation models within the defense sector. While these models are effective in fostering collaboration between the military, academia, and industry, their application has not been without risks. Future studies could explore alternative or complementary innovation models that may offer different benefits or mitigate potential drawbacks, such as conflicts of interest or over-reliance on private entities for critical military capabilities.

To address these limitations, there is a need for increased scientific research in this area. This includes promoting better collaboration between military research centers, universities, and industry partners to endorse knowledge exchange and innovation. Encouraging military universities and research institutions to engage more deeply in research and publish findings related to drone usage, innovation models, and doctrinal development will be critical. Future investigations should also provide an enhanced focus on the human factors associated with drone operations, such as the training and psychological well-being of drone operators, as well as the societal and ethical implications of increased drone deployment in military contexts.

Additionally, future research could benefit from a comparative analysis of drone doctrines and usage across different NATO and EU member states. This would identify best practices and potential areas for standardization, thus enhancing the effectiveness and interoperability of multinational forces. By addressing these gaps, future studies contribute to an enhanced understanding of the role of drones in modern military operations and guide both policy and practice in the Portuguese defense sector and beyond.

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