



ESCOLA NAVAL

talento e brio

Francisco José Teixeira da Costa



Drone Warfare:

**Operational Context, Countermeasures and Tactical Insights
for the Portuguese Marine Corps**

A dissertation submitted in partial fulfillment of the requirements for the
degree of Naval Military Sciences, specialization on Marines



Alfeite

2024



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Infante de D. Afonso



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Terror from Above

"Let me tell you a story

A bedtime story

Let me tell you a story

Of Predator drones with giant wings

Equipped with hellfire missiles

And "light of God" lasers

Choking the skies over Northwest Pakistan

Let me tell you a story

A daytime/nightmare story

Of grandmothers as "bug splats"

And children as "double taps"

Let me tell you a story

An everyday story

Of terror from above

Villagers burned, body parts strewn

Over cultivated fields

Let me tell you another story

The official story

A Drone Warfare story

Let me tell you a story

Of precision strikes

Where no innocent is mutilated, incinerated

Or murdered

Let me tell you a story

But we know this story is a lie."

Aroosa Kanwal

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Abstract

The dissertation focuses on the study of Drone Warfare. This field has been growing, and in recent years, with the implementation of new technologies, doctrines, and system capabilities, there has been a need for adaptation by the world's armed forces. The objective of the dissertation is to provide the Portuguese Navy with a contemporary operational study of Drone Warfare, testing, comparing, and evaluating C-UAS (Counter-Unmanned Aerial Systems). This aims to ensure that the Navy uses and knows how to use the most efficient and cost-effective C-UAS to be prepared for future technological adversities in Drone Warfare.

During the dissertation, it was concluded that Drone Warfare is changing modern warfare, with daily technological advancements such as the implementation of new technologies and more capable systems. It was tested the PITBULL WINGMAN and SWATTER systems, and evaluated their use for the Portuguese Marine Corps, as well their capabilities and employment. It was proved the ballistic plate protects the combatant and improves C-UAS efficiency. Lessons learned indicated that the use of these systems is most efficient in fast, light, small and specialized forces, with the use of one UAV (Unmanned Aerial Vehicle) and one C-UAS for every 4 men, and a need for an ISR (Intelligence, Surveillance and Reconnaissance) unit. It was also identified a need for TTPs (Tactics, Techniques and Procedures) and the development of UAV operator training, which this dissertation seeks to address.

These conclusions will be important to facilitate and advance the work produced by the X31 and CEOV (*Célula de Experimentação Operacional de Veículos não Tripulados*, Unmanned Systems Innovation and Operational Experimentation Cell) units in Drone Warfare, providing current TTPs, possible operational organizations, system usage security, and understanding of the current and future world of Drone Warfare.

Keywords: Countermeasures; Drone Warfare; Jamming; Spoofing; Unmanned Aerial Systems

Resumo

A dissertação foca-se no estudo de *Drone Warfare*. Este campo tem crescido e, nos últimos anos, com a implementação de novas tecnologias, doutrinas e capacidades de sistemas, tem havido uma necessidade de adaptação por parte das forças armadas mundiais. O objetivo da dissertação é fornecer à Marinha Portuguesa um estudo operacional contemporâneo sobre *Drone Warfare*, testando, comparando e avaliando C-UAS. Isto visa garantir que a Marinha utilize e saiba como usar os C-UAS mais eficientes e rentáveis para estar preparada para futuras adversidades tecnológicas de *Drone Warfare*.

Durante a dissertação, concluiu-se que *Drone Warfare* está a mudar a guerra moderna, com avanços tecnológicos diários, como a implementação de novas tecnologias e sistemas mais capazes. Foram testados os sistemas PITBULL WINGMAN e SWATTER, e avaliou-se o seu uso para o Corpo de Fuzileiros Portugueses, bem como as suas capacidades e emprego. Provou-se que a placa balística protege o combatente e melhora a eficiência dos C-UAS. As lições aprendidas indicaram que o uso destes sistemas é mais eficiente em forças rápidas, leves, pequenas e especializadas, com o uso de um UAV e um C-UAS para cada 4 homens, e a necessidade de uma unidade de ISR. Identificou-se também a necessidade de TTPs e o desenvolvimento de formação para operadores de UAV, que esta dissertação procura abordar.

Estas conclusões serão importantes para facilitar e avançar o trabalho produzido pelas unidades X31 e CEOV em *Drone Warfare*, fornecendo TTPs atuais, possíveis organizações operacionais, segurança no uso de sistemas e compreensão do mundo atual e futuro da *Drone Warfare*.

Palavras-Chave: Contramedidas; *Drone Warfare*; *Jamming*; Sistemas Aéreos Não Tripulados; *Spoofing*

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Table of Acronyms and Abbreviations

AA100	Active Antenna 100
ACK	Acknowledgement
AI	Artificial Intelligence
ALADDIN	Advanced holistic Adverse Drone Detection, Identification, and Neutralization
ANAC	<i>Autoridade Nacional de Aviação Civil</i> , Portuguese Civil Aviation Authority
ANACOM	<i>Autoridade Nacional de Comunicações</i> , Portuguese Communications Authority
APCs	Armoured Personnel Carrier
BVLOS	Beyond Visual Line of Sight
C-UAS	Counter-Uncrewed Aerial Systems
CAA	Civil Aviation Authority
CEOM	<i>Centro de Experimentação Operacional da Marinha Portuguesa</i> , Portuguese Navy Operational Experimentation Centre
CEOV	<i>Célula de Inovação e Experimentação Operacional de Sistemas Não Tripulados</i> , Unmanned Systems Innovation and Operational Experimentation Cell
CEPA	Center for European Policy Analysis
CEPT	European Conference of Postal and Telecommunications Administrations
CL	Coordination Level
CNA	Center for Naval Analyses
CNAS	Center for a New American Security
COTS	Commercial off-the-shelf
CST	Computer Simulation Technology
CTS	Clear-to-Send
DIY	Do it Yourself
DJI	Dà-Jiang Innovations
DW	Drone Warfare

EDM4S	Electronic Drone Mitigation 4 - System
EIRP	Effective Isotropic Radiated Power
EO	Electro-Optical
ERP	Effective Radiated Power
EU	European Union
EUROCAE	European Organization for Civil Aviation Equipment
EW	Electronic Warfare
FAA	Federal Aviation Administration
FOB	Forward Operational Base
FPV	First-Person View
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HALE	High Altitude Long Endurance
HVT	High-Value Target
ICAO	International Civil Aviation Organization
ICNIRP	International Commission on Non-Ionizing Radiation Protection
ICRC	International Committee of the Red Cross
IDF	Israel Defense Force
IEC	Infrared Emitter and Detector
IFV	Infantry Fighting Vehicle
IR	Infrared
ISIS	Islamic State of Iraq and Syria
ISM	Interference and Spoofing Mode
ISR	Intelligence, Surveillance, and Reconnaissance
ISR-T	Intelligence, Surveillance, Reconnaissance, Targeting
ISTAR	Intelligence, Surveillance, Targeting, Acquisition and Reconnaissance
JARUS	Joint Authorities for Rulemaking on Unmanned Systems
LIDAR	Light Detection and Ranging
MALE	Medium Altitude Long Endurance
MIT	Massachusetts Institute of Technology

MT-LBs	Multi-Purpose Tracked Vehicle-Light Armored
MTI	Moving Target Indicator
NATO	North-Atlantic Treaty Organization
NIJ	National Institute of Justice
NW	Networking Warfare
PB	PITBULL
PTSD	Post-Traumatic Stress Disorder
RAM	Random Access Memory
REPMUS	Robotic Experimentation and Prototyping with Maritime Unmanned Systems
RTS	Request-to-Send
RF	Radio Frequency
RPA	Remotely Piloted Aircraft
RTH	Return to Home
SA	Situational Awareness
sUAS	Small Uncrewed Aerial Systems
SANT	<i>Sistemas Aéreos Não Tripulados</i> , Uncrewed Aerial Systems
SAR	Specific Absorption Rate
SDR	Software Defined Radio
SLAM	Simultaneous Localization and Mapping
TRL	Technology Readiness Level
TTP	Tactics, Techniques and Procedures
U.K.	United Kingdom
UAC	<i>Unidade de Apoio de Combate</i> , Combat Support Unit
UAS	Uncrewed Aerial Systems
UAV	Uncrewed Aerial Vehicle
UCAV	Uncrewed Combat Aerial Vehicle
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea
UPF	<i>Unidade de Projeção de Força</i> , Projection Force Unit

US	United States
USA	United States of America
VBS	Virtual Battle Space
VLOS	Visual line of Sight
VTOL	Vertical Take-Off and Landing
ZEE	<i>Zona Económica Exclusiva</i> , Exclusive Economic Zone
ZLT	<i>Zona Livre Tecnológica</i> , Free Tech Zone

1. Introduction

*“Rushing like the wind; slow-stirring like the forest; consuming like fire; immobile like a mountain. **They are as hard to know as shadows.** They move like rolling thunder...”*

Sun Tzu

Drone Warfare, as a discipline, has gained importance, in recent times, due to modern military conflicts around the world, with the proliferation and utilization of uncrewed aerial vehicles (UAV) in armed conflicts. Their increasing capabilities pose a threat to all States and non-state actors who pursue military objectives. The fast technological evolution of UAVs, accompanied by their widespread adoption internationally, has accelerated the creation of numerous effective countermeasures to mitigate their risks.

The Portuguese Marine Corps is a highly mobile, specialized force with few modern electronic warfare systems, is particularly vulnerable to the threats posed by Drone Warfare. The need to develop and implement effective counter-unmanned aerial systems (C-UAS) has become a necessity for the Portuguese Navy. The dissertation aims to contribute to the solution of this issue by analyzing C-UAS of Drone Warfare to find the best solutions.

The dissertation begins with the presentation of the work objectives, research methodology, where the hypotheses are formulated and the problem presented, and structure. Following this, a documentary and exploratory study on the background of Drone Warfare will be conducted, theoretically and technically addressing important concepts for C-UAS such as Jamming and Spoofing, the current classification dedicated to UAS and C-UAS, legal issues in the use of UAS and C-UAS in the civilian and military world, and the ethical and moral issues of Drone Warfare and Drone Violence.

In the state-of-the-art section, through deductive thinking and Popper's scientific method, the operational context of Drone Warfare, current types of C-UAS, and exploratory interviews for gathering pertinent information will be analyzed. With the background and state of the art of Drone Warfare defined, C-UAS systems will be

analyzed, simulated, and tested, focusing on their employability for the Marine Corps, as well as their potential harm to combatants, through a quantitative research strategy.

In a qualitative manner, lessons learned from armed conflicts, operational organizations for Drone Warfare, tactical considerations, and training will be subsequently analyzed to create and deliver a Drone Warfare manual for the Marine Corps to use as doctrine for Drone Warfare.

The work concludes by addressing the results found during the master's dissertation and the verification of the hypotheses formulated at the beginning of the work. The study will be of thorough investigation, with a combination of interviews, literature, comparisons and experimentation, in order to place the Portuguese Navy ahead in the “drones’ race” and to reach a new milestone in Drone Warfare.

1.1. Motivation

Modern warfare is in a constant and progressive evolution due to increasingly rapid and pertinent technological advances. At this moment, it is witnessed a fourth industrial revolution with the implementation and development of Artificial Intelligence (AI) in academia, industry, and defense, which will change both the civilian and military worlds (Ross & Maynard, 2021). Accompanying the industrial revolution is a new Drone Age, the Second Drone Age, which with the proliferation of commercial UAVs will forever change the dynamics of war, just as tanks did in World War I and fighter planes did in World War II (Rogers D. J., 2021). The impact of Drone Warfare with the abundant use of commercial UAVs together with Artificial Intelligence will be the true robotization of war.

The illegal and negative use of UAVs has several relevant impacts that the Portuguese Navy has already identified. It has been reported minor altercations between search and rescue Portuguese ships and Russian military ships across the Portuguese sea (Guerreiro & Vitorino, 2023). Presence of foreign Russian ships in the Portuguese exclusive economic zone has increased from 10 ships in 2020 to 46 in 2023 (Melo G. e., 2024), such ships could be equipped with UAVs to surveil or attack the

Portuguese Navy. There have also been reports of the use of commercial UAVs by maritime traffickers to monitor security forces activity (Haugstvedt, 2021). However, the Chief of the Navy Staff has identified these gaps and observed the various current conflicts such as those in Ukraine and Gaza, which represent the current state and difficulty of Drone Warfare, seeking to adapt and update the Portuguese Navy to be able to respond to these challenges (CEOM, 2024). To this end, the Chief of the Navy Staff Gouveia e Melo has introduced the concept of ““Light and Fast””, which aims at using specialized personnel in Drone Warfare, both in UAV operation and in countermeasures (Melo H. E., 2017). He also aimed to create a specialized unit in Drone Warfare, X31, which will, through unmanned systems, assist the armed forces in aerial, land, and maritime components (X31, 2024).

However, the implementation of these measures is still in its early stages, with a great need for doctrine, scientific knowledge, and TTPs to help fighters implement and understand the object of study. Therefore, the motivation of the dissertation in formulating tactical techniques and procedures to provide to the Portuguese Marine Corps is justified to prepare future combatants to engage in modern armed conflicts where Drone Warfare is the norm. A study of the current operational context will be conducted, analyzing conflicts such as the Second Nagorno-Karabakh War, the conflict in Ukraine, Gaza and Yemen. The current ranges of C-UAS and UAVs that present innovative capabilities and are used in ongoing conflicts will be exposed and evaluated. Non-kinetic measures for destroying UAV will be explained, and C-UAS will be tested to ensure their conscious and efficient use in the battlefield.

In a time as dangerous and technologically advanced as the present, the realization of an extensive and detailed master's dissertation on such a technologically, robotized, and current form of warfare becomes extremely relevant, important, and necessary for a Navy that searches to be useful, holistic, and technologically advanced.

1.2. Objectives of the Dissertation

The objectives for the dissertation are divided in four different sections:

- Knowledge- With the utilization of new UAS and C-UAS and the increase in their employment in armed conflicts, the existing skepticism regarding new technologies dedicated to Drone Warfare has also increased. This was observed in conversations with Marines during system experimentation and interviews. Therefore, the dissertation has the following objectives in the knowledge section:
 - To instruct Portuguese Marines on Drone Warfare, both in terms of its capabilities, dangerousness, and implemented technologies.
 - To abolish the existing skepticism in the Portuguese Navy regarding new technologies dedicated to Drone Warfare.
- Protection- With the proliferation of UAVs in recent years, there is a need to protect combatants through countermeasures. These non-kinetic countermeasures that address the electromagnetic spectrum, identified by experts as the most effective way to neutralize unauthorized UAVs, can affect the combatant through the manipulation of the electromagnetic spectrum. Therefore, it becomes necessary, in addition to testing the systems and experimenting with their effectiveness, to also understand their harmfulness to the operator, seeking their protection. With this, the objectives in this section are as follows:
 - To protect the combatant against enemy or unauthorized UAVs through Spoofing and Jamming.
 - To protect the combatant against the absorption of harmful energy emitted by the countermeasures.
- Employment- With the need to adopt UAS and C-UAS in the Marine Corps, targeted by the “Light and Fast” Concept, there is a need to study and understand how various armed forces employ these means in their operational organizations, to apply and recommend a nominal

operational organization for the Marine Corps. Therefore, the objective for this section is the following:

- To recommend for the Marine Corps, with a view to the “Light and Fast” Concept, an operational organization that aims to use UAS and C-UAS as observed in modern Drone Warfare.
- Doctrine - As employment comes, the techniques, tactics, and procedures in the operation of UAS and C-UAS are necessary for combatants to be able to respond in a timely and safe manner against enemy or unauthorized UAVs. Considering the lack of doctrine dedicated to Drone Warfare at the NATO and Portuguese Navy level, the need to recommend training considerations and TTPs for the Marine Corps is envisaged. Therefore, the objectives are as follows:
 - To create and deliver a Drone Warfare Manual that aims to compile TTPs drawn from current conflicts and armed forces so that combatants can survive the inherent difficulties of Drone Warfare.
 - To evaluate and solve the current training dedicated to UAS and C-UAS operators in the Marine Corps.

These are the objectives for the master's dissertation, of high importance and necessity, which will be solved by the hypotheses formulated in the following chapters.

1.3. Research Methodology

The research methodologies are the means applied to achieve the objectives defined in the previous chapter. For this purpose, the IUM (*Instituto Universitário Militar*, Military University Institute) notebook was used as a reference to correctly apply the research methodologies. The 'Research Onion' was followed, as can be seen in Figure 1, to demonstrate the methodologies used in the dissertation.

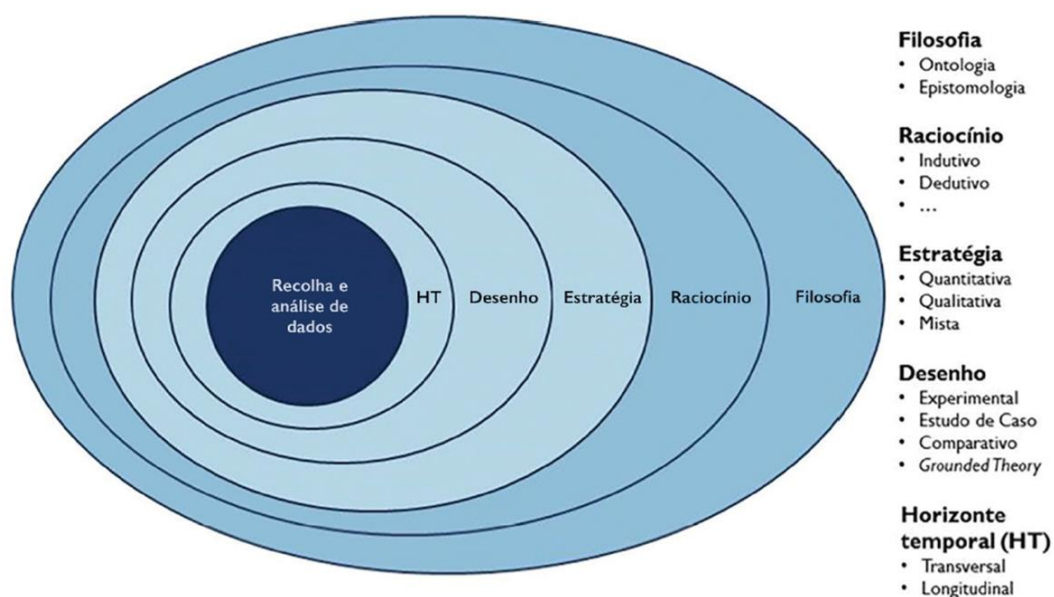


Figure 1- "Research Onion" for Research Methodologies¹

Initially, the study presented will be based on scientific knowledge through systematic study and research as it aims to verify theories established through Popper's scientific method and deductive reasoning. Drone Warfare will, then, be considered as a phenomenon which is recognizable, original, useful and objective. The research will therefore look to its laws and prove its principles and hypothesis formulated. The study advocates the importance of Drone Warfare in modern military theaters, aspiring to achieve a greater global understanding of the topic within the Portuguese armed forces.

The work will have an ontological consideration since the reality will be analyzed as a concrete structure studying its relations with operational environments and Drone Warfare. It will take an interpretative stance, as the author's innate knowledge and judgement will analyze the results of the qualitative and quantitative data from tests and documents research to reach the conclusions of the work.

Therefore, the reasoning will be deductive, observing general facts from conflicts such as those in Ukraine, Nagorno-Karabakh, Gaza and Yemen, to formulate concepts and principles that will assist in determining the best system and tactical methods to survive in today's battlefields with the new dynamics of warfare. An intensive study of

¹ Figure taken from (IUM - Centro de Investigação e Desenvolvimento (CIDIUM), 2019)

Drone Warfare will be conducted, covering the UAVs used in current conflicts, their capabilities, doctrinal classifications, countermeasures, and the behavior and tactical planning that fighters must adopt to address new challenges.

Thus, the work will follow Popper's scientific method with an application of critical thinking, divided into five phases as seen in Figure 2,

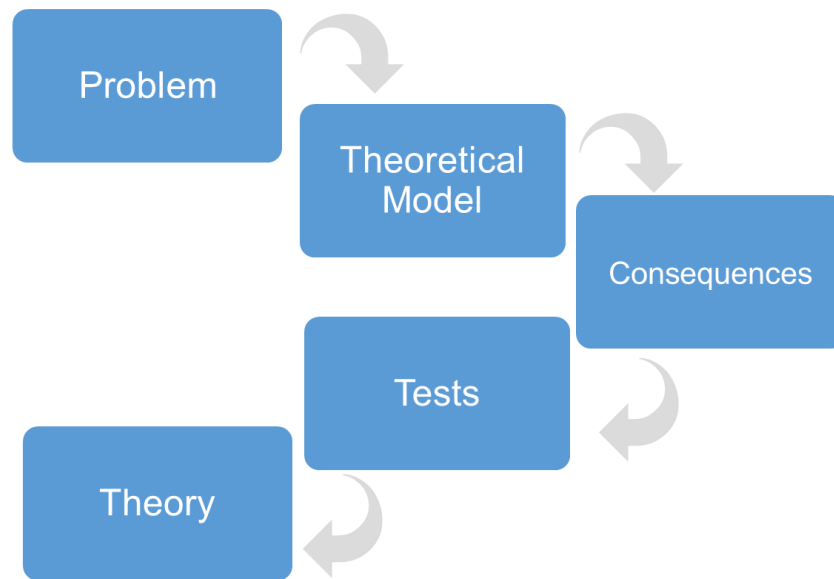


Figure 2- Popper's Scientific Method for the Dissertation

The framework, observing the scientific method applied, is the following (IUM - Centro de Investigação e Desenvolvimento (CIDIUM), 2019):

- Problem Statement: There is currently a development of technologies related to autonomous systems, both in their autonomy, combat power², and capabilities, which have been observed in recent conflicts such as the Conflict in Ukraine, Gaza, Yemen and Nagorno-Karabakh. Therefore, an in-depth study of Drone Warfare, in its knowledge of the combatants, its protection, employment of UAS and C-UAS and doctrine becomes

² Combat Power is defined as the total means of “destructive, constructive, and information capabilities that a military unit or formation can apply at a given time.”, (Maj. Thomas R. Ryan Jr., 2022)

necessary and advantageous to prepare the Portuguese Marine Corps for the new challenges of UAS observed today.

- Construction of a Theoretical Model: The Theoretical Model is divided into Observation and Formation of Hypotheses.
 - Observation: To explore the problem and gather documented data, a background study on UAS, C-UAS classification and non-kinetic means of neutralizing UAVs will be made. Moreover, an analysis of the legal, ethical and moral use of UAVs will be assessed. The current operational context of Drone Warfare will be analyzed and studied, examining the current range of UAVs and C-UAS and verifying their capabilities. C-UAS will be experimented with and tested in simulated and semi-controlled environments within the Portuguese Marine Corps to assess their effectiveness and harm to the future combatants. Finally, Tactics, Techniques, and Procedures (TTPs) will be formulated, as training and doctrine of the Portuguese Marine Corps, so the future combatants can be prepared against military challenges.
 - Formation of Hypotheses: According to the objectives envisaged and the study formulated in the background and state of the art, the hypotheses are the following:
 - Knowledge-**H1**: The study of Drone Warfare will gather information necessary and important which will significantly reduce skepticism and increase understanding among Portuguese Marines.
 - Protection-**H2**: non-kinetic countermeasures, such as Spoofing and Jamming, effectively neutralize unauthorized UAVs without causing harmful effects to operators.

- **Employment-H3:** Through the study of different operational organizations for Drone Warfare, it will be possible to implement a recommended operational organization for the Marine Corps.
 - **Doctrine-H4:** Through the study of different TTPs adopted by armed forces in current and recent conflicts, it will be possible to formulate and deliver a Drone Warfare Manual, which will improve combat readiness and response times against enemy or unauthorized UAVs.
- **Deduction of Specific Consequences:** According to the four hypotheses formulated for the various objectives of the work, several results are expected:
 - **Knowledge-C1:** The dissertation on Drone Warfare will significantly reduce skepticism and increase understanding among Portuguese Marines, improving acceptance of new UAV technologies and better decision-making.
 - **Protection-C2:** The experimented C-UAS are valuable and efficient systems to neutralize enemy UAVs, and the ballistic plate showed to be a “shield” for the operator against the energy emitted by the countermeasure.
 - **Employment-C3:** An operational organizational was formulated and recommended for the “Light and Fast” Concept of the Portuguese Marine Corps which improves coordination and integration of Drone Operations.
 - **Doctrine-C4:** A Drone Warfare manual was formulated and sent to the Portuguese Marine Corps which led to more consistent responses and greater interoperability.

- Testing of Hypotheses: To test the previously formulated hypotheses, the following will be made:
 - Knowledge: To lower the skepticism and improve knowledge of the Portuguese combatants of Drone Warfare a deductive study of qualitative reasoning will be made through an operational context of four different conflicts (Yemen, Second Nagorno-Karabakh War, Ukraine and Gaza) and modern C-UAS used in recent conflicts, as well as several exploratory interviews to gain valuable information on Drone Warfare from different national and international specialists on the matter.
 - Protection: To test the impact of C-UAS on the human body of the combatant a simulated test will be made in CST Studio to find how much energy is absorbed by the combatant. To evaluate the C-UAS experimented in semi-controlled environments, operational constraints will be implemented to assess their employability in Portuguese Marine Corps and their efficiency. Both analyses will follow a quantitative analysis.
 - Employment: To recommend an operational organization to the Portuguese Marine Corps a study on different operational organizations from various armed forces for Drone Warfare will be analyzed, such as: Ukraine, Russia, Serbia, United States of America and Israel. The analysis will be of qualitative nature and deductive reasoning.
 - Doctrine: To create a Drone Warfare manual, a study on training, TTPs and checklists used by different armed forces will be assessed, for later recommendation and evaluation of the current in the Portuguese Marine Corps. The analysis will be of deductive reasoning and qualitative nature.

- Introduction of Assertions into Theory: With the formulated hypotheses and their predictions, the testing of the same, and the approval of their application, it is possible to conclude the topics studied with the positive effectiveness of the C-UAS, positive employment and usefulness of the formulated TTPs, and the verified low harm of these systems to combatants. Thus, the written content can be included in the current theory surrounding Drone Warfare. However, the study must continue as the object of analysis is dynamic and recent with new technological advances daily, requiring constant study and testing of new systems for new UAVs such as the employment of new doctrine formulated for Drone Warfare to the Portuguese Marine Corps.

The research strategy will be mixed, using qualitative and quantitative studies, as the comparison and data acquisition from historical operational contexts, formulation of TTPs and comparison of current C-UAS and modern UAVs will have a qualitative approach. And a quantitative approach when realizing tests and experiments with participant observation, developing empirical data.

Finally, the research design will be (IUM - Centro de Investigação e Desenvolvimento (CIDIUM), 2019):

- Longitudinal: Seeking, within the operational historical context, to study four different cases, in this case, conflicts, to obtain the greatest amount of data and knowledge, from different temporal instances. This case will be analytical where the abundance of a factor (Drone Warfare) in a certain population (conflicts) is sought.
- Experimental: In testing C-UAS, where the electromagnetic spectrum and potential radioactivity in controlled environments as well as their capabilities in a semi-controlled environment. In the end, a comparison will be made to determine the best system and for what type of scenario.
- Case Study: The object of study will be the Portuguese Marine Corps,

serving as both the means and the end for the work. The systems experimented with will be from the Marine Corps and allied institutions, and the knowledge developed in the work will be for the benefit of the Portuguese Marine Corps.

- Comparative: From the research phase to the product. Comparing various UAVs and C-UAS with their capabilities and countermeasures, both in experimentation and in the study of current conflicts.

In conclusion, the study will be of scientific knowledge with an ontological consideration, using deductive reasoning and Popper's scientific method of a mixed nature. It aims to study the current condition of Drone Warfare, including UAVs, countermeasures, jamming, spoofing, and the execution of experimental tests and techniques, tactics, and procedures.

1.4. Structure

The master's dissertation is divided into nine chapters, as you can see in Figure 3. The first chapter will be the introduction, where the motivation, objectives, research methodology, and structure of the dissertation will be presented.

The second chapter will address the background of Drone Warfare, giving inputs on important definitions for the work, an analysis of the most used and efficient ways of UAV countermeasures (jamming and spoofing), classification, and legal and ethical study of UAVs and C-UAS in the military and civilian dimensions. The purpose of this chapter is to provide the reader with an introduction to Drone Warfare with definitions and an analysis of the legal framework utilized nowadays in Drone Warfare.

The third chapter will cover the current state of the art of Drone Warfare with an operational context. It will also discuss the current range of UAVs and C-UAS used in current conflicts, classifying countermeasures systems into three types. It will also address the current means that the Portuguese Marine Corps has for Drone Warfare. The objective of this chapter is to instruct Portuguese combatants on the current

capabilities of the Portuguese Navy and those of other countries, observing the necessary needs and difficulties noted in current conflicts.

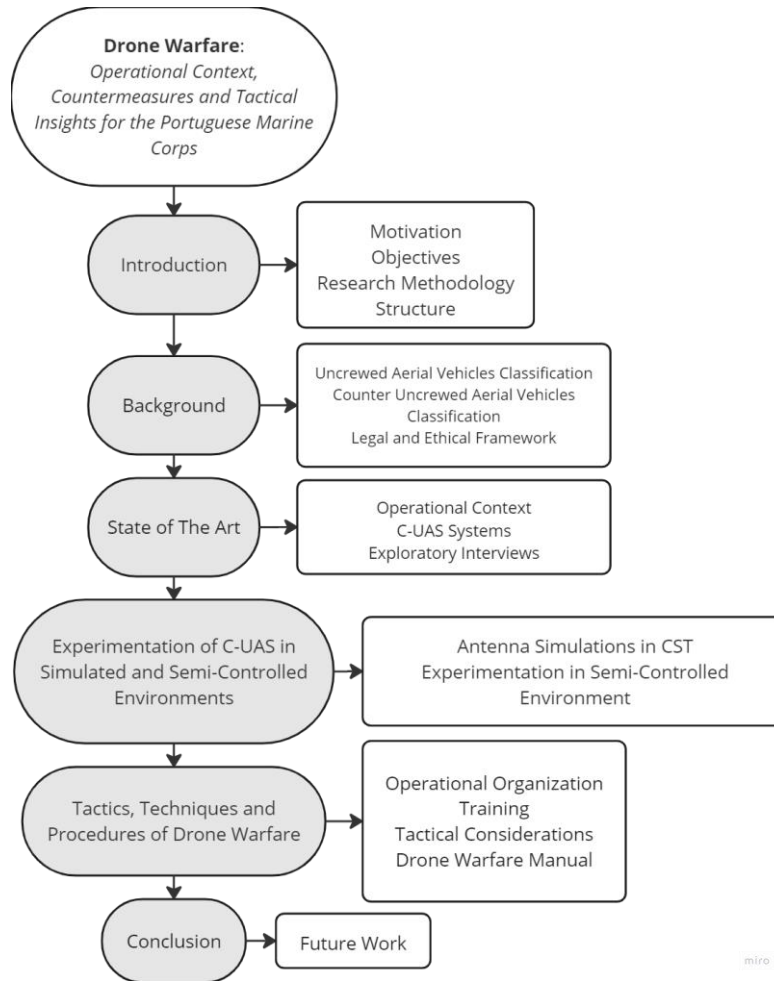


Figure 3- Dissertation's WorkFlow

Chapter four aims at scientific study in simulations and experiments in semi-controlled environments of the systems of the Portuguese Marine Corps and allied institutions, to verify their capabilities such as accessibility, range, acquisition time, robustness, and harm to the human body.

Chapter five aims at the formulation of TTPs, and the study of operational organizations developed by foreign countries, whether allies or not, that demonstrate capabilities and changes in favor of Drone Warfare, thus being able to compare and analyze the state of the operational organization of the Portuguese Marine Corps and the current doctrine used for this type of combat. Training and tactical considerations

will also be considered. The objective of the chapter is to formulate a Drone Warfare manual to be used by the combatant to acquire the lessons learned in the master's dissertation and apply them on the battlefield to meet the challenges presented by Drone Warfare.

Chapter six will be the conclusion where the hypotheses will be verified for their success and the impact of the study of the master's dissertation on the Portuguese Marine Corps will be addressed. Future work for continued study of Drone Warfare will also be discussed to keep fighters informed of technological advancements in the field.

Chapters seven, eight, and nine are respectively the bibliography, appendixes, and annexes.

2. Background

*“Attacks, I argued, now take place over thousands of kilometers against state military assets, diplomatic sites, chokepoints of international trade (at sea and on land), and the civilian centers of nation states. This is the current state of the world, one of **global drone diffusion**.”*

Dr. James Patton Rogers

A drone, according to the dictionary, is a male bee with the only function of fertilizing the queen bee (Cambridge, 2024). This definition then gave the inspiration to name the first unmanned biplane made in 1935 which was named “Queen Bee” (Markarian & Staniforth, 2021). But the first unmanned aerial vehicle used was in 1849 as unmanned hot air balloons by the Austrian forces in the battle with San Marco Republic (Seharwat, 2021). Since then, began the construction and proliferation of drones to be used in armed conflicts, initiating the study of Drone Warfare discipline, (Gusterson, 2016).

Drone warfare can be divided into two distinct ages, each characterized by its technological advances and challenges. The first Drone Age is considered by current experts as the abundant use of drones by the United States forces during the period after September 11th (Rogers D. J., 2021). Drones were mainly used for ISR (Intelligence Surveillance and Reconnaissance) functions or surgical destruction of HVT (High Value Targets). The MQ9A-Reapers and MQ-1 Predators were phenomena with immense precision and destructive capacity. Up to that point, drones were large technological units with high operational altitude, endurance, and range, that could destroy enemy targets with pin-point precision (Rogers J. P., 2023). But the paradigm shifted with the Second Drone Age.

The Second Drone Age, for some, is defined as the widespread and global proliferation of Unmanned Aerial Systems (UAS) and armed commercial drones, used not only by technologically advanced armed forces but also by unconventional rebel forces (Rogers D. J., 2024). The low cost and wide availability of drones in the market have led to their adoption and modification for use in warfare and the civilian world, leading to a true Fourth Industrial Revolution, driven by Artificial Intelligence and the

Internet of Things (IoT) (Ross & Maynard, 2021). For others, and for the authors, it is believed that the Second Drone Age began with the Second Nagorno-Karabakh War, considered the first war to be primarily fought by more advanced autonomous robotic systems on the battlefield (Antal C. J., 2022), with a first-time major war effort in loitering munitions drones employment in war. Either way, the Second Drone Age is characterized by the proliferation of Commercial Off-The-Shelf (COTS) and Do-It-Yourself (DIY) Drones in armed conflicts, due to their low cost and low risk, minimizing expenses on artillery pieces and human resources. Their use extended from state actors to non-state actors and terrorist groups like Hamas, Houthis and ISIS, (Rogers D. J., Remote warfare increasingly strategy of choice for non-state actors, 2019) Their capabilities increased as rapidly as their implementation, as they are becoming stealthier, smaller, faster, and more lethal, effectively replacing heavier and more expensive drones (Council, 2020).

The term drone has been conventionally defined as an unmanned short-sized flying machine capable of performing various functions such as photography, reconnaissance, and video (Boyle, 2020). "Drone" is the popular term for a UAV (unmanned aerial vehicle), which would be the military definition for "an aircraft which is intended to operate with no pilot" (International Civil Aviation Organization, 2011). Therefore a UAV would be any aircraft to be remotely piloted by an operator or completely autonomous, which is different from the term RPA (Remotely Piloted Aircraft) which is defined as "An aircraft where the flying pilot is not on board the aircraft" (Administration, 2023). This definition assumes the necessity of an operator to pilot an unmanned aircraft, which a UAV does not necessarily have to. So, every RPA would be a UAV but not every UAV is an RPA. This happens as well with the UCAV (Uncrewed Combat Aerial Vehicle) definition, UCAVs are a sub-part of UAVs that are designed specifically for combat with targeted strikes capabilities being the only difference between the two (Smith, 2022). Nevertheless, this definition has become a little blurred since new COTS UAVs have optimized their efficiency and capabilities and become all, at some point, multi-purpose UCAVs. In summary, the correct denomination of a drone would be UAV (Unmanned Aerial Vehicle), however, current developments

in gender identity in war by using the term “man” (Clark, 2019), and the absence of an “aircrew” in aircraft have elevated the issue of defining UAV as an Uncrewed Aerial Vehicle, being this term the nowadays adopted definition (Sayler & DeVine, 2022).

In addition to the various definitions presented previously, a classification that should also be mentioned is the normalized confusion between the definition of a missile and a UAV, which has been increasing with the Ukrainian Rocket Drone “Palianytsia” as seen in Figure 4 (Saballa, 2024).

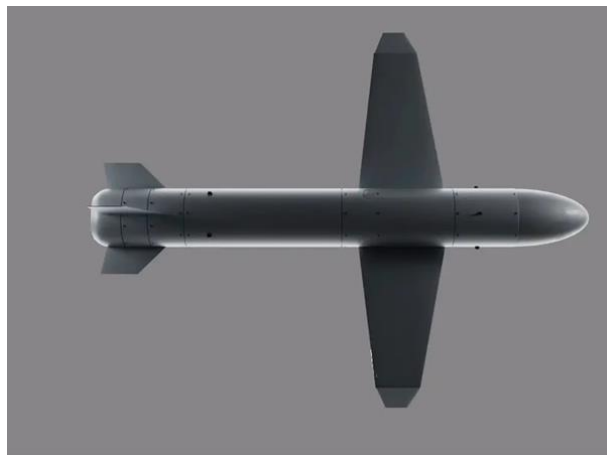


Figure 4- "Palianytsia" Rocket Drone³

It is important to differentiate missiles from UAVs, given that with technological advancement, especially in autonomy dedicated to UAVs, there has been an increase in the misidentification of missiles as UAVs. The main differences are observed in the functions that a UAV can adopt, both reconnaissance and logistical, which a missile cannot have. The most advanced missiles have pre-programmed flights, therefore they are not remotely controlled like UAVs, thus presenting fixed and shorter ranges with primarily explosive payloads, unlike UAVs (Schmidt & Haider, 2021). Therefore, the “Palianytsia” cannot be considered a drone or UAV but rather a cruise missile.

Even though the growing autonomy of a UAV , it is not completely autonomous, yet, therefore, the United States Army defines the term UAS (Uncrewed Aerial System) which is a three-part system that includes the UAV, a control station, or ground station

³ Figure taken from (Saballa, 2024)

that includes the operator and communication links between the two (Headquarters, Department of the Army, 2023) as you may see in Figure 5.

From here on out, the term UAV (Uncrewed Aerial Vehicles) will be utilized to reference aerial drones, with any capabilities. UAS (Uncrewed Aerial Systems) to reference the communication links, the operator, and ground stations that successfully employ the UAV.

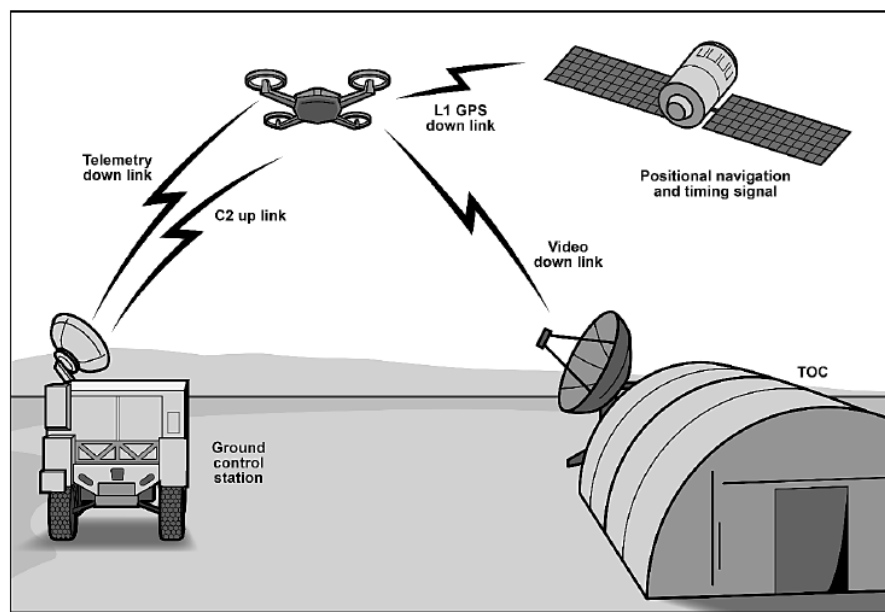


Figure 5- UAS constitution⁴.

The impact of UAVs on the battlefield became more apparent during the conflict in Ukraine in 2022. UAVs, which were, initially, specialized heavy war pieces that flew over the operational area to gather information about the enemy space have evolved into COTS systems that can be purchased for 200€ to harm and destroy the enemy, with capabilities of ISR as of combat. A study done by Forbes has unveiled the efficiency of employment of these systems with their costs of neutralization of enemy assets being extremely low in comparison with another kinetic types of destruction, becoming a true dynamic warfare change, as seen in Figure 6 (Battlegrounds, 2023).

⁴ Figure taken from (Headquarters, Department of the Army, 2023)

UAVs, along with their functions, have changed with the dynamization of new technologies and their use in modern warfare. A simple commercial UAV with an attached explosive device, intended to be dropped on the enemy or simply to impact it, has proven to be more dangerous and efficient than big pieces of conventional destruction (Battlegrounds, 2023). It is estimated that in 2047, UAVs will be capable of decision-making in nanoseconds and fully autonomous (Decoeur, 2012). The US (United States) Department of Defense has invested 30.8 billion euros in this effort (Union, 2013).

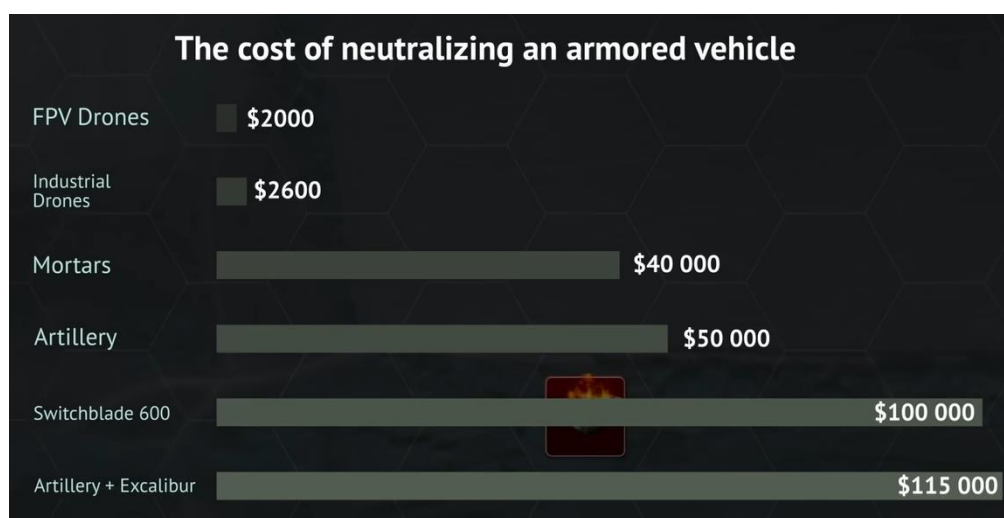


Figure 6- The Cost of Neutralizing an Armored Vehicle⁵

The UAVs rapid proliferation in the last decade led to uncertainty regarding legal applicability and the rapid development and distribution of UAVs and their technology, combined with the lack of transparency in the policies currently implemented in the international community, highlights the need for a concise and detailed study on the legal aspects of UAV use and their countermeasures, their development and utilization, (Hasian, 2016). For that, it is necessary to define UAVs and name them properly while classifying them and characterizing them, so it is possible to analyze their legal and ethical issues.

⁵ Figure taken from (Battlegrounds, 2023)

2.1. Uncrewed Aerial Vehicles Classification

Military operators across all nations quickly realized the immense capabilities and possibilities that these COTS UAVs possessed. In addition to the currently marketed capabilities, they are excellent for delivering materials, producing cinema films, and serving as formidable weapons of war capable of neutralizing, incapacitating, and recognizing the enemy (Boyle, 2020). They can also transport the wounded, ammunition, and forces to predefined geographical points (Baker, 2023).

Due to the constant evolution and changing role of UAVs in combat, some classifications and distinctions of UAVs have become irrelevant or outdated in the new reality they face, with no unified classification or characterization of UAVs. There are several classifications into different groups by various expert entities on the subject that need to be discussed and evaluated to reach a consensus on a worthy and useful UAV classification.

UAVs can be differentiated by various metrics: weight, wingspan, speed, payload, endurance, operational altitude, flight mode and accessibility. These distinctions are important because a UAV flying at 3km above the ground, equipped with guided missiles, will necessarily have different functions, weight, and components than a 10 cm commercial UAV, with a camera and payload, and a mandatory ground station with a minimum of two operators, one navigator and one gimbal operator. However, the latter can be operated by a single person, in real-time, just like the FPV (First Person View) UAVs that are widely used in the conflict in Ukraine and Gaza (Amble, 2023).

Starting with the distinction made by the United States Army, they differentiated UAS types and UAV types. UAS were divided into six different groups based on their weight, speed, and operational altitude, as you can see in Table 1. This division could also be applied to UAVs, even though the latter were divided into three groups according to their flight mode and operation.

UAS Group	Maximum Weight (lb.) ^a	Nominal Operating Altitude (ft.)	Speed (mph)	Representative UAS
Group 1	0-20	<1,200 ^b	<115	Most commercial hobby drones (e.g., DJI Phantom series), RQ-11 Raven, Wasp
Group 2	21-55	<3,500 ^b	<290	ScanEagle, Silver Fox, BUSTER
Group 3	<1,320	<18,000 ^c	<290	RQ-7 Shadow, RQ-21 Blackjack, RQ-23 Tiger Shark
Group 4	>1,320	<18,000 ^c	Any airspeed	MQ-8 Fire Scout, Predator, MQ-1C Gray Eagle
Group 5	>1,320	>18,000 ^c	Any airspeed	MQ-9 Reaper, RQ-4 Global Hawk, MQ-4C Triton

Table 1- US Army UAS Classification. ⁶

This approach, although comprehensive in involving UAS and UAV differently, is not the most useful for the difficulties found on today's battlefield. A significant portion of UAVs used on the conflicts ground falls into GROUP 1 of UAS with a weight below 10 kgs. Thus, greater compartmentalization of this group is deemed necessary since it is the most widely used type of UAV in current conflicts (Ahmed, Mohanta, Keshari, & Yadav, 2022).

In Table 2, it is noted the lack of an existent class of UAVs that are uniquely multirotor which this table does not consider, joining them to the rotary-wing class. Multirotor systems are like helicopters, their biggest difference to a Fixed-Wing is their significant small size, hovering capabilities, urban combat capabilities and lack of a need for a landing strip, (Vergouw, Nagel, Bondt, & Custers, 2016). Multi-rotor UAVs are mostly known as quadcopters, which are multi-rotors with four rotors and are deemed sufficient and effective, with accounts of North American soldiers claiming their advantages against other types of UAVs like fixed wing (Broman, 2018). Operators considered the quadcopters the “most versatile and mechanically easy to construct” (Sheth & Patel, 2013). With abilities to fly where fixed wings and other UAVs could not, with extreme agility and handling (Broman, 2018). Consequently, a class made specifically for multirotor should be done with an incremental study of its capabilities. Moreover, an international effort to include VTOL (Vertical Take-Off and Landing) aircraft in UAV classification is necessary due to their unique characteristics. VTOL have

⁶ Table taken from (The National Academies of Sciences, Engineering and Medicine, 2018)

the capabilities of multi-rotor and fixed wing combined, creating a great advantage for a more complex system, still they do not fit in nowadays UAV types and an effort has to be made to include them to their growing attraction (Ducard & Allenspach, 2021).

<i>Type</i>	<i>Advantages</i>	<i>Limitations</i>
<i>Fixed-wing</i>	• Increased flight time. • Generally low audible signature. • Carry larger payloads. • Greater speed.	• May have increased operational and sustainment requirements. • Needs room for takeoff and landing. • Must constantly move forward, not able to hover.
<i>Rotary-wing / multirotor</i>	• Vertical take-off and landing capable, which means they can make off from almost anywhere. • Ability to hover and stare capability. • Requires little training. • Low cost easy to acquire and conceal.	• Low load carrying capacity. • Limited speed.
<i>Balloon</i>	• Long duration. • Able to operate at high altitudes. • High load carrying capacity.	• Limited ability to maneuver. • Needs room for takeoff and landing.

Table 2- US Army UAV Classification⁷

NATO (North-Atlantic Treaty Organization), at the doctrinal level, also provides a classification for UAS, consequently classifying UAV, as shown in the following Table 3. NATO classifies UAS much more thoroughly than the United States Army (North Atlantic Treaty Organization, 2019). It categorizes them based on weight, category, application, operational altitude, endurance, and operational position. NATO suggests that UAS must be classified in three different classes (North Atlantic Treaty Organization, 2020):

- Class I (Small/Mini/Micro)-Generally man-portable, controlled by a single individual supporting a small unit. Low operational altitude, below the CL⁸ (Coordination level), and limited to VLOS (Visual line of Sight) operations.
- Class II (Tactical)- Flexible UAS that can support tactical and operational level commands. Can operate in VLOS and BVLOS (Beyond Visual Line of Sight).
- Class III (MALE/HALE/STRIKE)- Mostly strategic systems that work in theatre-wide areas that benefit operational and tactical requirements.

⁷ Table taken from (Headquarters, Department of the Army, 2023)

⁸ Coordination level, separation level between fixed and rotary wing aircraft. Where fixed wing aircraft will not fly below.

Characterized by a bigger payload, better data processing and robust communication architecture.

However, this classification, as indicated in the study, is considered limiting because the smallest class is Class I, covering all UAVs weighing less than 150 kg. It further compartmentalizes into three subclasses, with one of them being “Mini”, weighing less than 15 kg, which would be typical of UAVs used in the conflict in Ukraine and Gaza. This table also does not address commercial UAVs like DJI (Dà-Jiang Innovations) or Autel, which are commonly used in current conflicts, and all would fall into the “Mini” section of Class I.

NATO UAS CLASSIFICATION						
Class	Category	Normal Employment	Normal Operating Altitude	Normal Mission Radius	Primary Supported Commander	Example Platform
Class III (> 600 kg)	Strike/ Combat *	Strategic/ National	Up to 65,000 ft MSL	Unlimited (BLOS)	Theatre	Reaper
	HALE	Strategic/ National	Up to 65,000 ft MSL	Unlimited (BLOS)	Theatre	Global Hawk
	MALE	Operational/ Theatre	Up to 45,000 ft MSL	Unlimited (BLOS)	JTF	Heron
Class II (150 kg - 600 kg)	Tactical	Tactical Formation	Up to 18,000 ft AGL	200 km (LOS)	Division, Brigade	Watchkeeper
Class I (< 150 kg)	Small (>15 kg)	Tactical Unit	Up to 5,000 ft AGL	50 km (LOS)	Battalion, Regiment	Scan Eagle
	Mini (<15 kg)	Tactical Sub-unit (manual or hand launch)	Up to 3,000 ft AGL	Up to 25 km (LOS)	Company, Platoon, Squad	Skylark
	Micro ** (<66 J)	Tactical Sub-unit (manual or hand launch)	Up to 200 ft AGL	Up to 5 km (LOS)	Platoon, Squad	Black Widow

Table 3- NATO UAS Classification.⁹

Both American and NATO classifications of UAVs have limitations by not being up-to-date with the new technologies used in modern military theatres, for example, the Smart Dust UAV which is a UAV controlled with a micro-electro-mechanical system

⁹ Table taken from (North Atlantic Treaty Organization, 2019)

that due to its small form could become a threat for any C-UAS (Villa, Gonzalez, Miljevic, Ristovski, & Morawska, 2016), and is not considered in today's UAVs classification. The capabilities of sensors and their development, such as hyperspectral sensors, will also need to be a measure of characterization and classification, accompanied by the integration of AI packages, the introduction of Deep Learning in SLAM (Simultaneous Localization and Mapping), and the normalization of LIDAR (Light Detection and Ranging) in autonomous systems (Nex, et al., 2022). NATO standard ATP-3.3.8.2 has offered a categorization of types of sensors that can be used in UAS classification (North Atlantic Treaty Organization, 2020), and it can be seen in the Table 4.

With the integration of AI in UAS sensors such as MTI (Moving Target Indicators) will have an exponential increase in capabilities, readiness and efficiency with the ever-evolving deep learning of neural networks that Artificial Intelligence is based on. The detection will evolve into identification, therefore improving targeting and acquisition (Pal, Shovon, Mridha, & Shin, 2023).

UAS Sensors

Sensors	Capabilities
Electro-Optical	Captures images and video in the visible light spectrum. Relies on the ambient light. Gimbal operator and independent of the aircraft direction.
Infrared	Passive receivers, measuring temperature differentials between targets and backgrounds.
Radar	Active transmitter of radio frequency energy, processing it into useful information.
Moving Target Indicator	Detects and locates objects through programming.

Table 4- Types of UAS Sensors

Currently, the existing characterizations of UAVs do not consider these technological advances. In addition to what has been mentioned, there seems to be a lack of distinction between UAVs according to their autonomy. This is an important consideration because, according to the autonomy of the UAV, the countermeasures taken, and the estimated combat potential differ.

According to Table 5, autonomy can be divided into five levels: a human-controlled system, where a human operator makes all the decisions for the UAV

operation; an assisted system, where the system utilizes navigation systems to perform simple tasks to assist the operator; semi-autonomous systems, the actual state of the art of UAVs where they can autonomously navigate through pre-selected waypoints through GPS (Global Positioning System) signal; Conditional Autonomy, which some advanced UAVs are equipped with programs such as LIDAR with capabilities to avoid collision with objects and UAVs; High Autonomy where UAVs are extremely advanced with software like SLAM being able to navigate through rooms, buildings, and tunnels, detecting objects and mapping them and Autonomous which a UAV does not need any previous input and with its highly developed sensors, Artificial Intelligence and own navigation system, completing its tasks independently (Ennemark, 2023).

Autonomy Levels

Stages	Autonomy
0	Human-Controlled: The UAV relies entirely on a human operator for control and navigation.
1	Assisted Control: Basic automation assists the operator (hovering, GPS, stabilization, follow mode).
2	Semi-Autonomous: The UAV can follow pre-programmed flight paths (waypoints) using GPS.
3	Conditional Autonomy: The UAV adapts, avoids and identifies the environment.
4	High Autonomy: The UAV can handle complex scenarios.
5	Autonomous: The UAV does not need any human input.

Table 5- Autonomy Levels

In a more summarized manner, the European Parliament (Union, 2013), defined three categories of autonomy and dependence of autonomous systems on humans, which are divided into:

- Human-In-the-Loop: Systems remotely controlled by a human operator. Systems develop tasks delegated by the operator, independently, but

cannot attack without the command of the human operator.

- Human-On-the-Loop: Systems carry out the targeting process and its identification independently from the operator, but always under the supervision of a human with override capabilities.
- Human-Of-the-Loop: Systems that complete all the tasks independently, without the supervision of a human operator.

This identification and categorization of autonomy in robotic systems concentrate on the relationship of UAV and Human operator, which is important both in legal and ethical contexts, as culpability is differentiated. The autonomy of UAVs also aids in their classification and automatically distinguishes their function.

Lastly, a differentiation of UAV types through energy sources is important since some types of UAVs only use certain types of energy sources due to their weight and size which affect the employment and capabilities of the UAVs considerably. Depending on the energy source, range, noise, payload capabilities and destruction effects of the UAV may change (Antal C. J., 2022). There are four, now (Vergouw, Nagel, Bondt, & Custers, 2016), types of energy sources:

- Airplane Fuel, largely used for fixed-wing UAVs. Mainly hydrogen powered and quite expensive with lower energy efficiency compared to battery cells and longer refuel time (Townsend, Jiya, Martinson, Bessarabov, & Gouws, 2020).
- Battery Cells, used in small multirotor UAVs. Lithium batteries have lower recharge cycles and flight time In comparison with the rest of the energy sources (Townsend, Jiya, Martinson, Bessarabov, & Gouws, 2020). Widely used in quadcopters due to its simplicity and flexibility to the propulsion system (Saravanakumar, et al., 2023).
- Fuel Cells, for fixed-wings, combustion powered. Heavier, larger,

transmits more noise and requires more maintenance. Increase in flight duration and refueling time (Saravanakumar, et al., 2023).

- Solar Cells, mainly fixed-wing UAVs. Requires larger surface, sunlight and more expensive (Townsend, Jiya, Martinson, Bessarabov, & Gouws, 2020).

Considering the limitations presented in current UAV classifications, the author presents a possible classification of UAVs, in Figure 7, that aligns with the characteristics of future technological advances in uncrewed aerial vehicles.

The classification begins from the most detailed to the most comprehensive characteristic that can differentiate the various UAVs. It starts with their category, which aligns with the classification given by NATO and exemplified in Table 3. In this case, UAVs would be divided into 5 categories: Micro (<66g), Mini (<15kg), Small (>15kg); Medium (150kg-600kg), and Big (>600kg) (North Atlantic Treaty Organization, 2019).

Next, these UAVs would be divided into Wing Types, following the definition provided by American doctrine in Table 2, divided into Fixed-Wing, Rotary-Wing, and Multicopter (Headquarters, Department of the Army, 2023). This division was made because balloon-type UAVs are no longer as prevalent and efficient with new technologies, and the necessary differentiation between multicopter and rotary wing is provided.

Energy sources also appear as a classification factor because, with future developments in renewable energies and other power sources beyond lithium, they will be proliferated and necessarily categorized. Therefore, this is divided into Airplane Fuel, Battery Cells, Fuel Cells, and Solar Cells (Vergouw, Nagel, Bondt, & Custers, 2016).

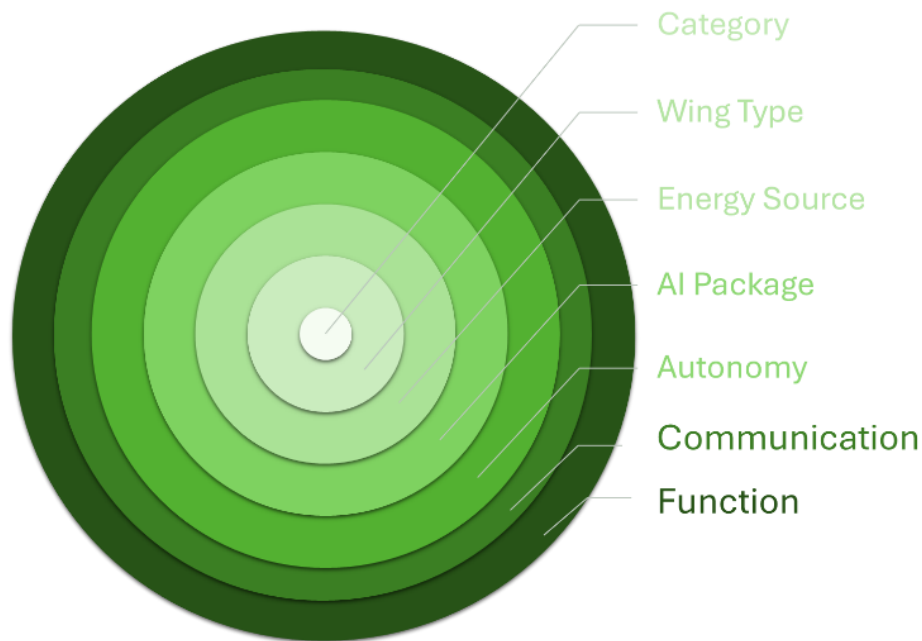


Figure 7- Possible UAV Classification

With advances in machine learning, deep neural networks, and Artificial Intelligence, it has become necessary to begin classifying UAVs according to their intelligence and consequently their autonomy. The current state of the art of AI offers the following categories of intelligence (Antal C. J., 2022):

- Artificial Narrow Intelligence: The application of algorithms to complete simple tasks, such as calculation software that facilitates the operator's task.
- Artificial General Intelligence: A system capable of human-like thought and human-like actions.
- Artificial Super Intelligence: Surpasses the cognitive abilities of human beings, still dystopian. Capable of performing missions better or equal to a combatant (Joshi, 2019).

Therefore, for the UAV classification, a UAV will be categorized according to its AI package in three factors: Narrow (Artificial Narrow Intelligence), Competent (Artificial

General Intelligence), and Intelligent (Artificial Super Intelligence) (Morris, et al., 2024). Autonomy would be divided into Human-Off-the-Loop, Human-In-the-Loop, and Human-On-the-Loop, as previously explained.

Communication links of UAVs are an important classification since the development of proper advanced wireless technologies and integration of 5G networks, therefore, the communication links of UAVs can be divided into Wireless and Wire-Guided UAVs (Zeng, Guvenc, Zhang, Geraci, & Matolak, 2021). Wire-Guided as with fiber optic connected UAV, immune to countermeasures and provides higher quality data transference. Wireless communications links can be divided in direct link, satellite, ad-hoc network and cellular network (Zeng, Guvenc, Zhang, Geraci, & Matolak, 2021).

Finally, UAVs will be divided according to their functions, combat, reconnaissance, and mixed (Singhal, Bansod, & Mathew, 2018). The reconnaissance category will be sub-categorized in the following UAS missions: Reconnaissance, Surveillance, Situational Awareness, Security, Targeting, Communication and Movement (North Atlantic Treaty Organization, 2023). And the combat category will be categorized in the following missions: Air Interdiction, Close Air Support, Personnel Recover, Suppression of Enemy Air Defences and Maritime Operations (North Atlantic Treaty Organization, 2023). In a more summarized way, one can see the different subcategorizations in Table 6.

Category	Wing Type	Energy Source	AI Package	Autonomy	Communication	Function
Micro (<66g)	Fixed-Wing	Airplane Fuel	Narrow	Human-In-the-Loop	Wireless	Reconnaissance
Mini (<15kg) Small (>15kg)	Rotary-Wing	Battery Cells	Competent	Human-On-the-Loop		Combat
Medium (150kg-600kg) Big (>600kg)	Multirotor	Fuel Cells Solar Cells	Intelligent	Human-Off-the-Loop	Wired	Mixed

Table 6- Advised UAV Classification: Sub-Categories

2.2. Counter Uncrewed Aerial Vehicles Classification

There are two categories of countermeasures for UAVs that fall into their mitigation or detection, kinetic or non-kinetic measures. Kinetic solutions can be defined as physical motions that destroy or interrupt the UAV hardware and non-kinetic are not physical motions but the neutralization of enemy UAVs by electronic or technological interference (Marketing, 2023). Hard-kill measures in a non-kinetic solution would be the usage of lasers, for example. Soft kills are disruptive techniques and examples are jamming and spoofing. In the Table 7 it is possible to see the different countermeasures that can be employed to neutralize UAVs.

Countermeasure	Description
RF jamming	Disrupts UAV's GNSS link, GPS, or GLONASS; without synchronization with GNSS system, a UAV will hover, land, or return to home
GNSS jamming	
Spoofing	
Hacking	Allows the C-UAV system operator to take control of or misdirect the targeted UAV by creating a virtual GNSS channel with wrong navigation information
Dazzling	Interception of UAVs navigation system and reading its flight plan and flight data
Laser	Implementation of high-power laser beam(s) to blind the camera(s) on the UAV
High-power microwave	Burns a critical part of the UAV's frame and components (see Chapter 3) using direct energy, causing a crash of the UAV
Shooting nets	Send pulses of high-power microwave signals, destroying the UAV's electronics components
Projectiles	Entangles drones and/or its propellers
Water cannons	Employs regular or custom-designed ammunition to destroy the incoming UAV
Interceptor drone	Directs high-pressure water towards incoming UAV, causing crash
Collision drone	A drone designed to intercept the target drone and bring it back to base
Falcon	A drone designed to collide with the target UAVs
Missiles	A specially trained falcon bird that catches UAVs as prey
Guns	Conventional missiles used for destroying large UAVs
Combined effectors	Conventional rifles used by snipers to shoot down the UAV
	A number of different and complementary neutralization techniques used in the same C-UAV system for increased reliability of neutralization

Table 7- Countermeasures for UAVs.¹⁰

In the study, the focus will be on non-kinetic, jamming and spoofing techniques,

¹⁰ Table taken from (Markarian & Staniforth, 2021)

since it has been proven the most effective and utilized way to neutralize enemy UAVs (Watson, 2018). Electronic Warfare, soft-kill, non-kinetic means are extremely present in recent conflicts, most importantly GNSS and communication jamming. In the Ukraine conflict it is easy to observe the effects of GNSS jamming through the conflict, as can be seen in Figure 8.

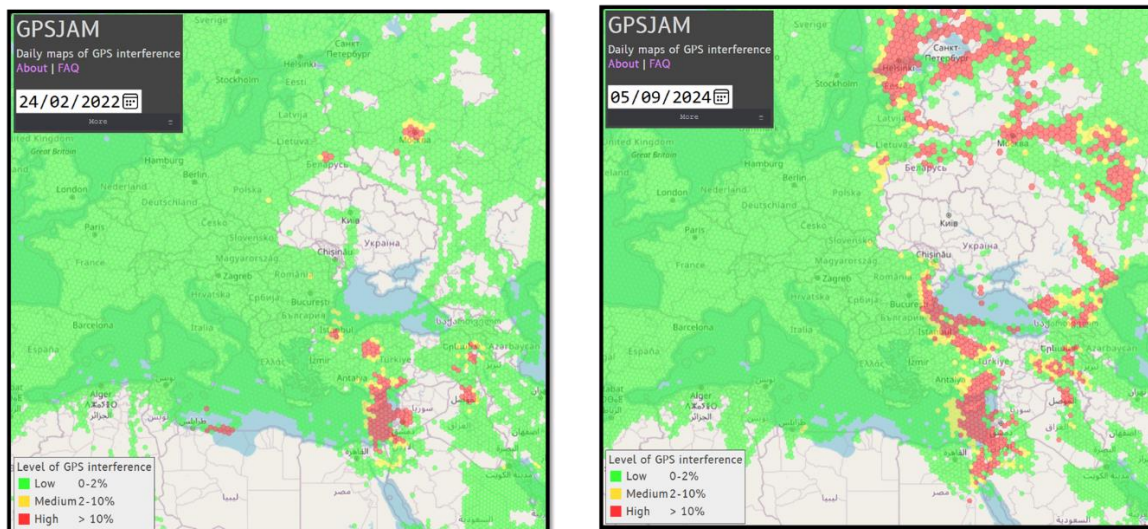


Figure 8- GNSS Jamming in the Ukraine Conflict¹¹

The Figure 8 demonstrates the accuracy of GNSS signals of civil aircraft through different regions around the world. Green areas show where 98% of aircraft report good navigation signal, yellow areas, where between 2% to 10% of aircraft have reported bad navigation signals, and red areas, where more than 10% report low navigation accuracy (Wiseman, 2024). These reports come from ADS-B exchange which broadcast information about their GNSS accuracy, therefore, the areas without color are areas where civil aircraft do not report or transmit information, which is obvious being areas of armed conflict. However, those areas show, over time, an increase in reported low accuracy GNSS signals in the frontiers of armed conflicts, as seen in Ukraine and Gaza. Therefore, the amount GNSS jamming and spoofing emitted in those conflicts is increasing and validates its importance of study as the best way to neutralize enemy unauthorized UAVs.

¹¹ Figure taken from (Wiseman, 2024)

Starting with jamming, it can be defined as:

The effect of unwanted energy due to one or a combination of emissions, radiations, or inductions upon reception in a radio communication system, manifested by any performance degradation, misinterpretation, or loss of information which could be extracted in the absence of such unwanted energy (Agency, 2020).

Jamming can affect wireless communications such as land mobile radio, Bluetooth, Wi-Fi, and GPS. Spoofing can be defined as "a system that receives radio beacon signals and rebroadcasts them on the same frequency to intentionally confuse navigation..." (Agency, 2020).

Spoofing can be defined as it "...involves transmitting false signals that look like correct signals but contain false information." (Adamy, 2015) causing false positions and navigation errors obtained by the aircraft. In this case, the C-UAS will introduce incorrect GPS altitudes and positions into the UAS, and it is extremely difficult for the operator to detect the attack, even more, so if it is a highly autonomous vehicle, making it highly efficient in armed conflicts.

Jamming and spoofing both work on disrupting the Data-link between the UAV, operator, ground station and/or satellite system, which becomes necessary to delve on its functions. As seen in Figure 9, the Data-link can be divided in (Nichols, Mumm, Lonstein, Ryan, & Carter, 2019):

- Up-link: From the operator to the UAV, it permits the control of the UAV, navigation system and payload sensors.
- Down-link: From the UAV to the operator, it permits the relay of data from sensors.
- Bi-Directional-link: Between UAV and the operator, it gives control of distance and azimuth of UAV.

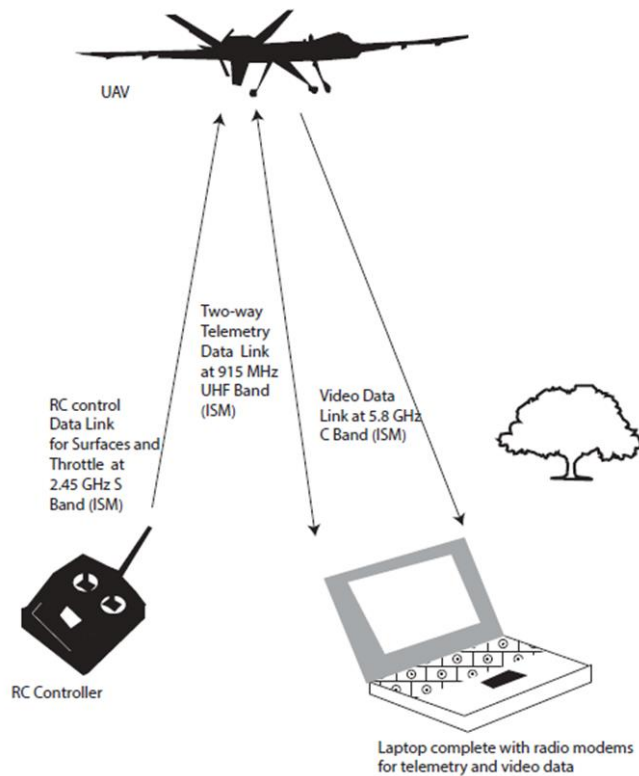


Figure 9- The UAV-Operator Data-link¹²

Therefore, in this chapter, we will address the study and definition of jamming and spoofing for UAV neutralization.

2.2.1. Jamming

The effect of Jamming depends on the power, location, and influence of the transmission and can be divided into different types of jammers, as seen in Figure 10.

Proactive Jammer transmits jamming signals with or without data in communication. This jamming does not allow frequency hopping and only operates on one frequency until its energy is depleted. It is divided into Constant, Deceptive, and Random. Constant Jammer prevents transmission by creating noise on the wireless channel. A Deceptive Jammer regularly transmits packets (rather than bits, as in the Constant Jammer), deceiving communicators into thinking a real message is being sent. A Random Jammer intermittently transmits bits or packets, aiming to save energy

¹² Figure taken from (Barnhart, Marshall, & Shappee, 2021)

(Grover, Lim, & Yang, 2014).

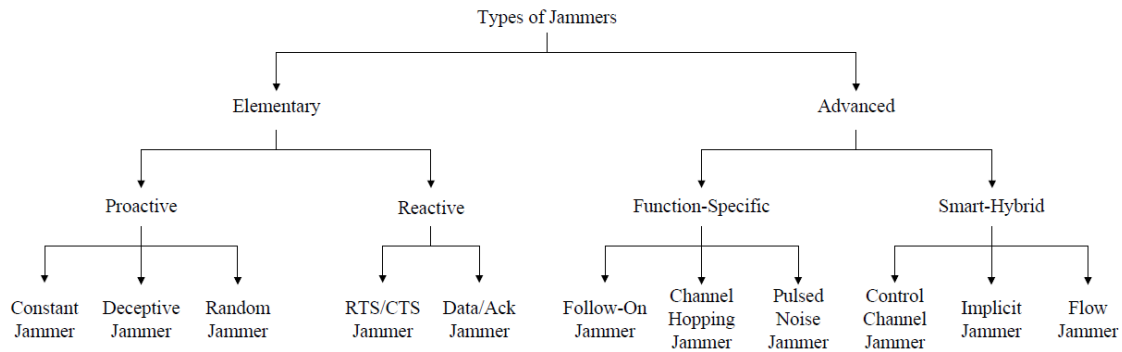


Figure 10- Types of Jammers. ¹³

Reactive Jammer only jams when activity is detected on the channel, seeking to interfere with the reception of the message. It is divided into Reactive RTS/CTS Jammer and Reactive Data/ACK Jammer. The RTS/CTS Jammer attempts to jam the channel when the RTS (Request-to-Send) is sent, preventing the receiver from sending the CTS (Clear-to-Send). The Reactive Data/ACK (Acknowledgment) Jammer disrupts the network by corrupting the data in transmissions (Grover, Lim, & Yang, 2014).

Function-specific jammers are implemented for a predetermined function, and they can be either proactive or reactive. They may work on one or multiple channels, changing them during their operation. Follow-on jammers tend to disrupt UAVs that frequently switch communication channels, with the sole purpose of identifying the utilized frequency. If the transmitter detects jamming on a channel, it switches to jam another frequency. Channel-Hopping Jammers proactively jump between channels, jamming multiple channels simultaneously. Pulsed-noise jammers can change channels and jam channels simultaneously (Grover, Lim, & Yang, 2014).

Smart-hybrid jammers are energy-efficient and aim to jam the right frequency band to disrupt most frequencies. They can be both proactive and reactive. Control-channel jammers work on multiple channels by attacking the control channel. Implicit Jamming Attacks disable the network node used and deactivate the functionality of

¹³ Figure taken from (Grover, Lim, & Yang, 2014)

other nodes in the network. Flow-jamming attacks involve multiple jammers to reduce traffic flow (Grover, Lim, & Yang, 2014).

Depending on the attack strategy, a jammer may have the same or different capabilities as the nodes in the network. In current conflicts, jamming is often performed on the reception frequencies of GPS signals used in GNSS (Global Navigation Satellite System) and Wi-Fi. In the case of commercial FPV UAVs widely used in Ukraine and Karabakh, the most effective method to neutralize them falls into five categories of jamming: Barrage Jamming, Tone Jamming, Sweep Jamming, Successive Pulses Jamming, and Protocol-Aware Jamming (Ferreira, Gaspar, Sebastião, & Souto, 2021):

- Barrage Jamming involves transmitting energy across the spectrum occupied by the target, increasing the receiver's noise level and preventing it from operating.
- Tone Jamming transmits a signal at the same frequency as the GPS operator, interfering with the central frequency of the signal and disrupting the connection.
- Sweep Jamming operates across the entire frequency band but does not emit a static signal, making it more efficient with a lower band and cleaning the entire frequency.
- Successive Pulse Jamming involves creating a sequence of pulses with a low-duty cycle, and when combined with the interfered signal, it jams the frequency wave, occupying the signal.
- Protocol-aware jamming can be used if the jammer has a similar architecture to the transmitter, allowing interference signals to blend in and destroy the transmitter's message, making it impossible for the receiver to detect any possible sent message.

Jamming can also interfere with radio communication signals, which UAVs must operate in the designated frequency assigned internationally. These signals are essential for the operation of the UAV for flight control, communication, video and data

information and telemetry channels (Markarian & Staniforth, 2021). Those signals are the following:

- 1.3 GHz, 2.4-2.485 GHz and 5.8 GHz: UAV control.
- 900 MHz, 1.2 GHz, 2.4 GHz, 5.8 GHz: communications and video transmission.
- 433 MHz or 869 MHz: telemetry transmission.

With an understanding of contemporary conflicts, an efficient and up-to-date C-UAS must have the above frequencies in the jamming program.

2.2.2. Spoofing

Spoofing is primarily used in systems with low-security levels, such as civilian GPS signals in commercial UAVs that do not require encryption or authentication to verify the origin of the GPS signal. This navigation signal is utilized in various UAVs in a satellite navigation system called the Global Navigation Satellite System (GNSS). It determines the position in longitude, latitude, and altitude, where velocity and timing come from systems such as GPS, GLONASS, GALILEO, and BEIDOU (Markarian & Staniforth, 2021).

The GNSS system is complex and consists of numerous subsystems (Markarian & Staniforth, 2021) such as: Satellites constellations, On-ground systems, The UAV GNSS receiver and Augmentation Systems. Augmentation systems are divided in: Air-based, satellite-based and ground-based (Markarian & Staniforth, 2021).

It is important to study GNSS systems and the navigation measurements of UAVs since modern UAVs utilize more than a single GNSS signal. If a UAV uses receivers from GPS and GLONASS, jamming only the GPS signals the UAV will go unbothered and the C-UAS will fail its purpose, this measure should be considered when building and choosing a C-UAS.

In the Table 8 and Table 9 it is possible to see the frequency bands utilized by

GPS and GLONASS systems.

System/Band	Frequency, Bandwidth
GPS L1	1,575.42 MHz, 15.345 MHz
GPS L2	1,227.6 MHz, 11 MHz
GPS L5	1,176.45 MHz, 12.5 MHz

Table 8- GPS Frequency Bands. ¹⁴

System/Band	Frequency, Bandwidth
GLONASS I-L1	1,602 MHz, 6.5 MHz
GLONASS I-L2	1,246 MHz, 5 MHz
GLONASS II-L1	1,575.42 MHz, 6.5 MHz
GLONASS II-L1	1,600.995 MHz, 15.365 MHz
GLONASS II-L2	1,248.06 MHz, 8.75 MHz
GLONASS II-L3	1,202.025 MHz, 20.46 MHz
GLONASS II-L5	1,176.45 MHz, 10.22 MHz

Table 9- GLONASS Frequency Bands. ¹⁵

Various spoofing techniques can be used effectively to neutralize most UAVs used in modern military theaters, such as Simple Spoofing, Intermediate Spoofing, Spoofing with Multiple Transmitting Antennas, Spoofing with High Gain Antennas, and Sophisticated Spoofing (Ferreira, Gaspar, Sebastião, & Souto, 2022).

- Simple Spoofing: This technique can generate false GNSS signals.
- Intermediate Spoofing: The attacker generates false signals synchronized while attacking each channel of the target by encoding phases aligned with genuine signals.
- Spoofing with Multiple Transmitting Antennas: Used only for multiple receiving antennas.
- Spoofing with High Gain Antennas: An attack based on the use of

¹⁴ Table taken from (Markarian & Staniforth, 2021)

¹⁵ Ibid

antennas with sufficient gain to separate GNSS signals from noise.

- **Sophisticated Spoofing:** It can be carried out by a set of synchronized attacks, with information on the three-dimensional position of phase centers and their antennas.

In addition to the spoofing techniques already demonstrated, GNSS spoofing may have two different attack techniques (Khan, Mohsin, & Iqbal, 2021):

- **Meaconing:** Replaying the original GNSS signal of the UAV causing a time-drift on the enemy UAV.
- **Fabrication:** Fabrication and transmission of false GNSS signals to deceive the GNSS receiver of the UAV, therefore, giving control of the UAV to the spoofer.

2.3. Legal Framework

With the technological development and commercialization of UAVs and C-UASs to the civilian population, there is an increase in their proliferation and capabilities. With these increments, concerns about the legal, ethical, and moral aspects of their use grow. The EU (European Union) Commission estimates that in twenty years, the UAV sector will employ more than a hundred thousand people and have an economic impact of ten billion euros per year (Hartmann, Jueptner, Matalonga, Riordan, & White, 2023). The lack of a regulatory framework concerns the EU Commission, leading to an urgent need to establish one for the civilian and military dynamic.

Various organizations and conventions seek to address these unresolved issues, such as the ICAO (International Civil Aviation Organization), and the International Regulatory Aviation Convention, which analyzes issues in the civil aspect. Other organizations include EUROCAE (European Organization for Civil Aviation Equipment) and JARUS (Joint Authorities for Rulemaking on Unmanned Systems), which focus on the military and armed conflicts side. Despite the numerous actors involved, legal regulation

is considered outdated according to new conflicts and developments (Hartmann, Jueptner, Matalonga, Riordan, & White, 2023). However, applying legal regulation in this context is challenging due to the autonomy of UAVs increasing (Directorate-General for Justice and Consumers (European Commission), 2019), and its exponential proliferation. The continuous development of UAVs and its capabilities have worried, not only military and international organizations, as Silicon Valley institutions and philanthropists around the world, mainly due to AI in UAVs, because:

Once developed, they will permit armed conflict to be fought at a scale greater than ever, and at timescales faster than humans can comprehend. These can be weapons of terror, weapons that despots and terrorists use against innocent populations, and weapons hacked to behave in undesirable ways. We do not have long to act. Once this Pandora's box is opened, it will be hard to close (An Open Letter to the United Nations Convention on Certain Conventional Weapons, 2018).

In 2019, EU members states implemented regulations 2019/945 and 2019/947, respectively addressing the rules for the operation of uncrewed aircraft and dividing UAV operations into three categories (open, specific, and certified), depending on the risk of UAV operation (European Aviation Safety Agency, 2015). The use of autonomous vehicles falls under the certified section, requiring prior authorization for UAV operation diminishing the risk (2019/947 of 24 May 2019 on the rules and procedures for the operation of unmanned aircraft , 2019).

Therefore, there is a need to study and define a legislative framework to regulate the use of UAVs and their countermeasures at the international and national levels to address the new challenges demonstrated in recent civilian and armed conflicts. .

2.3.1. Uncrewed Aerial Vehicles Civilian Concerns

Regulating UAV incidents in civilian soil is a recent and ongoing difficulty for numerous countries. COTS UAVs have implemented autonomous behaviors such as RTH (Return to Home), collision avoidance, and some, following the operator autonomously.

These characteristics complicate the legal process in a possible incident or accident with a bystander. Culpability becomes unclear due to the autonomous behavior of the UAV, or the operator or the manufacturer. Considering this, in the EU, implying the UAV as an aircraft, falling under this legislation implies that it is irrelevant whether the UAV was under the operator's control or not (Rechtsprechung, 2019), being the operator, not the owner of the UAV, the guilty.

In addition to accidents caused by UAVs, legal situations related to privacy may also arise. UAVs, as a rule, are equipped with cameras that transmit visual images that can infringe on an individual's privacy and be considered a crime if the filmed person has not given consent. It is not necessary to keep the images or videos. The mere act of the camera passing over the individual is sufficient. This individual has the legal right to disable the UAV immediately to protect their privacy (Rechtsprechung, 2019).

Given the previously presented challenges, it will be necessary and of interest to address them from a national perspective in Portugal. In Portugal, the legal framework established for the use of UAVs is regulated by ANAC (*Autoridade Nacional da Aviação Civil*, Portuguese Civil Aviation Authority), the regulation of the electromagnetic framework for C-UAS is measured by ANACOM (*Autoridade Nacional de Comunicações*, Portuguese Communications Authority). Both offer legal definitions and restrictive frameworks for their use. ANAC compels a mandatory registration by the operator to operate UAS in national territory, in which the operator must identify their UAV and provide system information (Decreto-Lei nº 58/2018). Certain limitations have been imposed to prevent accidents and illegal activities regarding the use of UAVs (Sehrawat, 2021). These limitations include:

- Maximum operational altitude of 120m.
- Prohibition of flying over groups of people.
- Limited flight until 2.5km of airports.
- UAV operators must maintain a visual line of sight throughout the flight.
- UAVs must weigh a maximum of 25kg.

Anyone wishing to use a UAV must request permission from the ANAC and schedule the flight. Additionally, certain areas have been designated as prohibited for UAV flights, as depicted in the following Figure 11. These areas include large metropolitan zones, military zones, national parks and airports.

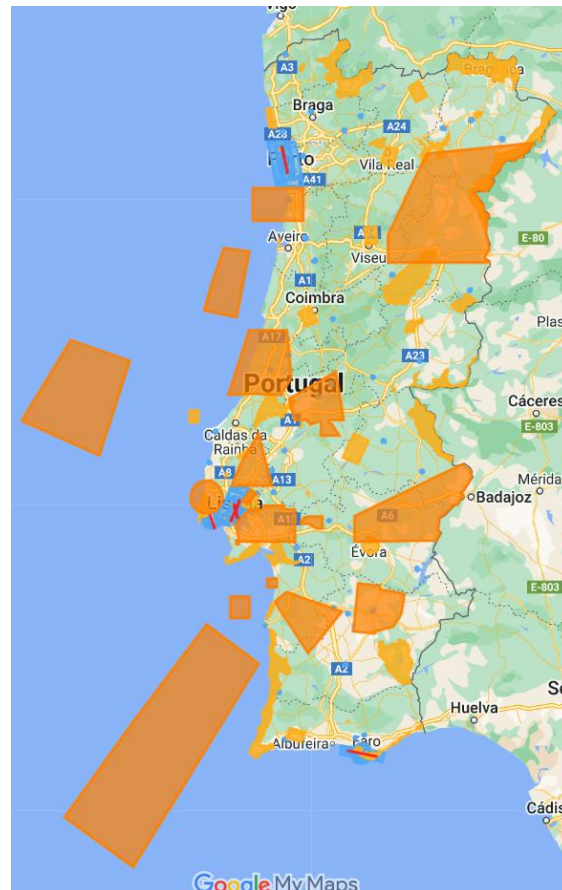


Figure 11- Unauthorized UAV flight areas in Portugal. ¹⁶

As a side effect of the technological progress of UAV usage the U.K. (United Kingdom) CAA (Civil Aviation Authority) formulated an interesting “Drone Code” that can be used as well in Portugal (Markarian & Staniforth, 2021):

- **Don’t** fly near airports or airfields.
- **Remember** to stay below 400 feet and at least 150 feet away from buildings and people.
- **Observe** UAV.

¹⁶ Figure taken from (Google, 2024)

- Never fly near aircraft.
- Enjoy responsibly.

2.3.2. Uncrewed Aerial Vehicles Military Concerns

The employment of UAVs in armed conflicts has become a very discussed and subjective matter, with a very divided opinion on its employment in unjustified and justified war (Seharwat, 2021). Either way, its employment must follow the laws of armed conflict which are: Distinction, Proportionality, Unnecessary Suffering and Military Necessity.

According to Distinction, the law of hostility defines that all actors in the conflict must distinguish civilians from combatants to avoid war crimes such as the killing of civilian as stated in the principle of distinction, article 48 of the Protocol Additional to the Geneva Convention:

In order to ensure respect for and protection of the civilian population and civilian objects, the Parties to the conflict shall at all times distinguish between civilian population and combatants and between civilian objects and military objectives and accordingly shall direct their operations only against military objectives (ICRC, 2010).

Therefore, if UAVs are used as a means of war, they must be able to distinguish combatants from civilians (Union, 2013). Besides that, Article 57 of the same Protocol states: “...take all feasible precautions in the choice of means and methods of attack with a view to avoiding or in any event minimizing incidental loss of civilian life, injury to civilians and damage to civilian objects” (ICRC, 2010). However, UAS has allowed to perform Distinction in a higher and more detailed manner, never has been used a weapon which could observe for hours the enemy and permit the correct judgement in time to assess the enemy. Therefore, UAS can comply with Distinction.

The principle of distinction, pairs with the principle of proportionality that states the military gain must exceed the damage of civilians, in Article 51 (5) (b) of AP I

(Additional Protocol I): “...an attack which may be expected to cause incidental loss of civilian life, injury to civilians, damage to civilian objects, or a combination thereof, which would be excessive in relation to the concrete and direct military advantage anticipated” (ICRC, 2010). However, UAS gives the ability and time for the operators to assess collateral damage and a possible mission abort in case of disrespect to Proportionality and Military Necessity, which means the combatants may only employ force against a legitimate military objective.

Members of international policy debate if drone strikes meet the principles mentioned above and if its use should become a war crime under international war law (Kreps, 2016). This debate goes in respect to Unnecessary Suffering which makes “Prohibited to employ weapons, projectiles and materials and methods of warfare of a nature to cause superfluous injury or unnecessary suffering” (ICRC, 2010). However, “...a missile fired from a drone is no different from any other commonly used weapon, including a gun fired by a soldier or a helicopter or gunship that fires missiles.” (Seharwat, 2021).

The use of UAVs as weapons removes the direct connection with the enemy and, in a way, the barbarity and human component of the conflict. Hence, it raises mercy-related issues that all actors in armed conflicts must respect. The option of surrender must exist and be adhered to, and the "No survivors" directive is prohibited (Seharwat, 2021). If an armed system cannot accurately assess surrender or personnel engaged in medical activities, its use should be avoided, as stated in AP I Article 35(2), considered as the Unnecessary Suffering principle: “...it is prohibited to employ weapons, projectiles and materials and methods of warfare of a nature to cause superfluous injury or unnecessary suffering” (ICRC, 2010).

In this way, NATO has defined six considerations that must be assessed before the use of a UAV as a means of war (North Atlantic Treaty Organization, 2017):

- Distinction: The individual must be a legitimate military target.

- Threat-based Necessity: Target is a significant threat to the state's interests.
- Military Necessity: Capture must be impossible or risky for civilians and state personnel and the weapon used must not inflict unnecessary suffering.
- Precaution and Proportionality: The target must be in the fire area identified and civilians will not be harmed.
- Sovereignty: international legal aspects in the foreign territory must be respected.
- Domestic Law: Domestic law must be assessed.

Therefore, it is concluded that the EU should seek transparency in the law between states regarding the use and proliferation of UAVs, advising states to impose measures that maintain their national and international security (Union, 2013). Thus, there is a need for the EU to establish an intergovernmental dialogue towards an international agreement in armed conflicts and civilian incidents and develop it to analyze the impact of AI in future autonomous systems.

2.3.3. Counter Uncrewed Aerial Vehicles Civilian Concerns

International regulation has defined radio regulations of frequencies controlled by the World Radiocommunication Conferences, organized every four years by the United Nations. In the EU, it is the CEPT (European Conference of Postal and Telecommunications Administrations) that regulates the frequencies used in the frequency spectrum. Now, no specific band has been allocated for small-scale commercial UAVs (Vergouw, Nagel, Bondt, & Custers, 2016). Therefore, this means that commercial UAVs use license-free frequencies such as 2.4 GHz to 5.8 GHz, corresponding to Industrial, Scientific and Medical, bands limitations (McNeil, 2018), and a maximum power of 125 mW of radiated transmission (AIR 802, 2024). These limitations can pose legal risks since commercial UAVs, usually produced in China, can be ordered with foreign frequencies that, in the local nation, may be designated for another purpose. As

the frequency is free, other devices using the same frequency can interfere with the operation (Yaacoub, Moura, Salman, & Chehab, 2020).

The use of a C-UAS, such as a jammer, raises legal concerns as its use can not only mitigate the UAS flight but also disrupt airports, ships, and other infrastructure with communication systems that operate in the jammed frequency band. The same happens with GPS signal spoofing. To address these measures such as those taken by the FAA (Federal Aviation Administration) in the United States seek to regulate their use to prevent collateral damage (Liu & Ziemba, 2021). In the European Union, there is no uniform regulation that member States can use, leading them to adopt and implement their national regulations. It is, however in study the project ALADDIN (Advanced holistic Adverse Drone Detection, Identification and Neutralization) in research to find trends, formulate regulations on legal and ethical considerations of C-UAS (Markarian & Staniforth, 2021). What is observed is that member states modify and apply existing aviation laws to UAVs, however, the lack of scrutiny of these laws in the face of current realities proves that these measures are insufficient and do not address their countermeasures (Sahar, 2018).

In Portugal, the use of the electromagnetic spectrum is governed by the legal framework established by Decree-Law 151-A/2000, of July 20, which prohibits the sale, acquisition, and use of signal jammers that affect the frequency bands used by network stations and radiocommunications (Decreto-Lei nº 151-A/2000). This is because they do not comply with the conformity requirements imposed by the directives for making radio equipment available on the market (Decreto-Lei nº57/2017) and for electromagnetic compatibility (Decreto-Lei nº 31/2017), which may prevent the establishment of communications with authorities and/or emergency services in case of accidents or emergency alerts, posing an increased risk to human life.

Therefore, their use may be allowed within the scope of the State's internal security activities, through the intervention of the security forces and services responsible for inhibiting the diffusion from radiocommunication systems, public or private, and electromagnetic isolation or blocking of telephone service in certain spaces

(Lei nº53/2008, 2008).

Despite the strict national regulations that Portugal and some countries may have, compliance is difficult, and enforcement is equally challenging. Therefore, other measures, such as no-fly zones, which some commercial UAVs already have embedded in their systems, allow the prohibition of their flight in sensitive or protected areas. Some laws, such as maximum altitude and weight for UAVs, have also been imposed (Rozenbeek, 2020). Nevertheless, these measures are not sufficient because FPV UAVs do not meet these geographical limitations, and UAVs piloted at night and high altitudes are difficult to neutralize, necessitating the need for more effective regulation of UAV countermeasures.

2.3.4. Counter Uncrewed Aerial Vehicles Military Concerns

The United Nations Charter Article 2, paragraph 4 is the number one regulation used for UAVs in wartime which states: “All members shall refrain in their international relations from the threat or use of force against the territorial integrity or political independence of any State, or in any other manner inconsistent with the Purposes of the United Nations.” (United Nations, 1945). However, it has two exceptions, (Cornthwaite, 2019). When the use of force in countermeasures is authorized by the United Nations, or when used in self-defense under Article 51 of the same Charter:

Nothing in the present Charter shall impair the inherent right of individual or collective self-defense if an armed attack occurs against a Member of the United Nations, until the Security Council has taken measures necessary to maintain international peace and security (United Nations, 1945).

There are three possible responses according to the potential threats posed by UAVs: a response to an armed attack, a response to a force not considered an attack, and a response to an enemy action not considered a force. An armed attack is considered when a UAV is conducting reconnaissance with an imminent kinetic force. In this case, the victim is authorized to use necessary and proportionate force to eliminate the threat with C-UAS, by Article 51 (United Nations, 1945).

Conversely, if a reconnaissance UAV is not considered an armed attack under Article 51, the principle of the use of force under Article 2, paragraph 4, cannot be applied. Until then, there can be no response from the affected party, who can only request the UAV to leave its territory (Cornthwaite, 2019). In a maritime context, this analysis is carried out in the UNCLOS (United Nations Convention on the Law of the Sea) Article 30 (United Nations, 1994).

The competition of C-UAS acquisition by military and civilian counterparts also represents an issue in overutilization in determined frequency bands that may result in congestions in important frequencies such as 2GHz to 4GHz, particularly involved with technologies such as Bluetooth, Wi-Fi, 4G and 5G (Ricciardi & Souque, 2023). Tactical radio communications will induce higher levels of electromagnetic radiation with the increase of 5G in modernized systems. Radar and SIGINT systems will have lower detection capabilities due to the increased use of the 3.5GHz band. In summary, designated frequency bands for military applications have never been more important (Ricciardi & Souque, 2023) to promote and maintain the efficiency of C-UAS.

To prevent congestion of these frequencies in the use of C-UAS for military purposes, Portugal has opted for the creation of ZLT (*Zona Livre Tecnológica*, Free Tech Zone), which provide free and secure zones where the use of the electromagnetic spectrum can be carried out without obstructing or damaging civilian communications. These areas primarily aim at training these systems for neutralizing UAVs in any environment and are being formed by the three Portuguese armed forces branches for experimentation and test purposes (Decreto-Lei nº67/2021).

2.3.5. Drone Warfare Ethical and Moral Concerns

Ethical and moral considerations are of utmost importance from the perspective of moral wounds that an operator can suffer from destroying enemy targets by means of UAVs. The use of UAVs in armed conflicts has dramatically increased cases of PTSD in military UAS operators (Phelps, 2021), both in the 1st era of drones by the USA and also with the conflicts in Gaza and Ukraine where their increase is verified (Saini, Raju, &

Chail, 2021). Therefore, it leads to the need to evaluate and understand the ethical and moral world of Drone Warfare.

Christian Ennemark, an expert on the ethical issues of Drone Warfare, begins by defining that "...armed drones, as weapons systems, are not mala in se ('inherently evil')...related moral concerns are generally not technology-specific but rather they arise from how drones are used" (Ennemark, 2023) which leads to the need to differentiate Drone Warfare, a political, public conflict with mutual risk for defense purposes, from Drone Violence, which is a criminal, private conflict with unilateral and aggressive risk.

The author argues that the moral and ethical wounds that a UAV operator can suffer are mainly from the source of Drone Violence, where their justification and morality are possibly null.

However, in Drone Warfare, the moral wounds are mainly derived from a "Tele-Intimate Violence" that is justified by:

... situating the killer 'at maximum range' from the victim, 'killing is made extremely easy' ...the operation of armed drones introduces new humanitarian risks because operators watching their on-screen kills are as morally disengaged from reality (and thus as immune to moral harm) as the players of violent computer games. (Ennemark, 2023)

The author then argues that the view of a UAV operator repairs the human condition of the target, through the visualization of the same during its distinctly human activity, such as smoking, drinking, and talking. Subsequently, the duality of the operator's life, who upon leaving the ground station begins to carry out the actions visualized on the target, creates a "Yo-Yo" effect and thus enables a moral risk in the operator.

Another aspect, of equal importance, is the integration of artificial intelligence in UAVs, which will have not only legal but also moral consequences. The discussion of this object of study is also divergent, with some experts arguing that only humans can make

moral decisions, and others claiming that the integration of artificial intelligence will improve the conscious and moral decisions of the operators or the systems themselves. However, “Genuinely moral discrimination by AI alone is impossible, then, because the critical element of judgement is missing, and this irreducibility of moral properties to physical properties is arguably what makes AI-driven discrimination impermissible.” (Ennemark, 2023).

For this purpose, Christian Ennemark developed a matrix of “AI Devolved Violence” as can be observed in Table 10, where he defines the various situations where the UAV operator should or should not take possession of the autonomous UAV to prevent moral harm.

Targeting:	Environment:	<i>Purpose of AI-assisted drone violence:</i>		
		Human-defensive ↓	Drone-defensive ↓	Offensive ↓
Anti-materiel	Low clutter →	RED-light HMI	RED-light HMI	RED-light HMI
	Cluttered →	RED-light HMI	RED-light HMI	GREEN-light HMI
Anti-human	Low clutter →	RED-light HMI	GREEN-light HMI	GREEN-light HMI
	Cluttered →	GREEN-light HMI	GREEN-light HMI	Not permitted
	Law enforcement →	GREEN-light HMI (without devolution of target selection)	Not permitted	Not applicable

Table 10- AI Devolved Violence Matrix¹⁷

The author defines “Meaningful Human Control” as the possibility for the

¹⁷ Table taken from (Ennemark, 2023)

operator to make decisions and perform critical functions in a timely and accountable manner, thus allowing for “Human Machine Interaction”. The author defines “Green-Light” situations where the UAV is engaged in actions of high moral risk, allowing the operator to take control of the UAV, and “Red-Light” for UAV actions of low moral risk, where the operator may not act on the UAV. Additionally, the author defined actions in “clutter” or “low clutter”, which respectively mean in the presence of many or few civilians.

It is understood from that in actions against humans with a high civilian presence, all UAV actions are “Green-Light” meaning high moral risk, which is understandable. In actions against materials with low civilian presence, all are “Red-Light” meaning low moral risk.

3. State of the Art

“Learn and adapt, or lose to those who do. This is the hard calculus of war. Capable people die when they ignore the reality of the modern battlespace, and the reality of modern war is changing ever faster as the methods of war continuously evolve with the advance of technology.”

Alexander Kott

To start the state of the art, it is necessary to provide an operational context with major conflicts where Drone Warfare is applied with a great and important range. For that, one must go back to the beginning of the second drone age, where the proliferation began and increased with non-state actors possessed, for the first time, UAVs (Rogers J. P., 2023). Therefore, the conflicts of major importance of study are the following:

- The Yemen Conflict. The conflict that started the second drone age in 2016 (Rogers D. J., 2019).
- The Second Nagorno Karabakh War. The first war won primarily by autonomous systems (Antal C. J., 2022).
- The Gaza Conflict. Where autonomous systems are taken to the edge with top-notch technologies and capabilities (Frantzman, 2021).
- The Ukraine Conflict. The conflict which made UAVs a main asset in warfare with field-tested capabilities and remarks (Bendett & PettyJohn, 2024).

These conflicts are the representation of the Second Drone Age, and the start of the Third Drone Age, giving rise to the development of commercial UAVs into complete UAS capable of inflicting damage on multi-million-dollar artillery pieces or infantry without the ability to defend themselves. In Figure 12 it is possible to geolocate them.

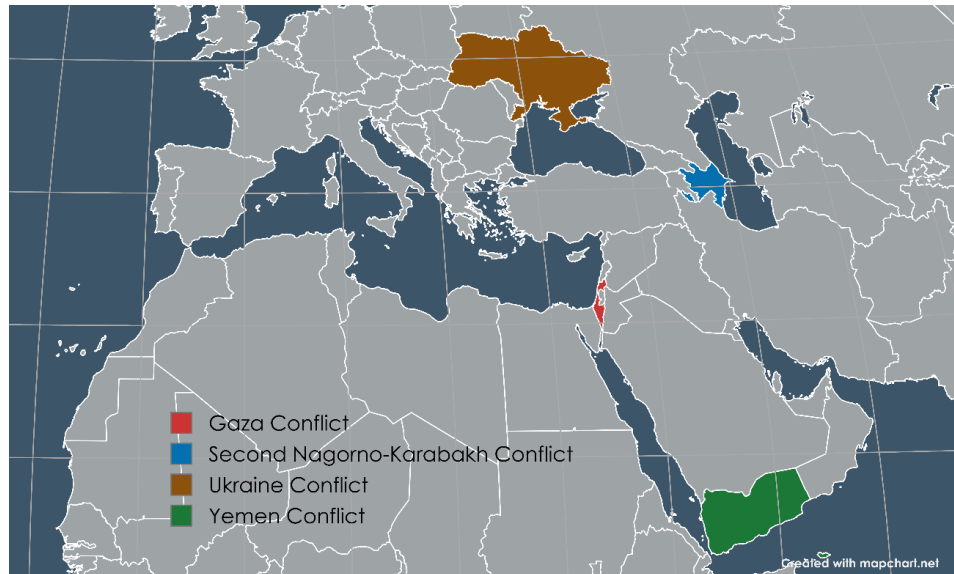


Figure 12- Analyzed Conflicts¹⁸

Next, it will discuss the current UAS used in combat, analyzing its efficiency and justifying its abundant use, aiming to detail its capabilities.

Existing C-UAS, built and used by companies or military forces seeking to respond to current challenges, will be addressed. Their capabilities, costs, and accessibility will be compared. Finally, at the end of this chapter, a more careful study will be conducted on the systems offered by the Marine Corps, the PITBULL WINGMAN system, and the SWATTER system, by the SWATTER Company, as these will be the ones studied in the dissertation.

3.1. Operational Context

The use of UAVs for military purposes goes back to the First World War, but the use of FPV DIY UAVs, and small UAVs as known today started with non-state actors and terrorist extremist groups in Iraq in 2014 (Kaag & Kreps, 2014). Terrorists would use DJI Phantom UAVs in Fallujah for gathering intel and target acquisition, making them perfect for covert and overt surveillance. In 2017, ISIS operated these UAVs against US forces in Syria (Rogers D. J., 2017). Then it was seen its proliferated and amplified use by terrorist

¹⁸ Figure taken from (MapChart, 2024)

group Houthis, in September 14, 2019, when low level cruise missiles destroyed Saudi Arabia's air defenses and 6 percent of the world's oil supply (Rogers D. J., 2019). Drone Warfare, since then, has evolved and proliferated with four recent or ongoing conflicts that best illustrate the emergence of the concept of Drone Warfare and its development on the battlefield. In these conflicts, various means and C-UAS were used, demonstrating the effectiveness of measures and countermeasures (Frantzman, 2021).

Study shows the proliferation and increase of UAVs in recent armed conflicts , in Figure 13, it is possible to see the quadratic growth of UAV usage correlated to the UAV destruction, reaching 11000 accounted and announced events of Russian UAVs being destroyed (Costa & Araújo, 2024). Dr. James Patton Rogers, a Drone Warfare expert that advises the UN (United Nations), NATO and EU Commission on Drone Warfare offers the same view, stating the following quote:

Today, over 113 nation States have military drone programs and at least 65 violent non-state actors have access to weaponized drones. According to the Center for the Study of the Drone, only 60 nation States possessed drones in 2010, meaning there has been an 88.2 per cent increase in drone-owning States in just over a decade (Rogers J. P., 2023).

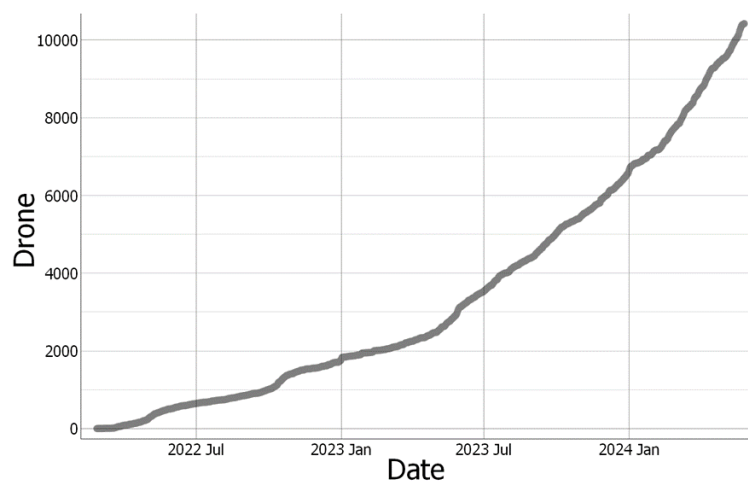


Figure 13- Russian UAVs Destroyed in the Ukraine Conflict¹⁹

¹⁹ Figure taken from (Costa & Araújo, 2024), the reference can be seen in Appendix A- Article Submitted to the RUSI Journal

Therefore, it is important to study and analyze the Ukrainian war as other conflicts that have expanded due to Drone Warfare to understand its progression, evolution and proliferation.

3.1.1. The Second Nagorno-Karabakh War

The Nagorno-Karabakh is an unstable region in the geostrategic area of the Caucasus. The war for the independence of the region began in 1988 when a large part of Armenians joined with the Socialist Republic of Armenia, deciding to take possession of the region from the Socialist Republic of Azerbaijan. The first war ended in 1994 with the formation of an autonomous region of Azerbaijan, comprising 20% of its initial size (Antal C. J., 2022). From 2008 to 2014, more conflicts emerged until a ceasefire was implemented. A conflict broke out on April 2, 2016, lasting four days, with 200 deaths on both sides.

The war in question, however, took place in 2020, starting on September 27 with Azerbaijani forces' attack against Armenian positions. This military offensive lasted for 44 days, concluding on November 10, 2020. Here, the concept of Drone Warfare in modern times began with the constant use of UCAVs such as the "IAI Harop", a kamikaze UAV, the "Orbiter 2M," and many others (Antal C. J., 2022). Approximately four thousand people died on both sides. UCAVs played a crucial role in the conflict, enabling surprise surgical attacks far from the front lines of the battlefield (Liic & Tomasevic, 2021). These means were instrumental in destroying significant artillery pieces, logistical depots, and supply points. The Turkish UCAV Bayraktar TB2, seen in Figure 14, demonstrated exceptional quality during the conflict, allowing for identification, tracking, guidance, and targeting (Antal C. J., 2022). This UAV proved so effective on the battlefield that it continued to be used in the start of Ukraine conflict. This UAV has an endurance of 24 hours with a maximum operational altitude of 8 km, measuring 6.5 meters in length, 12 meters in wingspan, and weighing 650 kg. It can be equipped with a payload of four guided bombs (Lowther & Siddiki, 2023).



Figure 14- Baykar Bairaktar TB2.²⁰

The inception of the Drone Warfare concept began with the Nagorno-Karabakh conflict as it “was the first war in history won primarily by robotic systems.” (Antal C. J., 2022). Drone Warfare effectiveness and destruction capability, in this war, can be seen in the words of John Antal, a retired Colonel of the US Army, author of the book “7 Seconds to Die”:

...an anonymous Armenian soldier who said that, when they heard the enemy’s Israeli-made Harop loitering munitions flying overhead, they had seven seconds to run or die. Seven seconds is a remarkably short time for a semi-autonomous weapon system to identify the target, verify a match with its targeting parameters, and strike (Antal C. J., 2022).

This conflict could be referenced as a tale of prediction of the Ukraine conflict, since both wars resemble the same characteristics in weaponry and warfare, while still being two years apart. The second Nagorno-Karabakh war has provided valuable insights and lessons in striking, speed, air power, maneuver and autonomy (Antal C. J., 2022). The war ended with a decisive victory for Azerbaijan, achieved through more cost-effective autonomous means that neutralized heavy and valuable enemy artillery.

3.1.2. The Ukraine Conflict

Following the timeline, the conflict in Ukraine began with Russia's invasion of Ukraine on February 24, 2022, intended to last between 4 to 5 days, to enable

²⁰ Figure taken from (Wikipedia, 2023)

annexation by August 2022. Despite Russia's numerical strength, they failed to achieve the desired end state due to limited planned courses of action, and Ukraine managed to mobilize using various means, including uncrewed aerial systems (UAS), to halt the Russian advance (Kunertova, 2023). It became evident that UAS and C-UAS are crucial in the new dynamics of warfare and need to be available across all branches and tactical methods (Zabrodskyi, Watling, & Reynolds, 2022).

The Punisher UCAV, a UAV produced in Ukraine and visible in Figure 15, also gained attention for being reusable, fast, precise, and lethal (Lowther & Siddiki, 2023). Weighing 2 kg, with a range of 45 km at cruise speed, a wingspan of 2.3 m, and flying up to an operational altitude of 400 m, with an endurance of 90 minutes. This UAV proved to be quite efficient for operations in the enemy's rear lines, with a particular impact on Russian supply lines, as well as transporting ammunition and fuel to friendly forces, highlighting the versatility of these systems.

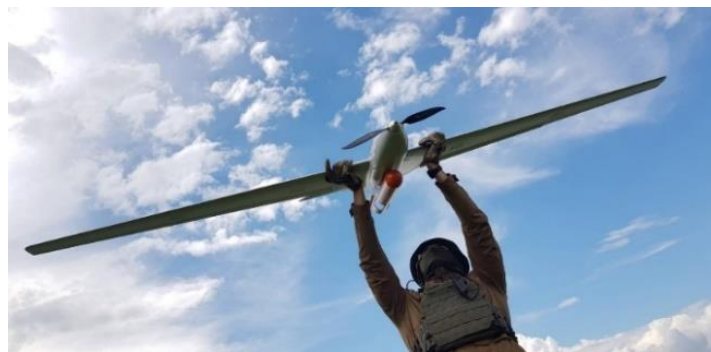


Figure 15- Punisher UCAV. ²¹

The Punisher UCAV can be classified as NATO Class I Small UAV, while Bayraktar TB2 is a NATO Class III MALE (Medium Altitude Long Endurance) UAV. Bayraktar TB2 was a necessary and important UAV for the Ukrainian forces in the beginning of the war, capable of destroying numerous Russian tanks and patrol boats, however, its use declined for smaller NATO classes UAVs, due to the distinctive slow low-flying characteristic of the TB2 becoming a target for good air defenses (Bendett, Bayraktar TB2 drones were hailed as Ukraine's savior and the future of warfare. A year later,

²¹ Figure taken from (Subotin, 2024)

they've practically disappeared., 2023). Since then, NATO Class I Small UAVs and Mini UAVs like quadcopter UAVs, visible in Figure 16, were the solution and highlight of the Ukraine conflict, along with a wide range of FPV UAVs. These UAVs are important and effective due to their speed, agility, and stealth. They can hover or move while carrying Molotov cocktails or other attached explosives. These UAVs have innovated the battlefield, pushing UAS towards a more combat-oriented role rather than just ISR.

The use of UAVs on both sides has proven to be an asset in the destruction of critical positions and enemy morale and will (Watling, 2023). UAVs demonstrate a relevant demoralizing capability as they are difficult to detect and increase anxiety due to their stealthiness and efficiency (Lowther & Siddiki, 2023). Uncrewed Aerial Systems (UAS) must be inexpensive, produced, and used in mass as 90% of them are destroyed on the battlefield (Zabrodskyi, Watling, & Reynolds, 2022). C-UAS are proven critical in protecting ground forces and ships from enemy UAVs. With this conflict, it was understood that the classification of UAS and UAVs into classes does not specifically address UAVs' new versatility and modality in modern conflicts. Old UAS were expensive and difficult to access, requiring training and command posts for control. At this moment, a simple ground operator in sheltered terrain can achieve the same effect (Zabrodskyi, Watling, & Reynolds, 2022). It is concluded that UAS will now be used with other forces and purposes in “...ISR, National Resilience, Fire Support, Air Defense, War at Sea and Strategic Communications” (NATO, 2023)



Figure 16- Quadcopter UAV. ²²

²² Figure taken from (Varenysia, 2024)

3.1.3. The Gaza Conflict

More recently, the conflict between Israel and Hamas began on October 7, 2023, and is still ongoing. The conflict started with a series of surprise attacks in Israel through the Gaza Strip. The attackers are part of the Islamic Palestinian Jihad, as well as militants from Hamas. The assault was aimed at military bases and civilian areas at the end of the Jewish holiday. Consequently, Israel declared war on Hamas. Since then, Israel has been bombing Gaza from the air and conducting ground operations. As of February 5, 2024, 1,200 Israelis and 27,000 Palestinians have been killed, with 60% of the buildings in Gaza destroyed (Zanotti & Sharp, 2024).

Drone warfare is widely present in the Gaza conflict, particularly UAV Swarms, where the concept was first used (Hambling, 2021). In Gaza, these UAV Swarms, resembling a Swarm of mechanized combat bees, are tasked with intercepting missiles fired from Gaza, as well as locating, identifying, and targeting enemy militants, as it can be seen in Figure 17. The Swarms allow for information exchange during flight, functioning as a single unit to avoid collisions (Hambling, 2021). Paul Scharre, Executive Vice President and Director of studies at CNAS (Center for New American Security), defined Swarms as:

Just as Swarms of insects, which individually, can nevertheless collectively perform complicated tasks, a cloud of tiny drones could similarly be used in novel and inventive ways. “Smart clouds” of 3D printed drones could flood a building, locating and identifying enemy combatants and civilians, or could even be airdropped over a wide area to find enemy personnel and material (Scharre, 2014).

The UAVs, due to their simplicity and efficiency, are technologically compared to the impact of the Kalashnikov AK-47 (Boussel, 2023), as any militant can easily use a UAV and produce drastic effects with it, without them, Hamas would not have the capacity to face the Israeli army (Ling, 2023). There is also an extreme use of suicide UAVs, kamikazes, like the Zouari UCAV, and UAVs designed to target watchers, cameras, and

Israeli communications. UAS are constantly used to drop ammunition for ground vehicles or to attack ships as seen in the conflict in Ukraine (Chávez & Swed, 2023). These modified commercial UAVs managed to overcome the well-known and impenetrable Iron Dome of Israel (Goudarzi, 2023).



Figure 17- UAV Swarm. ²³

3.1.4. The Yemen Conflict

The conflict in Yemen, like the Gaza conflict, is also long-standing and of a religious nature. The most recent one began in 2014 with the growing Houthi rebels of Shia faith confronting the Sunni regime. After the capture of the presidential palace in 2015 by the Houthi rebels (The Guardian, 2015), a military intervention was initiated by the United Arab Emirates and Saudi Arabia, supported by the USA (United States of America), against the militia sponsored by Iran (Sprengel, 2021). This fact is of extreme relevance for analysis and study due to its geopolitical nature, also presenting various developments in Drone Warfare. Various costs of the war have already been felt worldwide, such as the increase in fuel prices, due to the conflict focusing on three chokepoints namely the Strait of Hormuz, the Abqaiq Oil Processing Facility, and the Suez Canal (Moyer, Bohl, Hanna, Mapes, & Rafa, 2019).

Drone Warfare in Yemen is primarily used by the Ansar Allah forces against the

²³ Figure taken from (Antal J. , 2023)

coalition. COTS UAVs like the DJI Phantom were initially used in the conflict for reconnaissance purposes (Sprengel, 2021), until November 2016 when the first fixed-wing UAV, Qasef-1, was used in combat, which had combat capabilities. In September 2019, an attack was carried out against the Abqaiq Oil Processing Facility successfully hitting 17 out of 19 targets through a Swarm of 10 Iranian 3D printed systems that bypassed the defenses of an American Patriot, a French Shahine, and a Swiss Oerlikon (Hallinan, 2021). Recently, the range and capabilities of UAVs used have been increasing with the use of well-known UAVs like Ababil-3T and Shahed-129. Through the analysis of the nature of Drone Warfare in the Yemen conflict, it can be concluded that the conflict is a multidimensional test of hybrid warfare with political and social influences. There is widespread use of multifaceted UAVs with effects on both civilian and military levels (Sprengel, 2021).

3.1.5. Modern Drone Warfare

Modern Drone Warfare

	Conflicts			
	The Second Nagorno-Karabakh War	The Ukraine Conflict	The Gaza Conflict	The Yemen Conflict
UAV	Bayraktar TB2	The Punisher	IAI Heron	Shahed-129
NATO Class	Class III- MALE	Class I- Small	Class III- MALE	Class III- MALE
Range (km)	150	45	200	1700
Operational Altitude (m)	8000	400	10000	7000
Armed Payload	4 Guided Bombs	2.5 kg of Explosives	250 kg of Explosives	400 kg of Explosives
Function	Combat	Mixed	Mixed	Combat

Table 11- Modern Drone Warfare Analysis

With the analysis provided in the Operational Context it is possible to conclude most UAVs used in recent conflicts, their capabilities and functions. It can be concluded that the use of long-range Class III HALE (High Altitude Long Endurance) or higher, are

not, currently, the most used classes of UAVs, instead, there is a higher demand and application for Class I or II UAVs, with decreasing in size and increasing in capabilities with the advance in technologies. A summary table can be seen in Table 11. One can see the gain in range of the Shahed-129, compared to the rest array of UAVs, and that is due to it being of Iran origin. Iran builds and employs UAVs with longer ranges and capabilities to reach targets way over 1000 km (Rubin, 2023).

Although the range of military UAVs used in modern conflicts is still considerable, the use and employment of commercial UAVs, FPV quadcopters is growing and becoming more efficient and reliable, becoming a better option in cost-effectiveness compared to military grade UAVs

In addition to the previously mentioned UAVs, an exploration of COTS UAVs like the DJI Mavic 3 or Autel, widely used for ISR and combat, must be done. Their efficiency and significance on the battlefield were demonstrated to be so crucial that Mykhailo Fedorov, Ukraine's minister, requested UAV donations to fuel its UAV army (Pong, 2022), that represented a destruction efficiency of around one third on enemy artillery. With the disclosure of data from the conflict, a single mechanized brigade using UAVs from Ukraine, up to this moment, has been able to destroy 9 bases, 2 mortars, 4 ammunition depots, 17 tanks, 7 IFVs (Infantry Fighting Vehicles), 2 APCs (Armored Personnel Carrier), and 2 MT-LBs (Multi-Purpose Tracked Vehicle-Light Armored), also neutralizing 31 enemy soldiers, and injuring 45 (Zabrodskyi, Watling, & Reynolds, 2022). UAVs have changed and evolved according to the needs of soldiers with higher-quality cameras for better effects in ISR, or quadcopters with improvised explosive devices and cameras with payload and loitering munitions capabilities (Lushenko, 2024).

However, they still have vulnerabilities due to their simple and architectural aspects. Currently, they cannot fly in unfavorable weather conditions due to their low robustness and have a reduced battery capacity for a maximization of explosives payload. However, their use continues to be frequent, most importantly in Ukraine, with a request for 128 million to acquire more FPV and maritime drones of this type to face Russia (Martin, 2024). So far, 300,000 UAVs have been produced in the last year by

Ukrainian-founded companies (Balmforth, 2024), with longer ranges to perform deep strikes into the Russian rear.

Some of these FPV UAVs used in Ukraine are produced in local factories with the help of 3D printers, allowing modifications to the UAV to accommodate necessary combat qualities, as seen in Figure 18. They are then paired with UAV operator goggles for control (History, 2023). Typically weighing no more than 500g, they have a payload of up to 1kg, either to drop the explosive as ammunition or to impact the target as a kamikaze, with a maximum value of 1000€, in 2024. For comparison, the Switchblade UAVs cost around 12,000€, while a DJI MAVIC easily surpasses 2000€ (Burgess, 2023), all priced in 2024.

This FPV UAVs used in Ukraine belong to the NATO class I Mini and normally composed of an airframe, propulsion system, flight control system, sensor system, battery and control antenna (North Atlantic Treaty Organization, 2023).

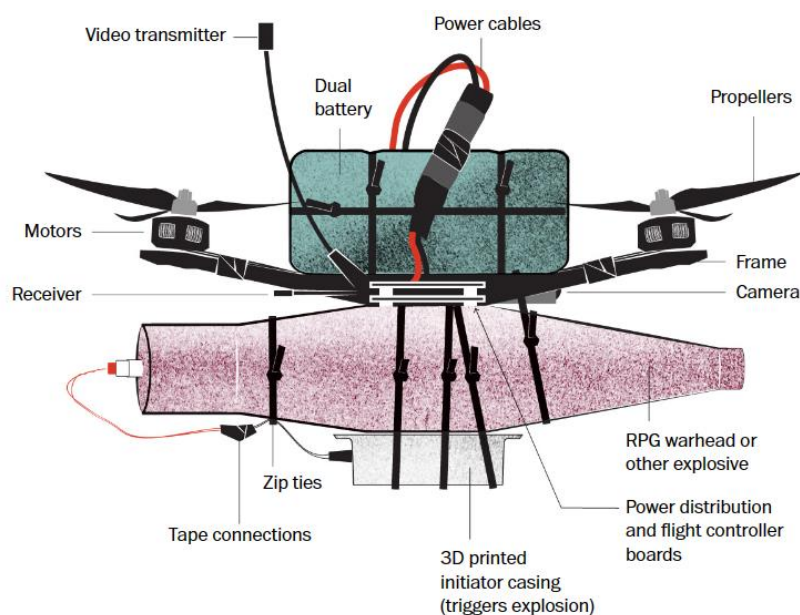


Figure 18- Components of an FPV Quadcopter. ²⁴

Typically, these FPV Quadcopters use explosives like RKG-3, which is an anti-tank grenade with the capability to destroy combat vehicles remotely. They can also employ

²⁴ Figure taken from (Horton & Korolchuk, 2023)

explosives such as C4 or modified MK-17, aiming to impact the barrel of combat vehicles or their generators to disable them. In addition to the UAVs produced by military units, commercial UAVs like DJI, Mavic, and Skydio are also utilized by the Russian and Ukrainian sides (Luzin, 2023).

Russia's armed forces employ Shahed-136 UAVs which are loaded with explosives upon launch and have pre-programmed GPS coordinates to target Ukrainian assets (Burgess, 2023). These UAVs differ from FPV Quadcopters and other commercial UAVs because they are not controlled by an operator and are not FPVs but rather a “Man-On-the-Loop” system, requiring only the GPS coordinates of the target and the firing order by the operator. These UAVs are especially robust, as countering them requires spoofing to a certain extent. They are true kamikaze UAVs, with a range of up to 1000 km, providing an advantage over the commercial UAVs mainly used by Ukrainians due to their longer autonomous range and different capabilities. Weighing 200 kg, with a length of 3.5 meters and a wingspan of 2.5 meters, they fly at 185km/h (Morwood, 2022). A destroyed Shahed-136 UCAV can be seen in the Figure 19.



Figure 19- Shahed-136 UCAV. ²⁵

Russian forces understand the capabilities and advantages that the Iranian

²⁵ Figure taken from (Ukraine, 2024)

Shahed-136 UAVs have, and by far, are the UAVs that most Russian Forces use. As can be seen in Figure 20, shahed-136 is the most destroyed Russian UAV, and therefore the most utilized, with more than 300 accounted events of destruction, only then being followed by the Orlan-10.

Therefore, currently, modern Drone Warfare is based on FPV UAVs mainly used by Ukrainian soldiers, and semi-autonomous, GPS-guided, UAVs used by the Russian forces. These FPV UAVs typically reach a range of 10 km with speeds of 100 km/h (Battlegrounds, 2023). DIY FPV UAVs also lack the best visual equipment, hence, they are accompanied by other UAVs, primarily DJI Mavic, which have better visual capabilities to assist in targeting, shooting correction and killing (Reuters, 2024).

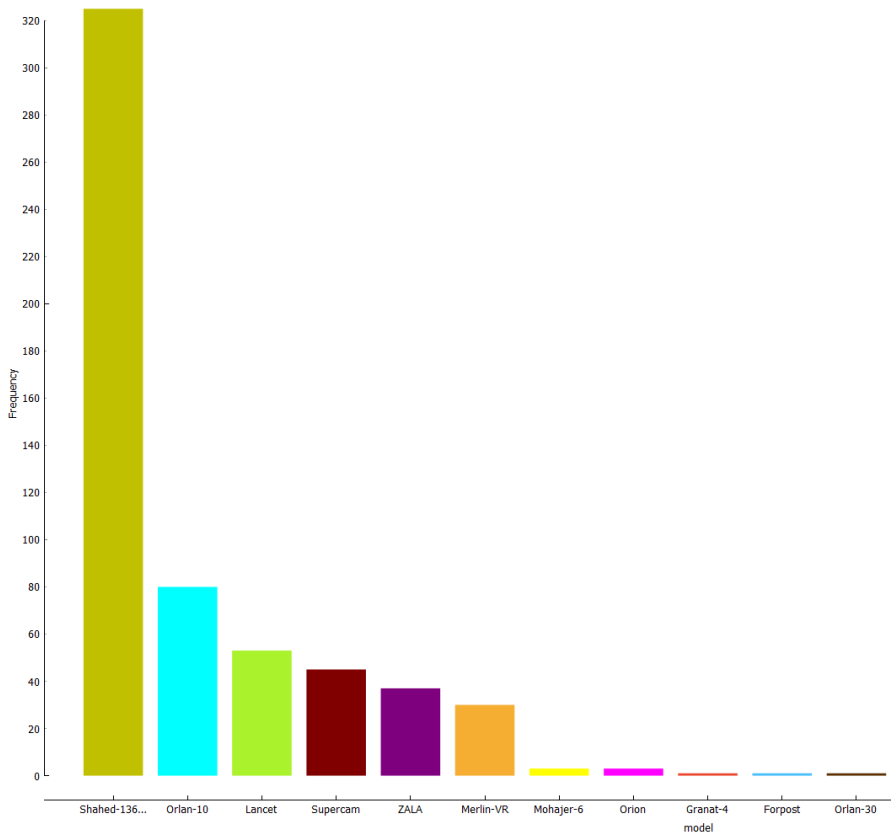


Figure 20- Russian UAV Models destroyed in the Ukraine War²⁶

However, Drone Warfare has only now started with the abundant use of these

²⁶ Figure taken from (Costa & Araújo, 2024), the reference can be seen in Appendix A- Article Submitted to the .

means. Nevertheless, the new difficulties and obstacles observed in their use require conflict actors to evolve and equip their UAVs more efficiently and robustly to maximize cost-effectiveness and increase their capabilities and purposes. Accounts have been stated on UAVs of low value as 500€ destroying a 6 million€ M1A1 Abrams tank (Army Recognition, 2024). These new UAVs, in addition to their explosive capabilities, use atypical frequencies that most anti-UAS systems cannot handle, making it almost impossible to be shot down by non-kinetic means (Hambling, 2023). Another example is the recent Fiber Optic UAVs, as you may see in Figure 21, also used and developed by Russian forces. These are not remotely controlled or operated by a UAV operator through frequency networks or signals, but rather through a fiber optic cable directly connected to the controller, reaching 10 km of range. This way, all currently used non-kinetic disruption measures are useless (Hambling, 2024).



Figure 21- Optic Fiber UAV. ²⁷

The proliferation, production, and development have not reached their peak yet, since Drone Warfare has only started its quadratic increase. New UAVs with better capabilities, weapons, range, and operational altitude will start to emerge. It has been shared statements of ISIS (Islamic State of Iraq and Syria) building capable UAVs made

²⁷ Figure taken from (Hambling, 2024)

of sticks with off-the-shelf navigations systems (Atherton, 2022), or UAVs capable of functioning with basic AI (Artificial Intelligence) to identify targets and to locate themselves by analyzing the geography and topography of the operation area in case of jamming or spoofing by the enemy (Axe, 2024), as it can be seen in Figure 22.

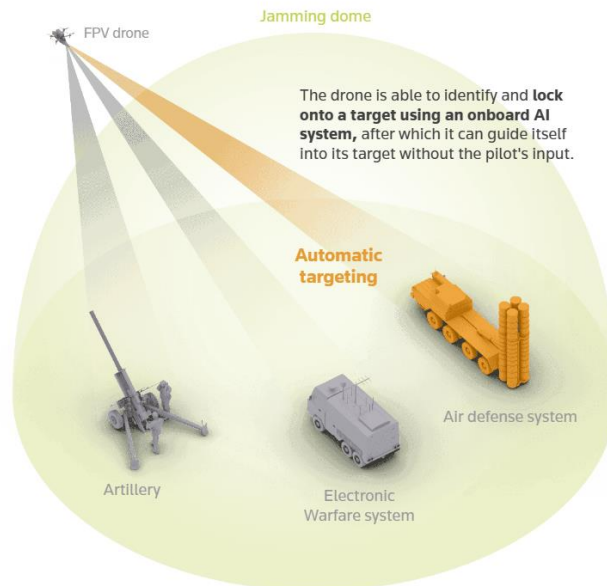


Figure 22- UAVs Future AI Capabilities²⁸

Still, the majority of NATO class I UAS are vulnerable to meteorological conditions and built-in fragility which leads to limitations in their use and efficiency, which increase C-UAS operators' capabilities (North Atlantic Treaty Organization, 2023). These UAVs have technological limitations due to limited battery and dependency on GNSS signals. Weather also plays an important part on the UAV limitation, prohibiting or increasing danger in the use of UAVs in certain meteorological conditions (North Atlantic Treaty Organization, 2023). However, Drone Warfare is dynamic, and the rate of technological progress will affect future UAV manufacture to overcome these limitations, making it more difficult for C-UAS operators to neutralize NATO Class I UAVs. The lessons learned from different conflicts were realized and demonstrated, in Table 12 it can be seen the lessons learned taken from the four conflicts analyzed.

²⁸ Figure taken from (Reuters, 2024)

Lessons Learned

Conflicts	Year	Lessons Learned
Yemen	2016	Start of drone proliferation. 3D Printed UAVs and first Uncrewed Surface Vehicles
Second Nagorno-Karabakh	2020	First war won by autonomous systems. High war robotization and higher autonomy level.
Ukraine	2022	Smaller and more capable UAVs. First Dronations and Dronariums.
Gaza	2023	New UAV technologies testing ground. Implementation of UAVs in Urban Operations.

Table 12- Drone Warfare Lessons Learned

3.2. C-UAS Systems

With the new difficulties represented in modern military theaters, private companies, and national and international security forces have begun to invest in disruption measures to face the new reality of Drone Warfare. This technology, ranges from fixed systems, as present in airports and military bases, mobile systems, such as Humvees and combat vehicles that allow defense in a broad area, as well as "Manpack" or hand-held systems, portable and carried by the fighter to defend their platoon, section, or team. There is another category that can be added to the C-UAS which is UAV-based which is the employment of a system installed on a UAV to neutralize another UAV. Due to its limitations and the few offerings of these systems in the market, this item will not be discussed. In Table 13 one can see the four categories and their meanings that will be analyzed in the following work.

Type of C-UAV System	Description
Ground-based: fixed	Systems developed for installations in fixed or nomadic applications
Ground-based: mobile	Systems developed for installations on vehicles and to be operated on the move
Hand-held	Systems developed to be operated by a single individual by hand; most of these systems look like rifles or small arms
UAV-based	Systems developed to be installed on UAVs

Table 13- Classification of C-UAS Systems. ²⁹

²⁹ Table taken from (Markarian & Staniforth, 2021)

But before analyzing the different C-UAS available in the market it is important to define what attributes and characteristics it should gather to be an efficient system. A C-UAS can have different functions such as detection, classification, identification, tracking, and neutralization (Markarian & Staniforth, 2021). NATO goes further and identifies a cycle that C-UAS must oblige so they can be effective, in kinetically or non-kinetically means, to neutralize the enemy UAV (North Atlantic Treaty Organization, 2023). NATO ATP-117 states that a successful C-UAS must detect the enemy UAV, track it, identify its model and capabilities, offer a decision-making option for the C-UAS operator or it is autonomously decided by the system and mitigate the adversities. After the enemy UAV neutralization, done by destruction, deterrence, defeat or capture, it must report the operator, resume its operating system and exploit (North Atlantic Treaty Organization, 2023). The Figure 23 easily displays the mentioned cycle.

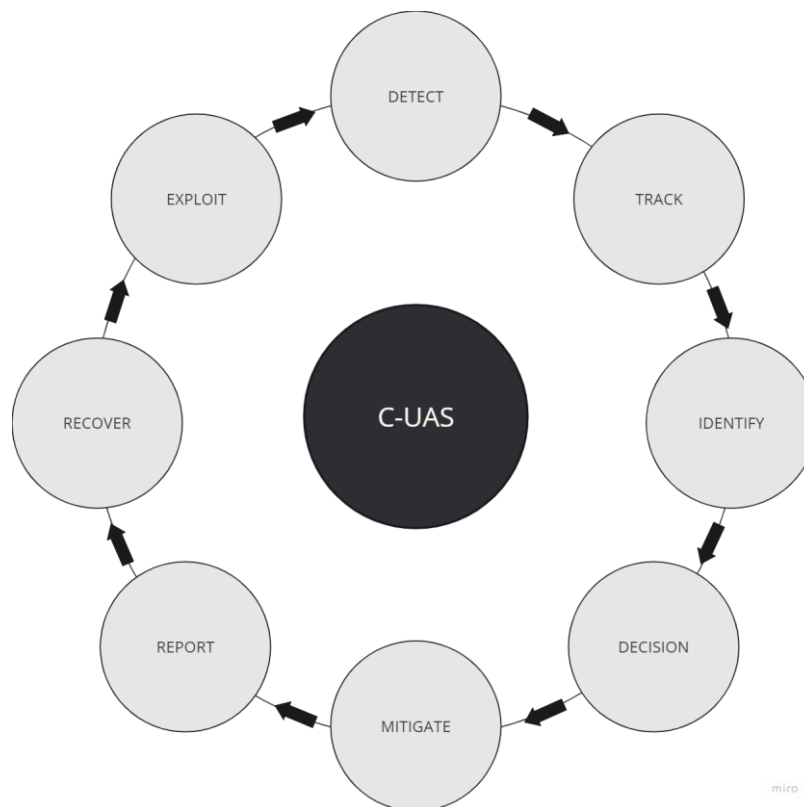


Figure 23- C-UAS Cycle³⁰

Ideally, a C-UAS integrated system capable of all these functions would be the

³⁰ Table taken from (North Atlantic Treaty Organization, 2023)

best choice for the modern battlefield, therefore, C-UAS will be searched and scrutinized according to these considerations.

3.2.1. Fixed Systems

The purpose of a stationary system is to defend a fixed area from unknown or enemy UAS at a defined distance. This is currently widely used in airports, military bases, and oil fields. With the proliferation of UAVs in civilian areas, it became necessary to implement these systems in airports because UAVs intentionally or unintentionally caused delays in their operation, as happened on April 19, 2023, when a civilian UAV was on the runway corridor of Humberto Delgado Airport, suspending flights for 1 hour (Gomes, 2023). Another example was in December 2019 when two unauthorized UAVs were blocking aircraft at London Gatwick Airport, delaying flights for 36 hours, causing inconvenience to 140,000 passengers and a loss of 50 million€ (Turner, 2019). In addition to civilian cases at airports and other facilities, it is interesting to mention military bases, such as in July 2017 when two UAVs violated the airspace of two US military facilities (Wright, 2017), which later led to the installation of C-UAS measures at the two bases.

Based on the examples given, it is evident that of the three problems presented, stationary systems are the best solution due to their autonomy, permanent power, and area defense.

According to MyDefence (MyDefence, 2023), these systems must have perimeter protection capabilities, therefore they must have high-resolution sensors such as infrared cameras and RF (Radio Frequency) jammers for 360 degrees. In the Figure 24 there is an example offered by MyDefence. It consists of an RF detector (WOLFPACK 210) that covers 360° and has a range of 10km, providing indications of the direction of the threat. When coupled with high-resolution cameras like the EO/IR (Electro-Optical/Infrared) Sensor it provides visual knowledge of the threats. The WOLFPACK can specify the model, capabilities, and coordinates of the enemy UAS. The jammer (DOBERMANN 360) allows jamming in 360° of GPS signals and frequencies commonly

used by military and commercial UAVs such as 2.4 GHz, 5.2 GHz, and 5.8 GHz.



Figure 24- C-UAS System (WOLFPACK and DOBERMANN 360).³¹

Another example is from IEC Infrared Systems, Lycan seeks, tracks, and shoots down unknown UAS. This system uses various sensors and capabilities such as High-resolution cameras with a range of 4.5km, detection of uncrewed aerial systems up to 4.5km, omnidirectional and directional jamming covering 360°, and the option of kinetic neutralization of UAVs up to 0.4km (Lycan C-UAS, 2024). Fixed systems are the magnum opus of C-UAS, with capabilities of detecting, classifying, neutralizing and deterring enemy UAVs completely autonomously. However, their fixed characteristic is a disadvantage to highly mobile and specialized forces and are the most expensive types of C-UAS, so their employment is limited.

3.2.2. Mobile Systems

In military conflicts from Israel to Ukraine, the main objective of UAVs is ISR and UCAVs to inflict as much damage as possible, in this case, to disable artillery pieces and combat vehicles that offer high firepower to the enemy. UCAVs, particularly in the conflict in Ukraine, have wreaked havoc on ground-based combat vehicles or convoys, highlighting the need to protect motorized vehicles in the field, as seen on March 4, 2024, when a convoy was halted by a UAV attack on a combat vehicle (Cook, 2024). Therefore, a need to protect mobile vehicles, large convoys and supply lines was

³¹ Figure is taken from (Fixed Solutions, 2024)

necessary, thus, the creation of C-UAS mobile products.

One example of a vehicular C-UAS is the DroneSentry-X from DroneShield (DroneSentry-X, 2024). It is fixed to a vehicle, offers 360° protection, and has detection and disruption sensors that function at any speed the vehicle may have. It provides protection against multiple UAVs with effects on RF and GPS signals and can be connected to the vehicle's battery.

Another example currently used by Russian forces is the vehicular Volnoret jammer, as observed in Figure 25. This jammer can be carried in a combatant's backpack, and used in pairs or more, as each of these jammers contains directional antennas, so multiple ones are needed to obtain 360°. It operates within the frequency range of 900 to 2000MHz, with the ability to interfere with signals beyond 1km (Army Recognition, 2023).

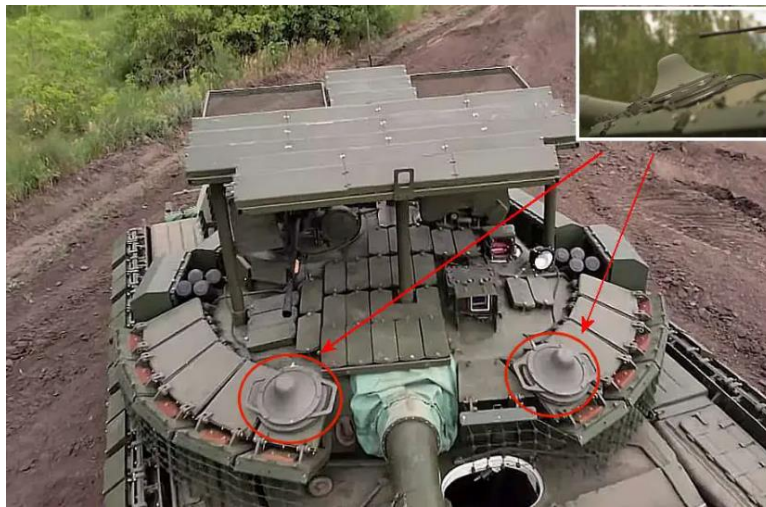


Figure 25- Volnoret Vehicular Jammer. ³²

Mobile C-UAS systems can be a cheaper and a more reliable solution than a fixed system. Due to their mobility, these systems can defend multiple forces as one, on the move and with a considerable range. However, while offering the same capabilities of fixed systems, many lack the classification cycle of enemy UAVs, and are dependent of

³² Figure taken from (Russia deploys tank-mounted Volnoret jammers in Ukraine, 2023)

the vehicle's battery to perform.

3.2.3. Hand-Held Systems

Despite the capabilities and characteristics of the systems demonstrated above, they all have a vulnerability that arises from military operations, which is the need to protect generic mobile and foot-mobile special operations groups. The generalized use of UAVs in the conflict in Ukraine has motivated the development of portable jamming and spoofing possibilities that could be used and managed by mobile special operation forces that would not be supported by vehicles with mobile devices.

One such example is the Lithuanian “EDM4S” (Eletronic Drone Mitigation 4-System) that has appeared extensively in the Ukraine forces in the current conflict. It can be seen in Figure 26 and these would function as primary weapons for selected operators in a section. This drone gun allows jamming of the normal frequencies of commercial UAVs and GPS signals such as 2.4GHz, 5.8GHz, and 1.5GHz for GLONASS (Tintera, 2022). Weighing 6kg, with a battery life of 1 hour and a range of 3 to 5km (MyDefence, 2023).



Figure 26- EDM4S.³³

Another example is the “DroneGun Tactical”, consisting of directional antennas and a control panel to select jamming frequencies. The neutralized UAS will either land on-site or return to the last point of flight (RTH), interrupting the operator's video

³³ Figure taken from (MyDefence, Counter Drone Technology, 2023)

transmission. It weighs 7kg with a battery life of 2 hours (DroneGun Tactical, 2024)

Portable C-UAS are the most modern and technologically advanced systems, becoming the most trusted and employed C-UAS option in the modern battlefield. Although they only have detection and neutralization capabilities, they offer a light and accessible way to deter enemy UAVs that small, specialized, on foot, forces necessarily need.

3.2.4. C-UAS Systems in the Portuguese Marine Corps and Allied Institutions

The question remains as to which system would be most useful for the Portuguese Marine Corps.

Stationary systems are not suitable for a highly mobile amphibious operations force, as the new “Light and Fast” concept seeks an extremely mobile, fast, and effective force (Melo H. E., 2017). Therefore, investing in a stationary system would only be practical for large-scale operations, such as battalion-level operations and above, or in the defense of a FOB (Forward Operational Base). In the case of the Portuguese Marine Corps, their forces typically reach a maximum detachment of 31 men, so a stationary system would not be the most suitable (Alves C. J., 2023).

Vehicle-mounted systems are an excellent response to various enemy challenges. These systems are extremely versatile, offering protection over a wide area, omnidirectional coverage, and mobility. When mounted on a light and agile vehicle, they can effectively defend a militarized column. Additionally, as their cost is lower than that of a stationary system, they can serve as an alternative to stationary systems. However, their purpose is unjustified when the protection they provide is for a vehicle with minimal value, importance to the mission and low combat power. For such cases, there are more economical and effective solutions available such as portable systems.

These more economical and effective solutions are found in portable or wearable systems. As previously explained and demonstrated, this equipment is much cheaper and has unique characteristics and purposes that align with the operational and tactical

activities of the Portuguese Marine Corps and its new “Light and Fast” concept. The advantages of a portable system are that it is much lighter, portable, and can be used in various tactical situations for its intended purpose. Any minimally trained soldier can use it and can support various efforts at the same time. If each section has at least one of these systems, they become a highly mobile and protected force against new threats. It becomes a much more tactical system than operational, protecting small, fast-moving forces for surgical actions in asymmetric operations, as envisaged in the Marine Corps with the “Light and Fast” concept.

Portable C-UAS may or may not replace the soldier's primary weapon, which could pose a disadvantage to the force and the soldier carrying it by partially losing combat power. However, there are other possibilities besides a UAV gun, such as a wearable system that is active in action. This alternative does not occupy the soldier's mind or hands but is attached to the soldier on the military vest or elsewhere, without obstructing the soldier. This is the case with the PITBULL WINGMAN system presented by MyDefence, as seen in Figure 27, of which the Portuguese forces already have four units. This system is quite advantageous as it allows for the detection and jamming of unknown or enemy UAVs without the soldier losing their combat capability. This system is almost autonomous, requiring only the soldier to select the frequency they want to jam or if they want to jam the UAV's GPS or Wi-Fi signal.



Figure 27- PITBULL WINGMAN System.

This system has been made specifically for special operations forces, however, it is relatively expensive, around 100000€, compared to other capabilities such as the DroneGun from Drone Shield, which costs 36,000€ (DroneGun Tactical, 2024), or the EDM4S (RF Jammer Gun) (Military Factory, 2020), which costs around 15,000€, all according to 2024 prices. However, its value is attributed to the maintenance of combat power for the combatant. For this situation, another alternative emerges, which will be studied, namely the Jammer produced by the SWATTER Company, called SWATTER (Swatter Company, 2021), which has the same and more functions than the DroneGun or the EDM4S by adding spoofing capability to the jamming that these prototypes already have (Ferreira, Gaspar, Sebastião, & Souto, 2022).



Figure 28- SWATTER. ³⁴

The advantage of the SWATTER jammer, as seen in Figure 28, over a more expensive system like the PITBULL WINGMAN lies in its ability to perform spoofing on the UAV, which is a much more effective and covert way to neutralize a UAV, since the operators may not identify the attack, and the addition of bigger directional antennas, thus increasing the range. In addition to its low cost, it also allows for control of the UAV and placement in a defined safe area by the combatant. This system would be very useful as a quick, inexpensive, and efficient alternative for the near future and in the absence of capable systems to counter UAVs present in the Portuguese Marine Corps. It would also be useful to equip naval forces with this system due to the emergence of Drone Warfare in naval contexts. Outfitting each ship with at least two of these systems

³⁴ Figure is taken from (SWATTER Company, 2023)

would be a step forward in protecting ships against new threats, while fixed systems are unavailable or too expensive.

In the Table 14 a comparison is made of the C-UAS analyzed in the previous chapter that would now help in deciding which system would be the most cost-effective for the Portuguese Marine Corps. It is possible to see a downgrade in range as the system becomes smaller and portable, but its efficiency comes with accessibility and reason. As the range, the capabilities downgrade as well as most of the portable systems do not detect or identify enemy UAVs, however the PITBULL WINGMAN becomes useful since it can gather those actions. SWATTER becomes an advantageous system by its low cost and spoofing capabilities.

C-UAS Comparison

	Fixed Systems		Mobile Systems		Hand-Held Systems			
	WOLFPACK DOBERMANN 360	Lycan	DroneSentry	Volnoretz	EDM4S	DroneGun	PITBULL WINGMAN	SWATTER
Bandwith (GHz)	2.4, 5.2, 5.8, 1.6	0.4-1.7, 2.4, 5.8, 1.6	2.4, 5.8, 1.6	0.9-2	2.4, 5.8, 1.5	2.4, 5.8, 1.6	0.433, 0.868, 0.915, 1.2, 1.6, 2.4, 5.2, 5.8	1.5, 2.4
Range (km)	10	4.5	2	1	3-5	2	3	2
Coverage	Omnidirectional	Omnidirectional	Omnidirectional	Directive	Directive	Directive	Directive, Omnidirectional	Directive
Capabilities	Detection, Identification, Jamming, Spoofing	Detection, Identification, Jamming, Destruction	Detection, Jamming	Jamming	Jamming	Jamming	Jamming, Detection	Jamming, Spoofing

Table 14-C-UAS Comparison

3.2.4.1. PITBULL WINGMAN

The PITBULL WINGMAN is a C-UAS that utilizes disruptive techniques to neutralize unknown or enemy UAVs. It is a product that is at TRL 9 (Technology Readiness Level), which should be used by a combatant without obstructing their motor skills, as you can see in Figure 29. The PITBULL WINGMAN system is the junction of two different systems PITBULL 101 and WINGMAN 103.

The WINGMAN 103 is a UAS detector, capable of detecting UAVs and their operators. It alerts the operator through a headset, via vibrations, and/or through light alarms on the top of the system. It is robust and waterproof, capable of being connected

to the PITBULL and working simultaneously to create a unified and effective system. Weighing 1110g, it detects UAVs in the frequency range of 2.4GHz to 2.5GHz and 5.15GHz to 5.875GHz, with a range of 6km in 10 seconds of acquisition and external batteries, of 500 grams, lasting for 14 hours. It is composed of omnidirectional antennas with 60° vertical and horizontal coverage, 6dBi gain, and circular polarization. However, it can be connected to an omnidirectional antenna to provide 360° protection, as seen in Figure 29. Its dimensions are 42mm x 96mm x 166mm, with a temperature tolerance ranging from -30°C to 65°C.



Figure 29- PITBULL WINGMAN System and AA100 Antenna.

The WINGMAN has four operation modes (MyDefence, 2023):

1. Automatic Mode: Detects UAVs using all available antennas, scanning possible frequencies.
2. External Antennas: Uses only external antennas, such as the AA100 (Active Antenna 100), as can be seen in Figure 39.
3. Direction Finding Mode for UAVs: Locks on to the direction of the strongest UAV detection.
4. Direction Finding Mode for Controllers: Locks on to the direction of the strongest detection of UAV operators at their control stations.

The omnidirectional antenna that can be connected to the WINGMAN is the AA100, robust, lightweight, and waterproof, with additional frequency bands that can be added to the WINGMAN system. Weighing 200g, it brings the total weight to 1310g, with dimensions of 28 x 40 x 220 mm, and frequency bands of 433MHz, 868MHz, 915MHz, 1.2GHz, 2.4GHz, 5.2GHz and 5.8GH. It has the same temperature tolerance as the WINGMAN system.

The PITBULL 101 is a wearable C-UAS jammer that can be connected to the WINGMAN to help neutralize unknown UAVs. It contains directional antennas to jam adversary UAVs. Weighing 1330g, it has a range of 1km with a 60° vertical and horizontal coverage and a longevity of 20 hours. It operates in frequencies of 2.4GHz, 5.2GHz, 5.8GHz, and 1.6GHz (GNSS), with a gain of 6dBi and Estimated Radiative Power (EIRP) of 8W, with circular polarization. It works with external batteries and has dimensions of 243 x 90 x 60 mm, with a temperature tolerance ranging from -30°C to 65°C.

The jamming performed by the system allows interference with the UAV's signal, diverting it from its intended route or interfering with the telemetry and audiovisual transmission to the UAV operator. Jamming can be performed on multiple UAVs simultaneously if they are operating at the same frequency band.

The PITBULL has five operating modes (MyDefence, 2023):

1. Automatic Mode: Requires WINGMAN to be connected and automatically jams when a UAV is detected.
2. ISM (Interference and Spoofing Mode): Jams frequencies in the 2GHz band.
3. ISM / Wi-Fi: Jams frequencies in the 5GHz band.
4. Wi-Fi: Jams frequencies in the 5GHz band that are not covered in the previous mode.
5. DJI Dualband: For UAVs that use typical DJI frequencies, operating on

both 2GHz and 5GHz simultaneously.

6. GNSS: For GPS signal only.

Multiple PITBULLs can also be networked together to cover a larger area with their directional antennas and jam different frequency bands simultaneously, as observed in the Figure 30.

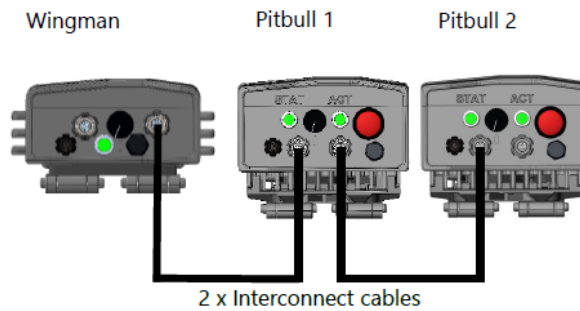


Figure 30- Daisy-Chaining PITBULL WINGMAN. ³⁵

The average transmission power of the PITBULL is 2W, and the maximum 10W, however, 60cm from the front of the device should be maintained while transmitting, at a 45° angle, as observed in Figure 31. The system also comes with a complementary feature that allows modification and updating of the system with new firmware of frequencies for more advanced types of UAVs.



Figure 31- Safety Distance, PITBULL WINGMAN. ³⁶

³⁵ Figure taken from (MyDefence, 2023)

³⁶ Ibid

3.2.4.2. SWATTER

The system uses commercial off-the-shelf equipment to provide a cheaper and less complex solution. It employs a SDR (Software Defined Radio) that is programmable by the operator, capable of signal processing, working as a transmitter and receiver (Akeela & Dezfouli, 2018). In addition to the jamming capabilities provided by the BladeRF x40 and GNU Radio software, the jammer also allows gaining control of the UAV through spoofing, enabling remote guidance of the UAV or predefining the geographical location for the UAV to park, by jamming the GNSS signal and subsequently transmitting false signals that allow the acquisition and indirect control of the UAV (Ferreira, Gaspar, Sebastião, & Souto, 2022). Furthermore, triangulation of the UAV position is completely done by the system, independent of other means, due to the system integrating three sensors and a receiver (Ferreira, Gaspar, Sebastião, & Souto, 2022).



Figure 32- SWATTER. ³⁷

The system features a ground station where the operator can check their location, allowing them to define a location where the intruding UAV can be parked. When the UAV is sighted, the user simply points the system at the UAV and triggers it, and the system will guide the UAV to the previously defined location. The system can

³⁷ Figure taken from (SWATTER Company, 2023)

also have a telescopic sight, bipod, grips, sling, and other types of optics. It consists of two withdrawable Yagi-Uda directional antennas, an external battery with 2 hours of duration, and a biometric sensor for the operator to unlock the security of the UAV gun.

The system has two types of jamming: one targeting the 2.4GHz operator-UAV communication link and another targeting the 1.5GHz GPS signal. The antenna has a gain of 14.8 dBi with an operational angle of 29° vertical and horizontal, providing a total system power of 25 dB.

According to the authors, the jammer was extremely effective, almost instantly starting the jamming process (Ferreira, Gaspar, Sebastião, & Souto, 2022). When jamming during flight, the UAV hovers in the same location, but, if jamming occurs before takeoff, the UAV does not leave the ground. After spoofing, the UAV receives a new route and positions itself in the area predefined by the anti-UAV system operator. The prototype and its use are seen in the Figure 32.

3.3. Exploratory Interviews

As part of the state-of-the-art review, several interviews were conducted with experts in Drone Warfare at both international and national levels. The intended objective is to gather information for the state-of-the-art section of the dissertation and Drone Warfare, acquire knowledge for future conclusions during the presented work, and contribute to the current advancement of Drone Warfare in the Portuguese Marine Corps.

The interviewees were as follows:

- Commander Faias Martins, commander of unit X31.
- Representative of ANACOM, general department of information and innovation.
- Ms. Marilia Frias, managing associate of Vieira de Almeida Enterprise, legal expert in the use of drones in civilian environments.

- Commander Jesus Alves, commander of the Force Projection Unit of the Portuguese Marine Corps.
- Dr. James Patton Rogers, NATO Country Director of the Full Spectrum of Drone Warfare Project, expert in Drone History.
- Samuel Bendett, Adviser with CNA and CNAS Strategy, specialist in Drone Warfare.
- Colonel (Retired) John Antal, specialist in Future Warfare.

The interview guides with the objectives for each interview, the questions asked, and the date of each are detailed in Appendix K- Interview Guides.

The following will present the conclusions and information extracted of important knowledge for Drone Warfare combatants.

3.3.1. Commander Faias Martins Interview

The interview conducted with Commander Faias Martins aims to understand and comprehend the employment of UAVs (Unmanned Aerial Vehicles) in the Portuguese Navy. The current organization, missions, and projects that are targeted for the systems under study.

Currently, the utilization and employment of UAVs in the Portuguese Navy is carried out by three different units:

- X31, which aims at the organization and management of autonomous systems.
- CEOV (*Célula de Experimentação Operacional de Veículos não Tripulados*, Unmanned Systems Innovation and Operational Experimentation Cell), which aims at the innovation and experimentation of autonomous systems.

- CEOM (*Célula de Experimentação Operacional da Marinha Portuguesa*, Portuguese Navy Operational Experimentation Centre), which aims at the application and employment of autonomous systems in maritime operations.

The three units employ the autonomous systems that, through international exercises, such as REPMUS (Robotic Experimentation and Prototyping with Maritime Unmanned Systems) (Marinha Portuguesa, 2024), collaborate and demonstrate the means to various international forces, thus pushing NATO (North Atlantic Treaty Organization) towards a more technologically advanced world.

However, these autonomous systems, largely UAVs, are still a scarce resource and an investment to be made by the Portuguese Navy. The existing UAVs in the Portuguese Navy are all NATO Class I, with the objective of acquiring NATO Class II or higher in the future.

From the interview, it was understood that the purpose of the systems aims to increase the surveillance capacity in the Portuguese sea and the respective ZEE (Exclusive Economic Zone). Due to their autonomous capability, high range, and aerial coverage, they allow for a reduction in the employment of combatants and an increase in maritime surveillance. These systems are also employed in land or amphibious operations through their delivery to the Marine Corps for missions or exercises with a detachment of drone operators under the command of the Marine Corps.

The training provided for drone operators in the Portuguese Navy is carried out by the X31 unit, which is not certified but follows the proper ARPRA-IB certification established by the Official Gazette for military UAV operators (Diário da República, 2020).

As for countermeasures, the only countermeasure existing in the Portuguese Navy for the neutralization of enemy or unauthorized UAVs is the PITBULL WINGMAN system demonstrated in the previous chapter, which demonstrates a lack and vulnerability to the adversities of Drone Warfare. Its training is allowed using

Technological Free Zones like CEOM, which allows the manipulation of the electromagnetic spectrum, but the training is simple and investment in the specialization of countermeasure operators is necessary.

3.3.2. Representative of ANACOM Interview

The interview conducted with the representative of ANACOM aims to understand the legal issues in the use of countermeasures dedicated to enemy or unauthorized UAVs.

Countermeasures can be kinetic or non-kinetic, but in both cases, their use is prohibited for civilians even in self-defense. Their use is only permitted for law enforcement purposes by security forces. Therefore, their acquisition, manufacture, and use by the population is illegal and punishable by law with fines or imprisonment.

In kinetic matters, their legality does not differ from the normality of legal cases; however, non-kinetic countermeasures that affect the electromagnetic spectrum can incur hefty fines due to their manipulation of frequencies dedicated to information, Wi-Fi, and GNSS, which can impair the navigation of aircraft, civil informational systems, and telecommunications networks. Therefore, technological free zones are excellent for spectrum manipulation and the testing of countermeasure systems.

3.3.3. Ms. Marilia Frias Interview

Ms. Marilia Frias is a specialist in legal issues related to the use of UAVs in civilian environments. The objective of the interview is to acquire knowledge about the use of UAVs in civilian environments, their dangers in permissive environments, and the challenges dedicated to their regulation.

It was understood that civilians must register online through ANAC (Portuguese Civil Aviation Authority, 2021). UAV operators must also register their UAS with ANAC to ensure their model, size, weight, and flight schedule (Portuguese Civil Aviation Authority, 2020).

The proliferation of UAVs, both in the military and civilian worlds, has led to increased air congestion, with small UAVs occupying airspace intended for larger aircraft. This has led to the implementation of a regulation dedicated to this airspace between civilian aircraft and UAVs, known as "U-Space" (Portuguese Civil Aviation Authority, 2023) as can be seen in Figure 33.

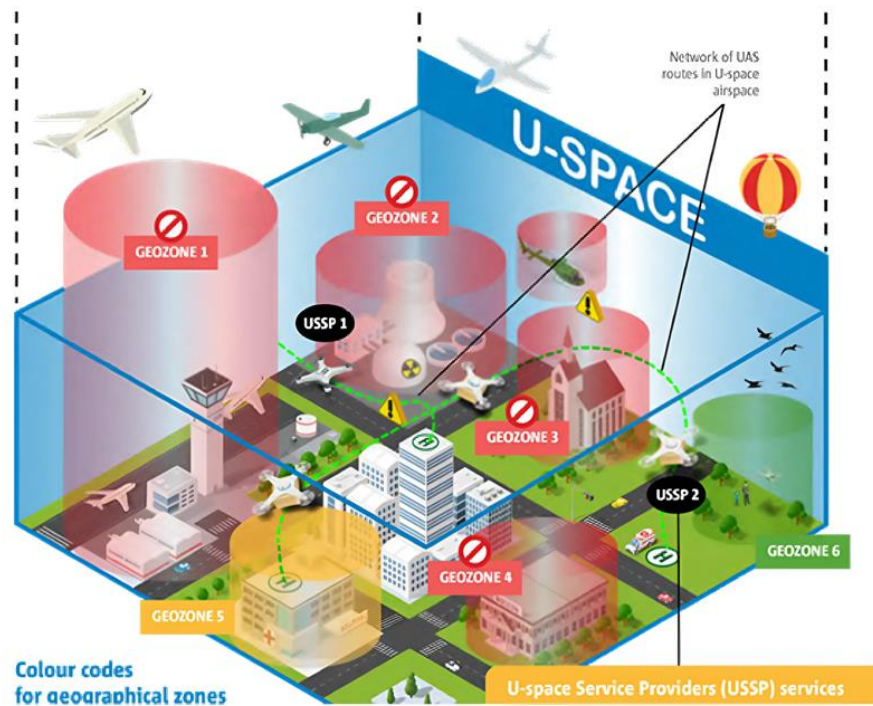


Figure 33- U-Space.³⁸

Another important aspect addressed, no less significant, was the implementation of new technologies such as artificial intelligence and swarm in UAVs, which can complicate the legal regulation of their use in both the military and civilian worlds. To this end, the EU has been working on a legal framework for artificial intelligence, which is yet to be published (European Parliament, 2024).

3.3.4. Commander Jesus Alves Interview

Commander Jesus Alves is the current commander of the UPF (*Unidade de Projeção de Força*, Force Projection Unit) which, together with the UOE (*Unidade de*

³⁸ Figure taken from (European Union Aviation Safety Agency, 2022)

Operações Especiais, Special Operations Unit), UMD (*Unidade de Meios de Desembarque*, Disembarkation Means Unit) e UAC (*Unidade de Apoio de Combate*, Combat Support Unit) form the organization of the Portuguese Marine Corps.

The UPF aims at the employment and preparation of marine forces for the various missions and exercises that the Marines may practice, and currently, there is an effort being made to equip UAVs for the action of combatants in both reconnaissance and offensive and defensive actions. This action aims at the use of dedicated means from X31 under the authority of the Marine Corps combat groups, operated by two operators from the original unit who operate both the UAVs and the countermeasures.

However, there is a loss of capabilities due to bureaucracies created by the systems belonging to a unit separate from the Marine Corps, something that Ukrainian forces managed to limit with direct employment of the systems under the responsibility of the forces that employ them. Training, as it is not carried out and conducted by Marines, also increases bureaucracy and the time needed to accomplish it.

3.3.5. Dr. James Patton Rogers Interview

Dr. James Patton Rogers is one of the most internationally recognized experts in Drone Warfare. He is at the forefront of the NATO doctrine dedicated to sUAS, the Full Spectrum of Drone Warfare project, and advises the EU and the UN on Drone Warfare. Dr. James Patton Rogers is a historian, focusing on the field of UAVs, and his interview is of greater interest due to his knowledge on the subject.

Dr. James Patton Rogers was the first to divide the history of drones into three ages:

- 1st Drone Age, starting in 2001 when the global war on terrorists began after 9/11, leading to the need to destroy critical targets in foreign and distant territories. In order not to employ ground forces, the use of UAS was observed to neutralize targets with high precision and minimal collateral damage without operators on the ground. These systems are

large pieces of machinery with high ranges and destructive capacity that reach NATO Class III.

- 2nd Drone Age began in 2016 with the start of the Yemen conflict, where these types of systems were not only operated by world superpowers like the USA with high technological and financial capabilities, but also by non-state actors like Hamas, ISIS, Houthis, and Hezbollah, who employ highly modified commercial drones like the DJI drones with destructive and kamikaze capabilities, thus changing the nature of Drone Warfare forever.
- 3rd Drone Age, without an exact date yet, is beginning to emerge with this type of equipment with new technologies such as Swarm, AI, and Autonomy implemented, increasing their capabilities and dangerousness, and making Drone Warfare a certain art of war for the next conflicts (Rogers D. J., 2024).

The interviewee assured the danger of Drone Warfare and its importance in combat, highlighting its complexity and difficulty. The new UAS classification carried out in the presented work, which can be seen in Figure 7 and Table 6, was shown to the interviewee and was positively verified and forwarded to NATO to take into account the future capabilities of drones with autonomy and artificial intelligence..

With the emerging and recent conflicts, Drone Warfare has been present, leading to the need for NATO member states to create and adopt solutions against aerial threats, establishing a "Drone Wall" on the Eastern flank of NATO to protect against enemy missiles and UAVs (Rogers D. J., 2022) as can be seen in Figure 34.

Finally, the interviewee was asked about the differences in technological advancement between an autocratic and a democratic regime. The finding was that although autocratic regimes have less regulation and thus faster and unlimited advancement, the NATO alliance is something that must be preserved, and it has a good path ahead with various member states seeing Drone Warfare as a reality and its

adoption and implementation as crucial.

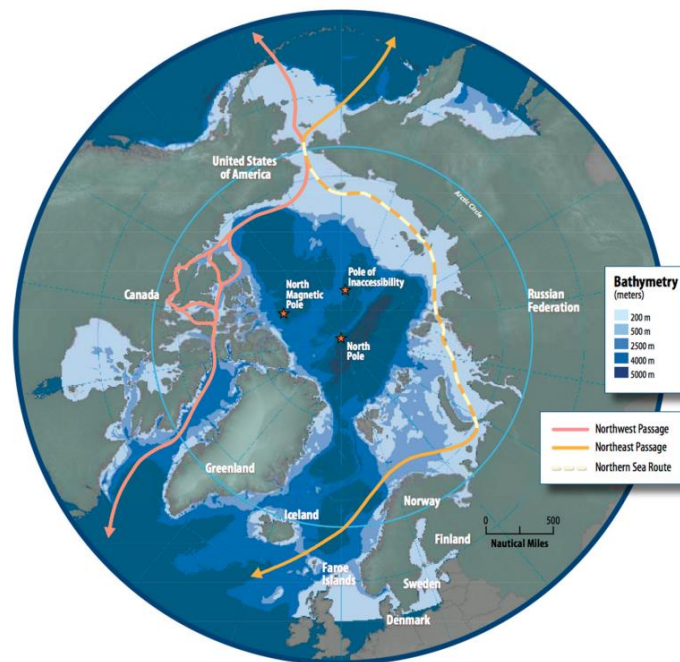


Figure 34- The NATO "Drone Wall".³⁹

3.3.6. Samuel Bendett Interview

Samuel Bendett is an advisor to CNAS (Center for New American Security) who specializes in Drone Warfare and its study in recent conflicts such as the Ukraine conflict. Therefore, the interview aimed to understand the lessons of Drone Warfare that can be drawn from recent conflicts and the next steps for international armed forces to adopt and prepare.

One of the most valuable questions asked was about the consideration of the Russian and Ukrainian armed forces regarding the Second Nagorno-Karabakh War and whether both learned from the conflict, which largely features Drone Warfare as seen in Ukraine. It was concluded that Ukraine indeed learned and applied the lessons learned with the rapid implementation of UAVs in its army. This includes experimentation, application, and modification in conjunction with the civilian world in donation and manufacturing. The Ukrainian forces were the first world forces to adopt a branch

³⁹ Figure taken from (Rogers D. J., 2022)

dedicated to autonomous systems, something that Samuel Bendett is still evaluating for its efficiency and value (Bendett & PettyJohn, 2024).

As for the Russian forces, learning was not verified, as their forces hardly adapted to the most recent and smaller UAVs, not integrating them organically into their operational organization and due to the lack of timely response of countermeasures against enemy UAVs.

Samuel Bendett characterized the conflict in question as a war of attrition, which will last a long time and is characterized mainly by the destruction of dismounted and mobile forces until the last resource is destroyed. Putting Portuguese forces in paradigm, Samuel Bendett argued that their numbers are few and the Marines would need a larger number of forces to face and withstand a war of attrition.

The importance of countermeasures was also identified, which are fundamental and the best resource to neutralize enemy UAVs, especially those of electronic warfare such as Jamming and Spoofing with a range of at least 500 meters. However, even these systems will have some difficulty responding against enemy UAVs that work in a wired manner through fiber optics or wire-guided, making them immune to non-kinetic countermeasures, revealing their importance.

3.3.7. Col. Ret. John Antal Interview

Colonel Retired John Antal was a colonel in the US Army and now specializes in Future Warfare. This interviewee has written two books of high importance for any military reader interested in military affairs: "7 Seconds to Die" and "Next War". The first is a necessary analysis of the first war fought mainly by autonomous systems, and the second is an inspection of other conflicts such as Gaza and Ukraine that lead to an introspection of future technologies and characteristics of the next war.

John Antal begins the interview with the statement that the second era of drones is not in 2016 but rather in 2020 with the second Nagorno-Karabakh war. In this conflict, the importance of air defenses against sUAS and the capabilities and flexibilities of UAS

for combat were observed for the first time, with a great preponderance of the TB2 Bayraktar UAS, which to this day makes relevant impacts in conflicts due to its eccentric capabilities. John Antal uses this conflict to address the "9 Disruptors" that armed forces must adopt to survive the future technological adversities of upcoming conflicts, which can be seen in Figure 35. Of the "9 Disruptors", those discussed in the interview and of interest to the study are "Super Swarm", "Fully Autonomous", and "Top Attack".

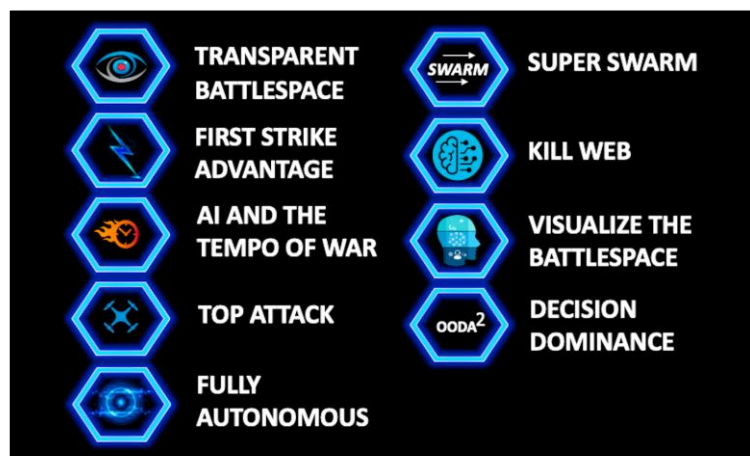


Figure 35- The "9 Disruptors" of War.⁴⁰

Starting with "Top Attack," a feature specifically dedicated to Drone Warfare, it serves to alert armed forces to new dangers coming from above the combatant. In previous conflicts, and especially for motorized forces like tanks, the enemy attacked from the front, side, or rear. However, at present, due to the nature of Drone Warfare, dangers come from above, with UAVs attacking the most vulnerable area of the tank, causing significant damage to military columns and motorized forces. This leads to the need to adopt defense and protection measures for the new axis of attack, which is vertical.

"Fully Autonomous" also targets Drone Warfare in terms of increasing autonomy dedicated to UAVs. John Antal defines that the autonomy of these systems will increase drastically, along with their dangers and capabilities. Therefore, he warns international forces to classify autonomy and find solutions against it. To this end, John Antal

⁴⁰ Figure taken from (Antal J. , 2023)

demonstrated a classification of UAV autonomy that aligns with that of the EU Commission, which can be seen in Figure 36.

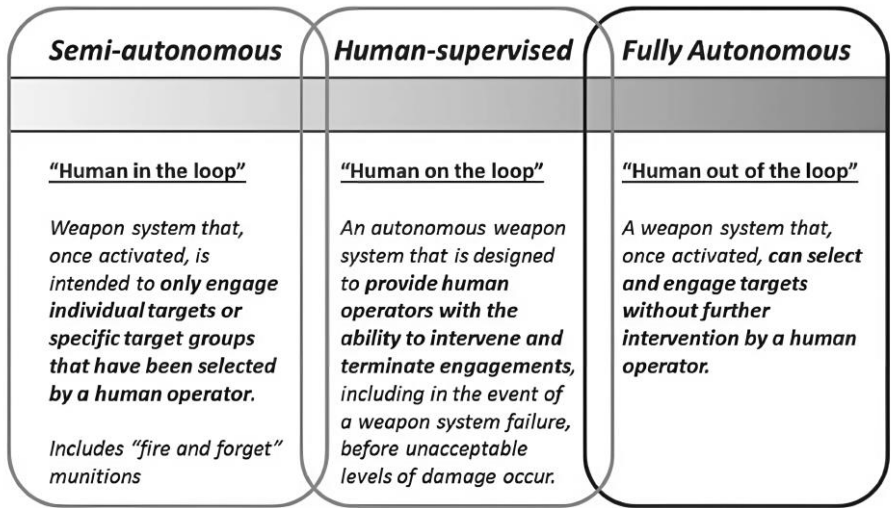


Figure 36- Autonomy Levels by John Antal.⁴¹

"Super Swarm" is defined by the interviewee as "...a group of AI-enabled, disposable, autonomous robotic systems that cooperate and are directed by a single "pilot" to attack multiple targets simultaneously from different angles" (Antal J. , 2023), , which, in a way, aligns with the normal classification of Swarm by Paul Scharre. It is observed that a Swarm necessarily needs to have some level of AI to coordinate with the other elements of the swarm. The normal definition that the interviewee characterizes as conventional Swarm is what is generally defined as Flock, defined as "...a discernable number of aircraft execute more abstract commander’s intent provided by aviators" (Wassmuth & Blair, 2018). In other words, a flock involves one operator per UAV forming a group of UAVs that mobilize in formations. This leads to the consideration that a Swarm is a Flock with AI and quite high autonomy, which is the current definition of "Super Swarm" by John Antal.

Applying John Antal's equation 3.1- Super Swarm for the correct definition of Swarm, we have the following:

⁴¹ Figure taken from (Antal J. , 2023)

Paul Scharre goes further and defines that Swarm can have various coordination methods, which can be seen in Figure 37.

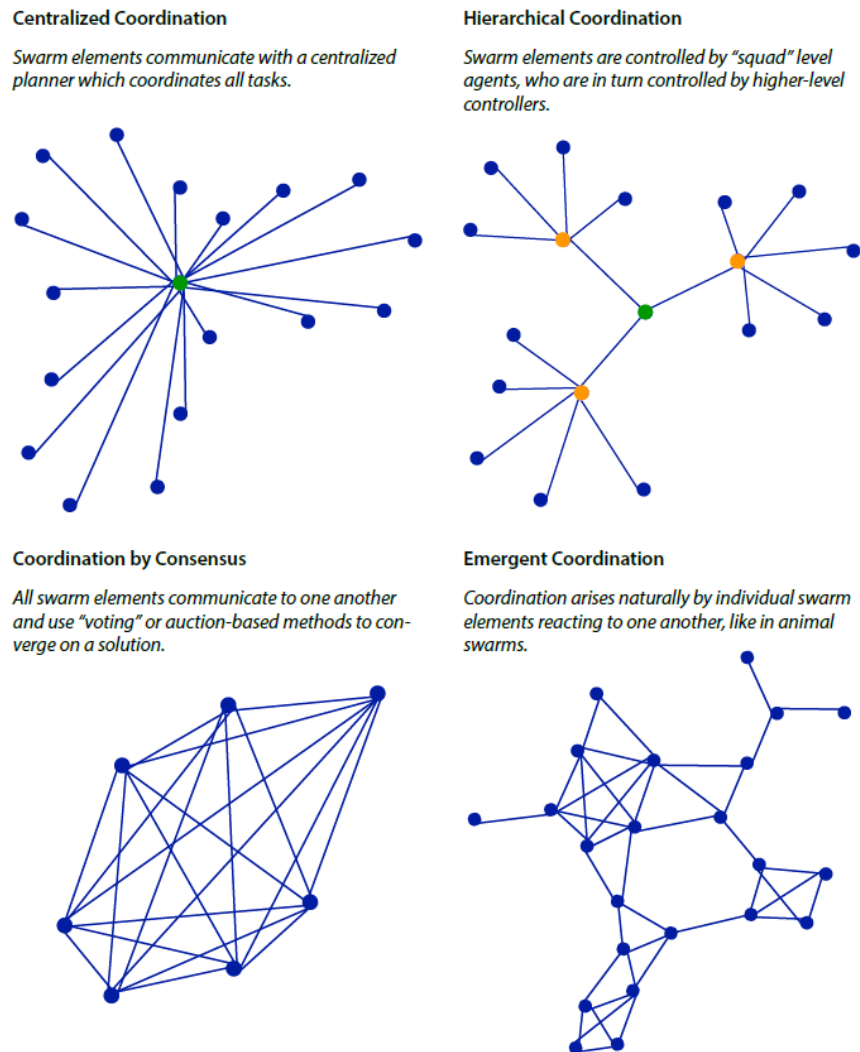


Figure 37- Types of Swarm Coordination⁴²

John Antal presented the difficulty of combating enemy UAVs and that the response to it is not about the best solutions but rather about evading the enemy through "Masking" which is "...the full-spectrum, multi-domain effort to deceive enemy sensors and disrupt enemy targeting. It is the active and passive ability to make military systems difficult or impossible to identify, locate, and target." (Antal J. , 2022), for which

⁴² Figure taken from (Scharre, 2014)

he defines the following 10 rules:

1. Know the sensors of enemy UAVs.
2. Provide optical camouflage.
3. Provide thermal camouflage.
4. Provide electronic camouflage.
5. Provide acoustic camouflage.
6. Neutralize the enemy's targeting system.
7. Implement and use decoys.
8. Confuse the enemy.
9. Blind the enemy.
10. Eliminate the enemy.

These are the 10 rules that John Antal presents as necessary to survive future Drone Warfare. John Antal believes that with the most recent sensors and capabilities of UAVs, these will detect the electromagnetic presence of the force, leading to its location and destruction, as seen in Figure 38.

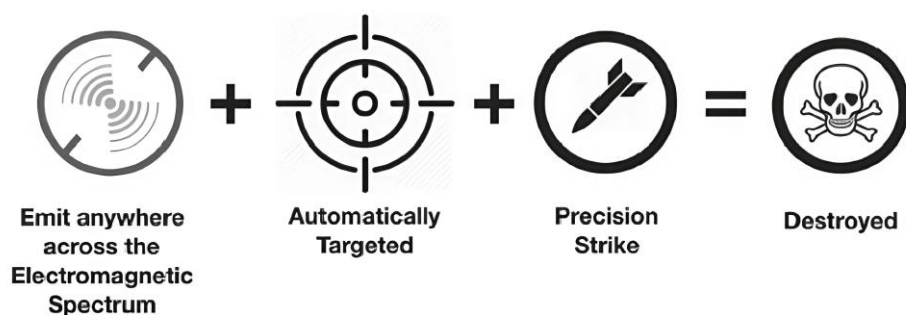


Figure 38- UAV Destruction Equation⁴³

⁴³ Figure taken from (Antal J. , 2024)

John Antal concludes the interview by stating that countermeasures and UAVs should be lowered to the echelon level and their use should be extended to a large part of the force due to their necessary capabilities in current and recent conflicts. He advises the use of wire-guided UAVs and, for each platoon, 3 Kamikaze, 3 bomber, and 1 ISR UAVs.

3.3.8. Conclusions

With the interviews conducted with various Drone Warfare specialists at national and international levels, a variety of necessary and valuable information was collected for the study and for the Portuguese Marine Corps, such as:

- The current use of UAVs in maritime, land, and amphibious operations of the Portuguese Navy, as well as the training dedicated to drone operators and existing systems.
- The current difficulties in employing UAVs in the Portuguese Navy and the bureaucracy involved.
- Civil legal issues dedicated to the use of UAVs that can be translated into the armed context, and the impact of these systems in the present and future.
- Civil legal issues dedicated to the use of countermeasures and the proper manipulation of the electromagnetic spectrum, as well as their training gaps.
- The three drone ages, their technological advancement, and the next steps for the armed forces and NATO.
- The lessons that should be drawn from the second Nagorno-Karabakh war and their implementation in current and recent conflicts, such as the importance of electronic warfare and the difficulties of a war of attrition.

- The "Full Autonomy," "Top Attack," and "Super Swarm" that will change the paradigm of Drone Warfare and how Swarm is expected to be applied in future conflicts in terms of AI and coordination.

These conclusions will allow for the extraction, application, and conclusion of information during the dissertation and promote knowledge and analysis of Drone Warfare in the current work and in the Marine Corps.

4. Experimentation of C-UAS in Simulated and Semi-Controlled Environments

*“Warfare is hyper-accelerated. If you move or emit any signal along the **electromagnetic spectrum** without being hidden, you will be detected in real-time, located precisely, targeted, and killed.”*

Col. Ret. John Antal

To comply with the Protection objectives of the dissertation, a study on the harmfulness, capacity, and accessibility of the systems studied within the Marine Corps should be initiated through simulations using CST (Computer Simulation Technology) Studio Suite (Dassault Systemes, 2024), allowing for the analysis of their efficiency, electromagnetic parameters, as well as their impact on the human body, with or without the ballistic plate. To reach this objective, an antenna with similar characteristics to the AA100 antenna from the PITBULL WINGAMN system, was modulated most importantly its impedance, through the study of “full-wave simulations”.

The simulation of its impedance is important to assure a correct and approximated approach to the real antenna, therefore, possible to maximize the power transfer (Nikolova, Ravan, & Amineh, 2012). CST Studio Suite offers “full-wave simulations” since it solves Maxwell’s equations in three dimensions.

Later in the study it will be evaluated the C-UAS that the Portuguese Marine Corps and allied institutions employ, according to determined operational requirements and C-UAS functions.

4.1. Antenna Simulations in CST Studio Suite

The CST Studio Suite is a high-performance 3D software that allows to modify, analyze, and optimize components and systems affecting the electromagnetic spectrum (Dassault Systemes, 2024). This tool enables the analysis of antenna capabilities applied in the software through simulations of different bands from the electromagnetic spectrum, conducting studies on gain, range, transmitted power, lost power, energy loss, and the antenna's radiation impact on the human body.

To evaluate the PITBULL WINGMAN system in the CST software, an approximated version of the PITBULL antenna was modeled. The antenna does not correspond to the same antenna used by the real system (which information is not open to public), but it still presents similar impedance matching and gain, across the frequency bands of interest, with the simulation of general monopole antenna. The real antenna and modulated antenna are shown in Figure 39. The AA100 antenna is an omnidirectional antenna that can be directly connected to the PITBULL WINGMAN, with detection up to 3 km, 360° coverage, a maximum transmitted power of 10W, and frequencies of 0.433GHz, 0.868GHz, 0.915GHz, 1.2GHz, 1.6GHz, 2.4GHz, 5.2GHz, and 5.8GHz (MyDefence, 2024).

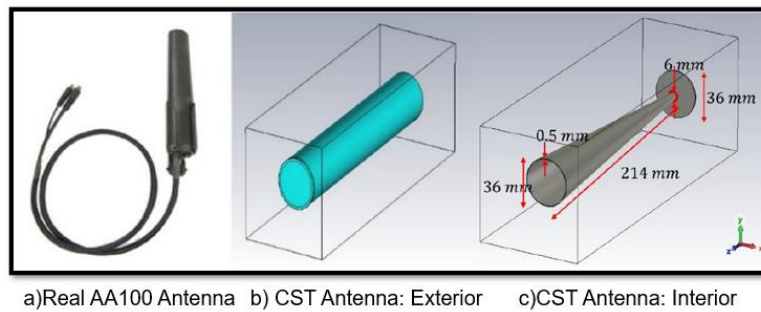


Figure 39- Real AA100 Antenna and CST Antenna.

The intended objectives with the study of the electromagnetic spectrum of the AA100 antenna simulated in CST are as follows:

- Analysis of input reflection coefficient.
 - Input reflection coefficient permits the study of return loss which is the reflected power from the antenna (antenna theory, 2015). Its study is important because a high return loss, close to 0 dB, means that a substantial portion of the power emitted by the antenna is being reflected and not radiated, thus ineffective. A low return loss, for example, -45 dB, is positive as it indicates that a greater portion of energy is radiated or absorbed as losses by the antenna (antenna theory, 2015). For reference, it was used

the typical -10 dB threshold to indicate proper impedance matching. Proper impedance matching means higher efficiency in power transmission, permitting better irradiated signals (Nikolova, Ravan, & Amineh, 2012).

- Analysis of radiated and total efficiency.
 - Radiation efficiency represents the ratio of radiated power to the power received by the antenna (antenna theory, 2016). High values, close to 0 dB, show that most of the received power is radiated, while extremely negative values indicate that a substantial portion of emitted energy is absorbed or reflected. Total efficiency considers radiated efficiency and losses such as conductor loss, dielectric losses, or impedance mismatch (antenna theory, 2016).
- Analysis of directivity, bandwidth, main and secondary lobes, and their direction in 2D and 3D.
 - Farfield is an electromagnetic region where the electromagnetic region is in a stable pattern, described as the inverse square law of power density (Dassault Systemes, 2020). This type of study allows the analysis of main and secondary lobes and their directivity (antenna theory, 2021).
- Calculation and analysis of SAR, Power Loss, and their effect on combatant safety.
 - Specific Absorption Rate (SAR) is a measure in W/kg of the energy absorbed by human tissue from radio frequency transmission (antenna theory, 2019). Power loss of an antenna is the power lost due to material resistance and other design deficiencies (Mekimah, Messai, & Belhedri, 2020). Studying these factors is

important to understand how much energy is lost due to materials and the potential harm to the human body.

- Calculation and analysis of the antenna's range using the Friis equation.
- Calculation and analysis of radiation penetration depth in the human body.

All defined objectives will be applied, studied, and analyzed for all frequencies of the system and for the three defined scenarios:

- Isolated Antenna.
- Antenna and Human Body.
- Antenna, Human Body, and Ballistic Plate.

The study of the system at all the mentioned frequencies is important to detect the impact of dielectric properties at various frequencies and to identify the frequencies at which the system operates effectively. The analysis of the antenna's electromagnetic spectrum in the three defined scenarios is necessary and relevant as it allows to predict the impact of the antenna on the future combatant operating it, thus verifying its harmfulness and the impact of the body on the antenna's efficiency. Two of the three scenarios can be seen in Figure 40.

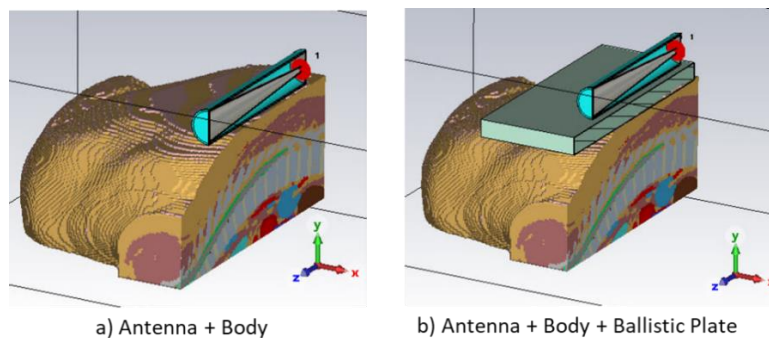


Figure 40- The Antenna's Scenarios

For the study of the last two scenarios, a human body model named HUGO was used, which is a firmware developed by MIT (CST Voxel Family, 2024), that is a simplified

human body, accepted by the scientific community as a reasonable look-a-like of a real human body, that goes in interest with the work objectives. This model allows the simulation of systems on bodies of age and size comparable to current Marine Corps combatants. For simulation purposes, only the torso area of the body was used, as it is the most sensitive area of the human body due to the proximity of the system and to avoid graphic capacity limitations. Yet, given the electromagnetic properties of the body, it is not expected that considering a larger volume would change the conclusions drawn hereafter.

For the study of the last scenario, a ballistic plate like the D13 ballistic plate of Snigel Design used by the Portuguese Marine Corps was simulated, with the same dimensions as in reality. Weighing 1400 g, 6mm of thickness and 25 by 30 cm in size. The material of the ballistic plate is classified but is mostly Aluminum Oxide. It offers Level III protection according to the NIJ (National Institute of Justice) scale. A space between the human body and the ballistic plate and the ballistic plate and the antenna was left at 1 cm distance.

4.1.1. Input Reflection Coefficient Analysis

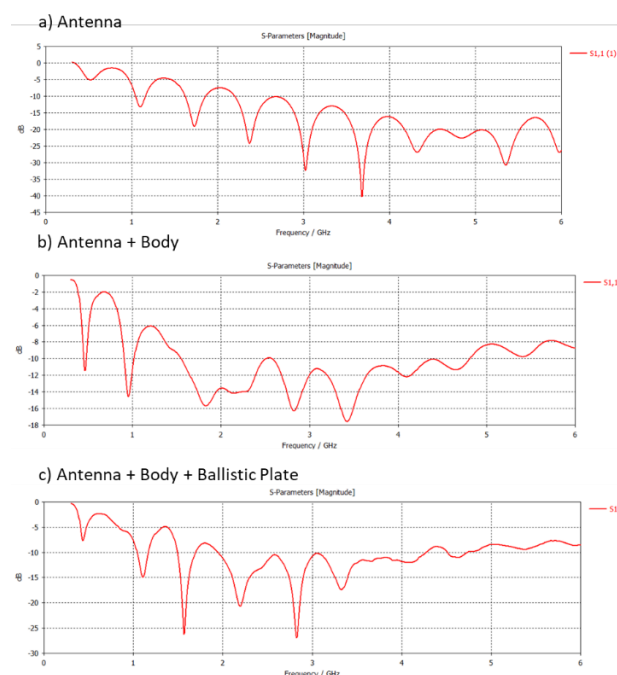


Figure 41- S-Parameters Study of the Antenna

4.1.1.1. Isolated Antenna

By analyzing Figure 41, the antenna in free space presents proper impedance matching above 2.2 GHz, thus covering the intended 2.4 GHz and 5.8 frequencies bands. Moreover, it resonates electronically at 400 MHz, although it fails to meet the -10 dB. Nevertheless, for the objective of the thesis, it enables drawing conclusions about the impact of the body, as will be shown in the next sub-section. Lastly, the antenna in these conditions does not present good matching at 900 MHz this will also change in the presence of the body, as seen ahead (antenna theory, 2011). This behavior can also be seen in 3D by Figure 42.

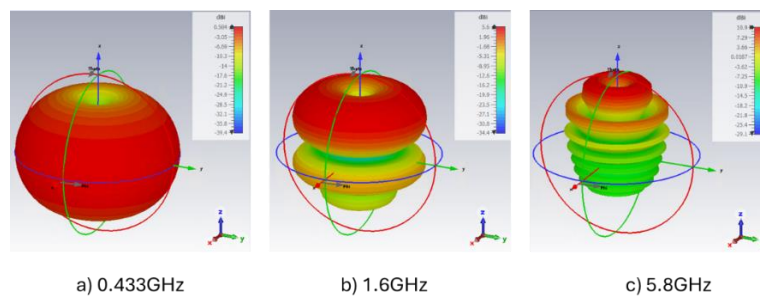


Figure 42- 3D Gain of Monopole Antenna in free-space at different frequencies.

4.1.1.2. Antenna and Human Body

Placing the antenna on the back of a human body can significantly affect the antenna's performance due to the absorption and reflection of electromagnetic waves. Human tissue, being conductive and possessing dielectric properties, can detune the antenna and affect its impedance matching (Chowdhury & Ali, 2016). The influence of the human body on the antenna's energy propagation is evident. However, lower frequencies showed a decrease in return loss, such as 0.433GHz, which went from -5 dB to -11 dB, and this is also seen at 0.868GHz. This is due to the longer wavelength with greater penetration capacity into material, in this case, human tissue, potentially absorbing this energy and altering the antenna's impedance (Afyfa, et al., 2016). The frequencies of 1.2GHz and 1.6GHz presented characteristics of relevant analysis: the first, in contact with the human body, behaved with a non-existent dip, dropping from -14 dB to -9 dB, and the second remained unchanged. Respectively, in the first case, the antenna was detuned, molding the electromagnetic environment at that frequency due

to the dielectric properties of the human body (antenna-theory, 2018). The second case is due to the antenna's design optimizing its performance for the 1.6GHz frequency, as it is the GPS signal. Higher frequencies all showed an increase in return loss due to the dielectric properties of the human body.

4.1.1.3. Antenna, Human Body and Ballistic Plate

The placement of the ballistic plate created an inverse process to that of the human body, increasing the return loss levels compared to the isolated antenna at lower frequencies, making the ballistic plate act like a barrier to these frequencies (Accuratus, 2013). This was not observed for 1.2GHz, 1.6GHz, and 2.4GHz, where these frequencies interact better with the ballistic plate properties, resulting in greater reflection of electromagnetic waves, providing more focused directivity and less disruption by the human body. Higher frequencies presented smaller dips, indicating worse impedance matching, thus lower efficiency, the opposite of what happens at the antenna's mid frequencies.

4.1.2. Efficiencies Analysis

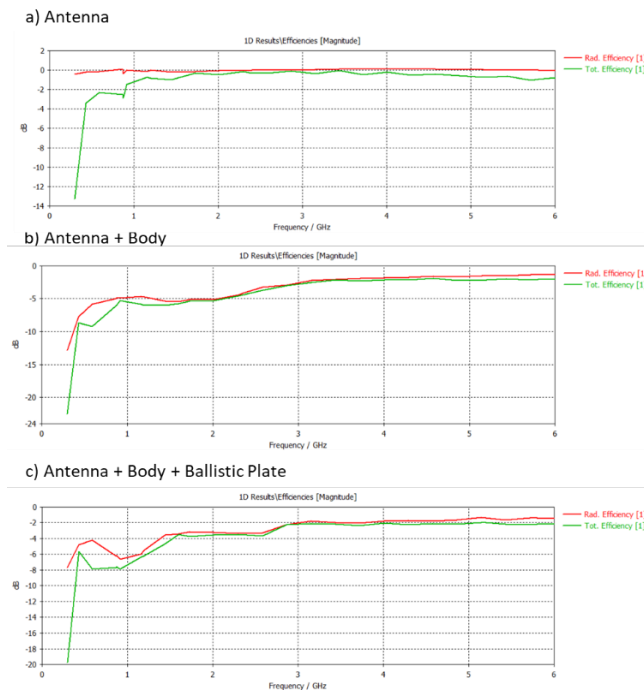


Figure 43- Efficiencies analysis.

4.1.2.1. Isolated Antenna

Figure 43 shows that the Isolated antenna has low total efficiency at the frequency of 0.433GHz. This is due to the longer wavelength that this frequency presents, which would require the antenna to be larger to maintain efficiency (Bancroft, 2004). Given its dimensions, a sizable portion of its energy is lost. However, an increase in efficiency is observed as the frequency increases, with values equal to or close to 0 dB. It is also demonstrated that the antenna is optimized for high frequencies, with a greater capacity to emit energy than to receive it, which meets the requirements for its operation.

4.1.2.2. Antenna and Human Body

When the antenna is placed on the back of the body, there is an overall decrease in the antenna's efficiency, with an average drop of -7.5 dB in total efficiency and -5.5 dB in radiated efficiency. There is a marked decrease at the frequency of 0.433GHz due to the presence of the human body, as human tissues can easily absorb low-frequency electromagnetic waves. The wavelength of 0.433GHz is approximately 69 cm, which is comparable to a human organ and can interact with frequency. At higher frequencies, the effect of the human body is smaller but noticeable, with little difference between total efficiency and radiated efficiency, indicating few losses but reduced emission capacity.

4.1.2.3. Antenna, Human Body and Ballistic Plate

With the ballistic plate in the equation, a considerable improvement in efficiency is observed, from a minimum of -23 dB to -19 dB. The influence of the ballistic plate, which mitigates the negative effects caused by the human body on the propagation of electromagnetic waves, is notable. The frequency of 0.433GHz continues to be the least efficient, with the greatest difference between radiated efficiency and total efficiency. At higher frequencies, the ballistic plate improves performance, such as at 1.2GHz. However, the performance remains negative compared to the isolated antenna.

In Appendix B- Efficiencies Analysis, a more detailed study of the average decrease in efficiencies in the three situations can be verified, identifying a greater average decrease in efficiencies with the ballistic plate. This is due to the high dielectric constant of aluminum oxide, which is the material of the ballistic plate. However, the ballistic plate can protect against electromagnetic absorption by the human body and reflect and redirect the antenna's energy for greater efficiency.

4.1.3. Fairfield Analysis

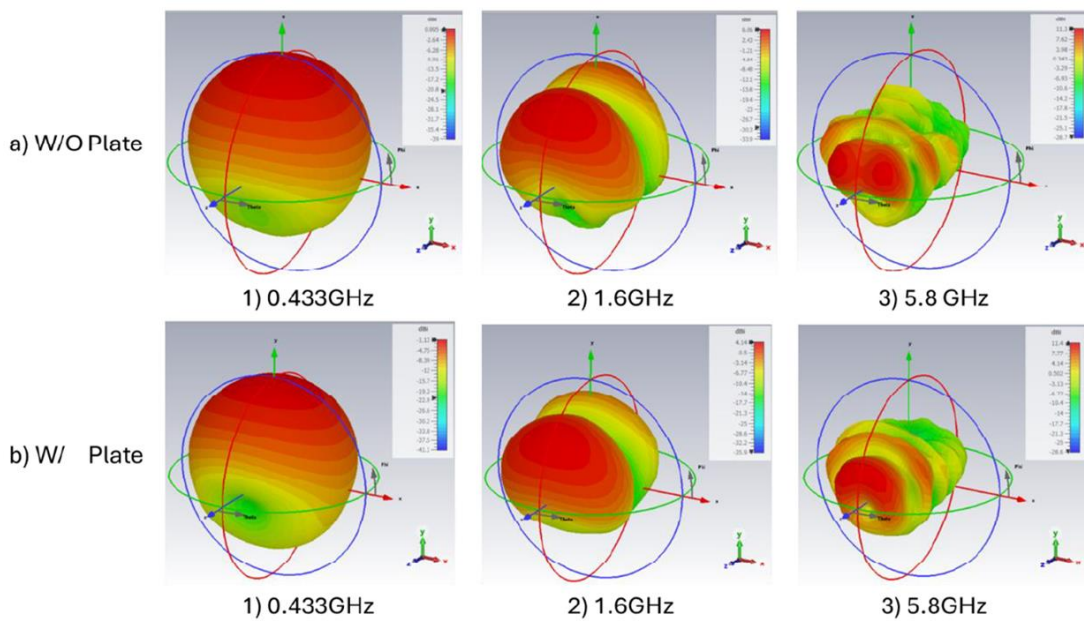


Figure 44- 3D Farfield analysis.

Three different frequencies, 0.433GHz, 1.6GHz, and 5.8GHz, were analyzed to understand the behavior of the antenna with or without ballistic plate in the simulation.

4.1.3.1. Analysis Without Ballistic Plate

Analyzing the frequencies in the absence of the ballistic plate reveals a pattern from the lower to higher frequencies. With the increase in frequency, there is an increase in directivity and gain due to the increased magnitude of the main lobe. The direction of the main lobe shifts to lower angles, the bandwidth decreases, and the side lobe is suppressed as the frequency increases. This is explained by the higher energy distribution focus characteristic of high frequencies, resulting in less interference caused

by side lobes. It was also noted the significative impact the human body had on the irradiated energy emitted by the antenna as seen in Figure 44, with a more noticeable impact as the frequency increases.

4.1.3.2. Analysis With Ballistic Plate

With the introduction of the ballistic plate, the standardized behaviors changed. There is an increase in the angular width at 0.433GHz, indicating a wider beam and a smaller side lobe, like the 5.8GHz frequency. However, this does not happen with 1.6GHz, where the main lobe is larger, the angular width decreases, and the side lobe increases. This is due to the dielectric components of aluminum oxide and the dimensions of the antenna, which favor the frequency. Overall, the introduction of the ballistic plate increased the angular width and side lobe level on average, decreasing the main lobe magnitude and main lobe direction. This demonstrates a negative effect on the antenna's focus and power and a positive effect on the beam and interference from side lobes.

The impact of the human body and the ballistic plate on the antenna's performance is evident, especially at higher frequencies, where signal deformation with diverse side lobes occurs. The body acts as a natural obstacle to electromagnetic radiation, as it absorbs and scatters energy. In fact, it is noticeable the increase in gain caused by the body, which, for the application in hands is helpful. However, therefore, the radiation in the opposite direction is negligible. In other words, the combatant should be aware of the very limited range, depending on the position of the PITBULL on the body. In the present setup, the antenna presents low gain in the negative direction of the Y axis.

4.1.4. Power Loss and SAR Analysis

Power Loss and SAR Analysis

Frequencies (GHz)	W/o Ballistic Plate		W/ Ballistic Plate	
	Power Loss (dB)	SAR (W/kg)	Power Loss (dB)	SAR (W/kg)
0.433	2.2	11.5	2.6	5.8
0.868	2.2	10.0	1.6	6.6
0.915	2.2	12.1	1.6	7.4
1.2	1.4	10.6	1.7	9.1
1.6	1.6	23.5	3.7	14.4
2.4	1.0	24.7	2.4	10.2
5.2	1.8	9.8	2.7	6.3
5.8	0.8	7.7	1.4	6.4

Table 15- Power Loss and SAR for simulation With and Without Ballistic Plate

By utilizing the New Field Monitors tool in the CST software, it was possible to calculate the energy absorption in the human body, with a maximum power transmitted by the system as 10W. This subsequently allowed the calculation of energy losses from the antenna during propagation in contact with the human body and the Specific Absorption Rate (SAR), which accounts for the absorption of the electric field by the body. Using CST, the energy losses with the human body and the SAR for situations of a combatant with and without a ballistic plate were determined. The results are shown in Table 15.

Several conclusions can be drawn about the effects of frequencies on the human body, with and without a ballistic plate, and the impact of the electrical properties of the ballistic plate and the human body on the absorption and reflection of radiated energy. Generally, SAR values decrease in the presence of the ballistic plate, indicating that it provides protection against electromagnetic energy exposure. There is a

noticeable decrease in SAR as frequency increases in both cases. This is because higher frequencies have shorter wavelengths, leading to more superficial absorption compared to longer wavelengths (EMF-Portal, 2024).

Power loss is greater with the ballistic plate at most frequencies, suggesting that the antenna operates more efficiently without it, as the plate absorbs or reflects some of the emitted energy. Abnormal behavior is observed at 1.6GHz, with the highest power loss occurring with the ballistic plate. This is explained by the interaction of the frequency with the aluminum oxide structure, reaching a resonance that maximizes absorption. Reducing the plate's thickness could decrease the power loss. A study carried out in Toulouse in controlled environment (Development, 2019), in an anechoic chamber, of the PITBULL WINGMAN, did come to the same conclusion as demonstrated above, 1.6GHz is the most dangerous frequency of the system as seen in Table 16, demanding some precautions to be adopted by the operator, as per example, safety distance.

Point	1	2	3	4	5	6	7	8	9	10	11	T	B	Max BS ⁽¹⁾
RMS electric field strength measured (V/m)	45	31	26	44	32	45	47	28	79 55 @ 2 cm	30	30	98 61 @ 5 cm 55 @ 7 cm	66 55 @ 5 cm	55
Maximal RMS electric field strength (V/m) (general public)	55													
Maximal RMS electric field strength (V/m) (occupational)	122													

Table 16- 1.6GHz Controlled Experiment of PITBULL WINGMAN⁴⁴

As seen in Table 16, PITBULL WINGMAN was tested in anechoic chamber for 1.6GHz frequency and power output of 2W. And it was concluded that it did not meet the criteria for protection from the public, only to be used for occupational purposes. However, the simulated experimentation realized in the present work was done for 10W maximum power output which does validate itself and the controlled experiment

⁴⁴ Table taken from (Development, 2019)

demonstrated above. The rest of the controlled experiment can be seen in

In the simulated experiment, it is also noted that without the ballistic plate, power loss is higher than with it at frequencies of 0.868GHz and 0.915GHz due to the dielectric properties of aluminum oxide. Detailed results are available in Appendix C- Power Loss and SAR Analysis.

4.1.4.1. Results

The study of antenna losses in the human body and the Specific Absorption Ratio (SAR) allows us to conclude the potential harm of the system to future military combatants. It is necessary to recognize the various energy absorption limits in the human body to understand if the energy emitted by the antenna meets the requirements. According to the International Commission on Non-Ionizing Radiation Protection (ICNIRP), the following limits are observed (International Commission on Non-Ionizing Radiation Protection, 2020), as shown in Table 17.

Basic restrictions for electromagnetic field exposure from 100 kHz to 300 GHz, for averaging intervals ≥ 6 min.

Exposure scenario	Frequency range	Local Head/Torso SAR (W/kg)
Occupational	100 kHz to 6 GHz	10
General public	100 kHz to 6 GHz	2

Table 17- ICNIRP Guidelines for SAR.⁴⁵

Considering the system's maximum power of 10W and Portuguese Marine Corps combatants as the public, the SAR limit for the local head and torso would be 2 W/kg. With or without the ballistic plate, all frequencies exceed this limit, however, the aluminum oxide ballistic plate helped to reduce SAR.

⁴⁵ Table taken from (International Commission on Non-Ionizing Radiation Protection, 2020)

4.1.5. Range Analysis

The study of range of the C-UAS is important since it is one of the most crucial factors of evaluating a C-UAS efficiency. The inclusion of the Human Body and the Ballistic plate may diminish the range of the countermeasures and, at last, make it less efficient. For that, the Friis equation was used to calculate its range for the three studied scenarios.

$$P_R = \frac{P_T G_T G_R \lambda^2}{(4\pi R)^2} \quad 4.1- \text{Friis Equation}$$

The Friis Equation shown in 4.1- Friis Equation considered the following:

- λ - Wavelength.
- f- Frequency. Which were the following: 0.433, 0.868, 0.915, 1.2, 1.6, 2.4, 5.2, 5.8 GHz.
- Pt- Power Transmitted. Which was considered 10 W, the maximum power transmitted of the system.
- Pr- Power Received (Power Sensitivity of drone). Which was considered according to the array of commercial UAVs available for the public.
- Gt- Gain of transmitting antenna. Which was calculated with simulation in CST Studio and included the effects of the Human Body and Ballistic Plate in the irradiated energy. Values available to see in Appendix E- Gain Analysis.
- Gr- Gain of receiving antenna. Which was considered according to the array of commercial UAVs available for the public.

With the variables defined, the Friis equation was then modified to be solved for range, which can be seen in 4.2- Range Equation:

$$R = \frac{\lambda}{4\pi R \sqrt{\frac{P_R}{P_T G_T G_R}}} \quad 4.2\text{- Range Equation}$$

It was possible, then, to calculate the range of the antenna, as shown in Table 18, considering the following values for the calculation:

- Power sensitivity as 0.1nW for frequencies up to 2GHz, 1nW for 2.4GHz, and 10nW for the remaining frequencies (antenna theory, 2015).

Frequencies (GHz)	Power Transmitted (W)	Power Sensitivity (nW)	Gain W/o Human Body and W/o Ballistic Plate (dB)	Gain W/ Human Body and W/o Ballistic Plate (dB)	Gain W/ Human Body and W/ Ballistic Plate (dB)	Wavelength (m)	Range W/o Human Body and W/o Ballistic Plate (km)	Range W/ Human Body and W/o Ballistic Plate (km)	Range W/o Human Body and W/ Ballistic Plate (km)
0.433	10	0.1	0.6	-1.0	1.8	0.7	18.9	15.7	21.7
0.868	10	0.1	3.5	3.2	0.9	0.3	11.3	10.9	8.4
0.915	10	0.1	3.6	3.4	0.3	0.3	11.4	11.2	7.8
1.2	10	0.1	4.1	3.8	3.8	0.3	12.1	11.7	11.7
1.6	10	0.1	5.1	4.1	6.1	0.2	9.1	8.0	10.2
2.4	10	1	7.1	6.4	7.0	0.1	1.8	1.6	1.8
5.2	10	10	10.3	10.4	11.6	0.1	0.8	0.8	1.0
5.8	10	10	11	11.4	12.0	0.1	0.8	0.9	1.0

Table 18- Antenna's Range Analysis.

It is evident that the range decreases with increasing frequency. This is explained by energy loss in free space and power loss (M.Mitofsky & University, 2024). The introduction of the human body also causes a decrease in range, which is further exacerbated at some frequencies with the insertion of the ballistic plate between the antenna and the body, as shown in Appendix F- Range Analysis. However, for all frequencies except 0.868GHz and 0.915GHz, a considerable increase in antenna range is observed with the ballistic plate. This is due to the dielectric components of the plate that have been previously considered and its protective capacity against interference. The range is considered reasonable, with a minimum of 800 meters for a frequency of 5.2 GHz, providing good protection for a combatant equipped with the AA100 antenna. Therefore, the range calculated is in accordance with what is expected from the PITBULL WINGMAN system, with the ballistic plate increasing its range as consequence from less energy absorption from the body. The calculation code for range can be found in

4.1.6. Jamming's Efficiency

It is also of interest for the study to understand the jamming efficiency that the simulated system presents, as the system's jamming capability is directly related to the protection of the combatant in neutralizing enemy or unauthorized UAVs.

Therefore, through the 4.3- Jammer's Equation, the jamming capability of the simulated antenna, approximated to the AA100 antenna of the PITBULL WINGMAN, will be tested, thus drawing conclusions about it.

$$J/S = ERP_j - ERP_s - L_j + L_s$$

4.3- Jammer's Equation

As verified in Figure 45, the efficiency of the jammer is determined by the jamming signal emitted and whether it is stronger than the UAV signal. Thus, jamming is a “battle” between signals, aiming to emit a stronger jamming signal and thereby disrupt the enemy UAV.

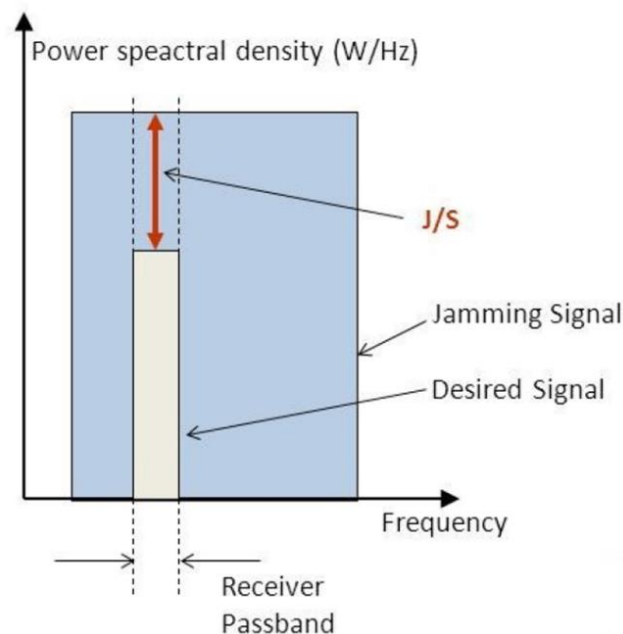


Figure 45- Jammer's Effectiveness⁴⁶

⁴⁶ Figure taken from (Nichols, Mumm, Lonstein, Ryan, & Carter, 2019)

Therefore, the variables are as follows:

- J/S - The Ratio of the Jammer power to the desired signal power at the input to the receiver being jammed in dB.
- ERP_j - The effective radiated power of the jammer (dBm).
- ERP_s - The effective radiated power of the desired signal transmitter (dBm).
- L_j - The propagation loss from jammer to receiver (dBi).
- L_s -The propagation loss from the desired signal transmitter (dBm).

Considering that the 4.4- ERP Equation is:

$$ERP = P_t + G_a \quad 4.4- \text{ERP Equation}$$

- P_t - Power transmitted.
- G_a - Gain of the antenna

Considering the presented variables adapted to the system under study:

- For 2.4Ghz.
- With Human body and without ballistic plate.
- Power Loss considered 1 dB.
- ERP for Jammer 8 watts, from data sheet.
- ERP for transmitter, 2W of Power transmitted and 5 dBi of gain.

So, it is concluded that 4.5- System's Effectiveness:

$$J/S = 39.03 \text{ dBm} - 38.04 \text{ dBm} - 0 + 1 \text{ dB} = \mathbf{2.96 \text{ dB}} \quad 4.5- \text{System's Effectiveness}$$

Which, regarding the 4.6- Efficiency Limits:

$$0 \text{ dB} < \text{Efficient Jammer} < 10 \text{ dB}$$

4.6- Efficiency Limits

Thus, it is concluded that the jammer under study is indeed efficient and respects the guidelines for an efficient jammer.

4.1.7. Depth of Radiation Penetration in the Human Body Analysis

By evaluating the electric field of the antenna coupled with the ballistic plate on the back of the human body and calculating the number of occasions where the energy reaches 37% of the value at the air/body boundary (Liu, Saw, & Kiang, 2010), it is possible to determine the number of penetration peaks in the human body. The electric fields of all frequencies were extracted along with their respective coordinates, and the magnitude was calculated and normalized so that the maximum value was considered 100%. Then, the electric field of each frequency was analyzed to obtain the number of values exceeding 37%, thereby identifying which frequency surpassed the barrier most often.

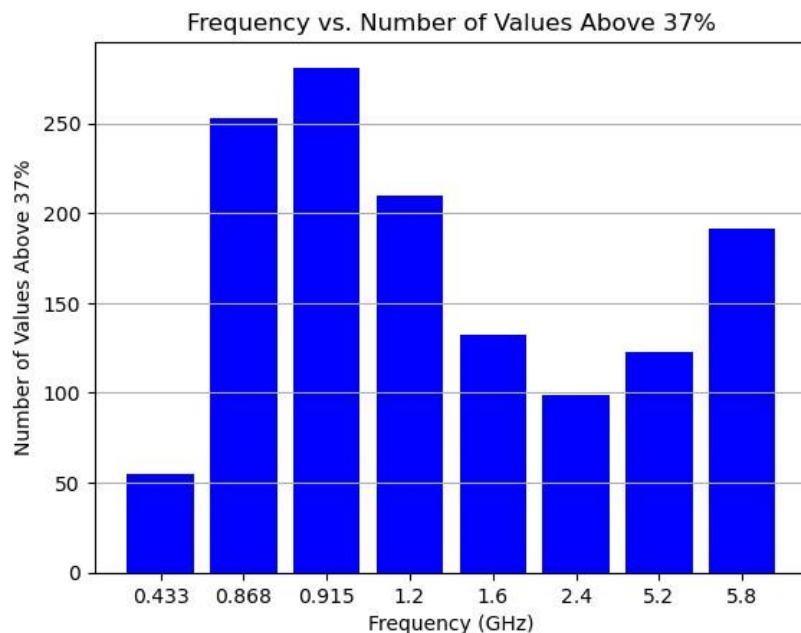


Figure 46- Number of Values above 37% for Every Frequency

Initially, the depth z at which the electric field exceeds 37% of the air/body

boundary was identified, determined to be 423mm. Each frequency was then normalized, and the values exceeding 37% were extracted, the code used for this process is found in Appendix H- Energy Depth Penetration Distance Calculation Code. The results are shown in Figure 46. And it is possible to see that the frequencies 0.868GHz and 0.915GHz are the frequencies which present more values that surpass the 37% barrier mark, due to their bigger wavelength and, therefore, deeper penetration.

It is also in interest to the study, to know the percentage of penetration values over 37% that each frequency demonstrated, as seen in Figure 47. It can be concluded that, as expected and previously demonstrated, the frequencies 0.868 GHz and 0.915 GHz have the most penetration values in the human body. However, these are not the frequencies with the highest penetration depth. The frequency 1.6 GHz, as previously proven, has the greatest penetration depth, with approximately 57%, followed by 1.2 GHz with 55%. Its calculation code can be found in Appendix I- Energy Depth Penetration Values Calculation Code.

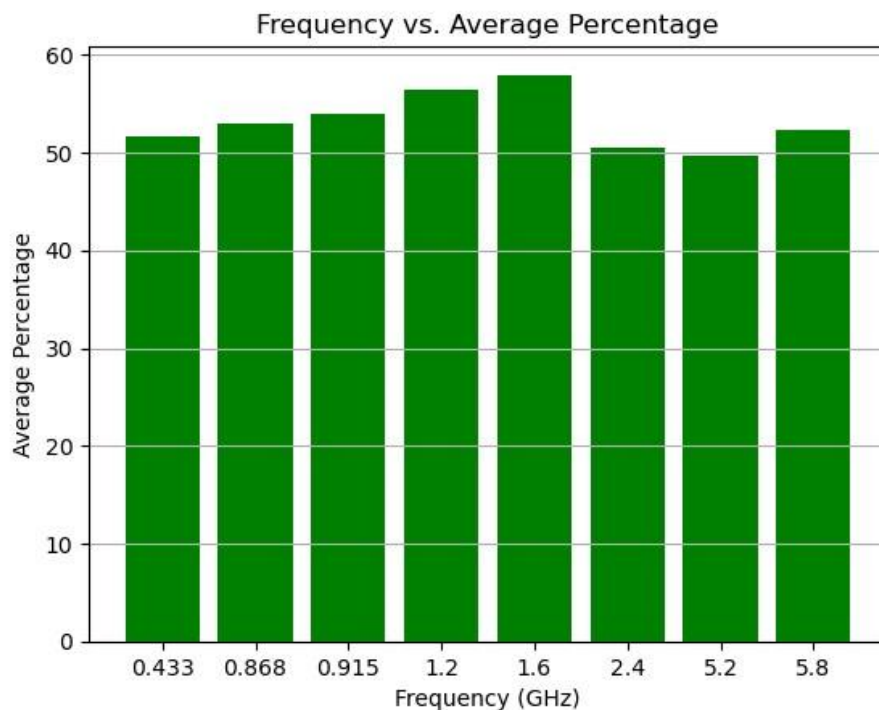


Figure 47- Average Percentage of Energy Depth Penetration for Every Frequency

4.2. Experimentation in Semi-Controlled Environment

In this chapter, the experimentation carried out in a semi-controlled environment of the two systems under analysis will be demonstrated: SWATTER and PITTBULL WINGMAN. The objective is to analyze their efficiency, range, accessibility, and capability to extract buried objects and make estimations regarding their employability and operational usage contexts.

As verified in Figure 23, an optimal C-UAS should possess the following functions of the C-UAS Cycle:

- Detection.
- Tracking.
- Identification.
- Decision.
- Mitigation.
- Report.
- Recover.
- Exploit.

Knowing that the systems under study are of a portable nature, they will not exhibit most of the functions represented above, however, they will be evaluated in that manner. In addition to the presented characteristics, the C-UAS should be analyzed according to the following operational requirements:

- Cost.
- Range.

- Accessibility.
- Durability.
- Capabilities.
- Weight.
- Combat Power.

With the operational requirements defined, it will be possible to begin the study and properly evaluate the systems in question.

4.2.1. PITBULL WINGMAN Semi-Controlled Experimentation

On February 21, 2024, an exercise was conducted to assess the readiness of combatants deployed to Lithuania, which included testing the C-UAS PITBULL WINGMAN. The exercise was organized and carried out by Lieutenant Brito Araújo. It took place at the Marine Corps facility, where the system's jamming capabilities were tested. The UAV used was DJI MAVIC 2.

The first test objective was to jam the RF signal of the UAV operator by blocking 2.4GHz frequency, making the UAV RTH. The second test objective was to forcefully land the enemy UAV by blocking the UAV GNSS signal through 1.6GHz, which was successful. It was found that the jammer, had detection capabilities, and when the UAV operator started the flight, the PITBULL WINGMAN would automatically alert its operator of an existing UAV in the area, and it would automatically perform jamming of the UAV Wi-Fi signal if the automatic mode was on, due to the 3 km range of the PITBULL WINGMAN system and its omnidirectional antennas. But it was tested, anyway, with the UAV on VLOS, and only started jamming when the C-UAS operator wanted, manually. The range tested of the jammer was a minimum 700 meters, with neutralization of enemy UAV. A summary of the tests can be seen in Table 19.

In conclusion, the system's efficiency and accessibility was noted, as it weighs a

total of 2kg, its intuitiveness, and optimal detection capabilities offering the system operator a SA of the Drone Warfare in the battlefield, using its directional and omnidirectional antennas. The jamming capabilities were also efficient. In Figure 48, the test conducted on the Marine Corps facility is shown, with the following military coordinates: C-UAS, 29SMC8785877871; UAV, 29SMC8814678107; UAV Operator, 29SMC8830578423.

	Results	Range (m)	Operational Altitude (m)	Drone Model
First Test	Jammed WiFi control signal at 2.4GHz, UAV initiated RTH	700	50	DJI MAVIC 2
Second Test	Jammed GNSS signal at 1.6GHz, UAV was forced to land on the spot	700	50	DJI MAVIC 2

Table 19- PITBULL WINGMAN Results



Figure 48- PITBULL WINGMAN Test

4.2.2. SWATTER Semi-Controlled Experimentation

The SWATTER system was tested in a semi-controlled environment at the Marine Corps facility on October 25, 2023, at the request of the Navy's Chief of Staff Gouveia e Melo. The objective was to verify the equipment's performance in neutralizing enemy or unknown UAVs (SWATTER, 2023).

Five different tests were conducted, each with varying ranges and distances, between the operator, UAV, and jammer for specific objectives, as it can be seen in Annex A- SWATTER Experimentation in Semi-Controlled Environment, different non-kinetic solutions for numerous UAV types were used.

The results found were that the SWATTER system has capability of UAV neutralization through Wi-Fi signal using 2.4GHz and 5.8GHz and the GNSS signal through 1.5GHz. With the jamming of Wi-Fi signal the UAV would proceed automatically to RTH, when GNSS signal suffered spoofing, it would be forced to land. The jamming was observed to range from 190 meters to 1.4 km. It was also tested the frequency hopping capabilities of UAVs to measure the effectiveness of the SWATTER system, when jamming, the UAV would change the frequency, resisting for 1 second, while the SWATTER would also change the frequency and subsequently jamming the UAV successfully.

	Results	Range (m)	Operational Altitude (m)	Drone Model
First Test	Jammed WiFi control signal at 2.4GHz, UAV initiated RTH	190	50	DJI MAVIC 2
Second Test	Jammed WiFi control signal at 2.4GHz, UAV switched to 5.2 GHz by Frequency Hopping	190	120	DJI Mini 2
Third Test	Jammed WiFi control signal at 5.2 GHz after Frequency Hopping	190	120	Autel EVO Nano Plus
Fourth Test	Spoofing of GNSS signals at 1.5 GHz, UAV landed on the spot pre-defined by spoofer	190	120	MAVIC Pro
Fifth Test	Jammed WiFi control signal at 2.4GHz, UAV initiated RTH, maximum range was tested	190	120	DJI MAVIC 2

Table 20- SWATTER Results

It was found that the system was more efficient when closer to the enemy UAV, and that the system can be modified to aggregate a larger band of frequencies to jam future enemy UAVs that use atypical frequencies not yet covered by the system, as per example 5.2GHz. In conclusion, it effectively disrupted unauthorized UAVs by blocking their RF and GNSS signals. A summary of the tests is seen in the Table 20.

4.2.3. Results

C-UAS Semi-Controlled Experimentation

Systems	Efficiency	Range (m)	Acessibility	Capacity	Capabilities	Weight (kg)	Combat Power
SWATTER	Jamming of control signals- RTH Spoofing of GNSS signal- Forced Landing on Pre-Defined Area	1480	Intuitive controls Not hands free	DJI MAVIC 2 DJI MINI 2 Autel EVO Nano Plus MAVIC PRO	Jamming Spoofing VLOS	6	Lower
PITBULL WINGMAN	Jamming of control signals- RTH Jamming of GNSS signal- Forced Landing on Sight	700	Complex controls Audio Assistant Hands Free	DJI MAVIC 2	Jamming Detection VLOS BVLOS	2	Higher

Table 21- Systems Comparison

As seen in the Table 21, the tests conducted on both systems were successful, with jamming and spoofing capabilities resulting in RTH (Return to Home) or forced landing by the UAV in sight or pre-position defined by spoofer. However, several comparisons can be made between the two systems, addressing various operational requirements and functions of the C-UAS Cycle.

- Regarding, firstly, the C-UAS Cycle, both systems do not possess the following functions: Tracking, identification, recover and exploit. Which means, the systems cannot autonomously follow the enemy UAV, nor identify its class and capabilities and autonomously recover and exploit after the neutralization. However, both systems represent mitigation functions, neutralizing the enemy UAV through jamming or spoofing. Moreover, the PITBULL WINGMAN system represents some important

functions that the SWATTER systems does not, which are: Detection, the WINGMAN searches for enemy UAVs in the range autonomously and if detected it Decides to neutralize it, Reporting to the operator through audio or lights its Detection and Mitigation. Therefore, the PITBULL WIGMAN system is a better C-UAS system overall.

- Analyzing the operational requirements selected before:
 - The PITBULL WINGMAN system is 100 000€ per unit, where SWATTER is around 15 000€, which is very important for acquiring new systems and evaluating its cost-effectiveness.
 - The range tested with the PITBULL WINGMAN system was 700 m where the SWATTER was 1480 m. Although the manufacturer states the PITBULL WINGMAN has 3 km of range, SWATTER may have more due to its directional antennas.
 - The SWATTER is a more accessible system who an operator can operate without much training. In contrast, the PITBULL WINGMAN system is more complex with several modes that can be difficult for an operator not trained or specialized in the system.
 - The SWATTER and PITBULL WINGMAN system are both robust, water-proof for military forces and defense purposes.
 - The SWATTER system has limitation which only works with VLOS, which means an operator must always have eyes-on-the-target during neutralization, which can be difficult for military operations in nighttime and maritime environments, against small and fast enemy UAVs. The PITBULL WINGMAN system works BVLOS and autonomously, therefore, the operator does not have to look for the enemy UAV or lose thought with it.

- The SWATTER system is exceptionally heavier than the PITBULL WINGMAN system, from 6 kg to 2kg, which can be a very complicated predicament for a combatant on the field.
- Lastly, the SWATTER system lowers the combat power of the operator, since it weighs 6kg and occupies the hands of the combatant, therefore losing the fire power to destroy the human enemy. In contrary, the PITBULL WINGMAN system increases the combat power of the operator, since the system only weighs 2kg and is body-carried, therefore, not occupying the combatant's hand and permitting destruction of the enemy with automatic rifle G3, and, at the same time, disrupting enemy's UAV communication.

4.3. Conclusions

With the study in a simulated and semi-controlled environment, the conclusions found were as follows:

- The use of the ballistic plate is recommended when using countermeasures as it considerably protects the combatant and increases the effectiveness of the antenna, as opposed to using the countermeasure without the plate.
- The PITBULL WINGMAN system is, in fact, an optimal system for the Portuguese Marine Corps, which aims for a "Light and Fast" Concept for light, fast, dismounted, and low-echelon forces. It is an effective system, corresponding to a large part of the necessary functions of a C-UAS, robust, effective, with a pertinent range and lightweight; however, it is extremely expensive and not very accessible.
- The SWATTER system is an effective, inexpensive, and accessible system, which justifies its lesser functional capabilities through Spoofing

capabilities that few systems on the market currently offer.

Therefore, it is concluded that, with the high employability of the PITBULL WINGMAN system in naval units, due to the lack of another electronic warfare system that allows protection against enemy or unauthorized UAVs, it should be employed in the Marine Corps for exercise and training. Thus, it is recommended to adopt a system like SWATTER, accessible and effective, that allows deployment in naval units for protection against UAVs, which a designated operator, without much specialization, can operate. In this way, the PITBULL WINGMAN system can be used for its intended purpose in the field, and in its absence, the SWATTER system can also be a solution for the marine forces.

5. Tactics, Techniques, and Procedures of Drone Warfare

*“The **Drone Warfare** employed in Ukraine has influenced the doctrine of military forces worldwide, and drones will be a standard part of warfare in the future.”*

Pete Morrison

The justification for implementing UAVs and their countermeasures in the Portuguese Marine Corps is sufficiently justified, however, more importantly, their implementation aligns with the new concept, known as the ““Light and Fast”” concept. This concept aims to combat the new hybrid, and asymmetric threats present in theaters of operations with new technologies through a “...light and flexible approach, prioritizing the element of surprise, information superiority, mobility, maneuverability, speed, and lethality, enhanced by new technologies...” (Brito, 2024). This way, the objectives defined for Employment and Doctrine will be satisfied in the present chapter as it is understood the need to implement the use of UAS for combat or reconnaissance of mobile, agile, low-level, special operations forces.

5.1. Operational Organization

Operational organization is one of the most important considerations of TTPs in the deployment of any system or method. The operational organization aims to model the tactical organization of forces of varied sizes and functions so that they can fulfill their tasks more effectively. Operational organization refers to “the cognitive approach by commanders and staffs supported by their skill, knowledge, experience, creativity, and judgement to develop strategies, campaigns, and operations to organize and employ military forces by integrating ends, ways and means.” (Joint Chiefs of Staff, 2011).

The study of operational organization in the deployment of UAS and C-UAS in armed forces such as those of Russia, Ukraine, Serbia, and the USA is intended to evaluate the current operational organization employed in the Portuguese Marine Corps, assessing whether it is the most efficient according to the new dynamics of Drone Warfare.

5.1.1. Ukrainian UAS and C-UAS Employment

The example of the application of UAS and C-UAS by Ukrainian forces in the current Ukrainian-Russian war is of extreme importance for analysis, as they have had real combat for implementation under extreme conditions. It has been observed that the use of UAS systems by the Ukrainians has provided a legitimate and considerable advantage in combat against Russian forces, allowing them to deliver strong blows to the enemy's rear through these systems (Halem, 2023).

It is observed that Ukrainian units work in parallel and coordinated manner between team levels, meaning that information acquisition and combat occur at a team level and at most a section level. However, analysis and targeting are done at the company and battalion levels (Halem, 2023). In this tactical working mode, there is much more fluidity and flexibility, with several ISR-T (Intelligence, Surveillance, Reconnaissance, and Targeting) teams deployed along the frontline, providing surgical information to the friendly battlefield's rear.

To combat enemy UAS, Ukrainian forces have created a 20km barrier with EW (Electronic Warfare) systems and air defenses. EW has proven to be the most efficient way to neutralize enemy UAVs (Reuters, 2024). Ukrainian forces use truck-mounted EW systems, mostly the American L3Harris mobile system, to perform a long air-defense barrier line in the face of Russia, protecting valuable assets, infantry units and equipment in the rear (Antoniuk, 2022). However, Russian forces present similar equipment, capable of disrupting Ukrainian's C-UAS. Therefore, Ukrainians are forced to use satellite disrupting measures, such as Elon Musk's Starlink, which avoids Russian cyber warfare⁴⁷ (Antoniuk, 2022).

The Ukrainian EW barrier has proven to be an asset of value, therefore, NATO has followed their steps with the future creation of a "Drone's Net" in the eastern flank, with the objective of deterring possible future drones attacks by Russia or China (Rogers

⁴⁷ Cyber Warfare is defined by "... a new form of warfare and represent an extension of the war from the demarcated battlefield into the boundless digital world." (Kestner, 2024)

D. J., 2023). In the words of Vilnius Interior Minister Agnė Bilotaitė, “This is a completely new thing—a drone border from Norway to Poland, the purpose of which would be to protect our border with the help of drones and other technologies.” (Cook, 2024).

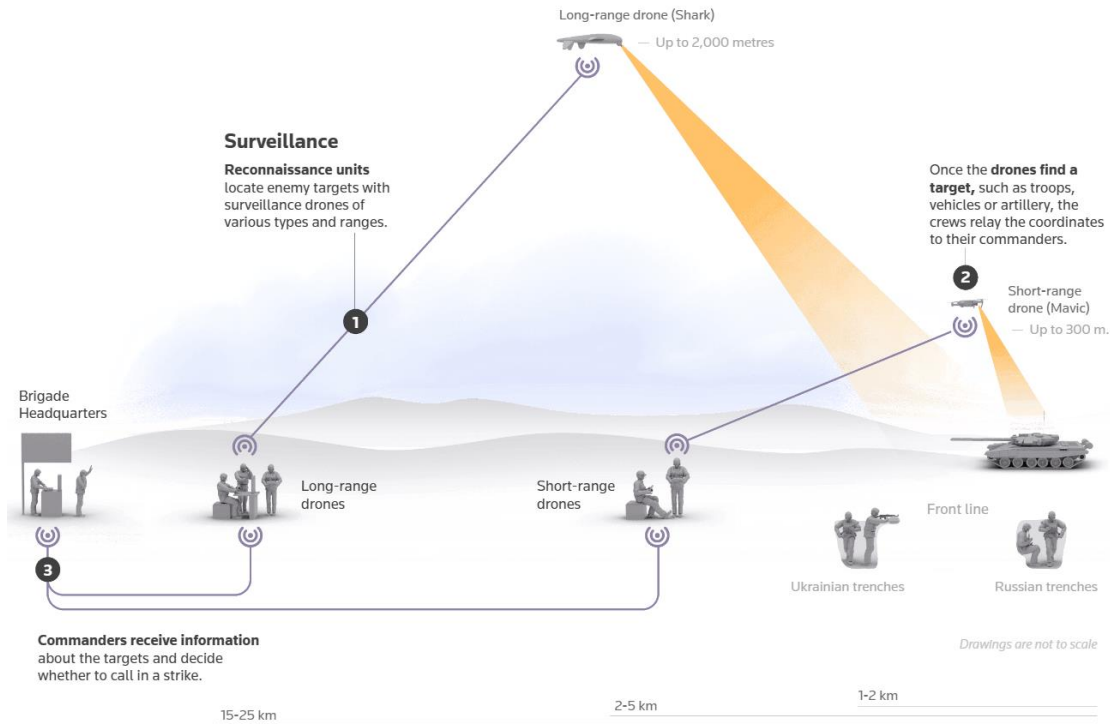


Figure 49- Ukrainian's Chain of Command and Operational Organization.⁴⁸

Reuters, a renowned international news agency, has performed a study on operational organization and TTPs developed by the Ukrainian soldiers in the current conflict (Reuters, 2024). As it can be seen in Figure 49. Reuters concluded that every brigade, around 5500 combatants in total, has an assault UAV company, around 120 men, dedicated to Drone Warfare, with most of these units using small commercial UAVs. They defined that the operational employment of these UAVs would follow three steps:

- Employment of long-range UAVs, NATO Class III MALE with high-resolution cameras and sensors to conduct ISR-T.
- Acquisition of targets, whose coordinates are sent to higher echelons and

⁴⁸ Figure taken from (Reuters, 2024)

eyes on target are maintained.

- Reception of information by the brigade headquarters and a decision is made to neutralize the target.

After the decision-making process, the target can be destroyed by UAVs or by artillery, leaving the UAVs to perform a reconnaissance and shot correction and kill confirmation duty.

Ukrainian units utilize FPV UAVs in teams of 4 men composed of a Scout, specialized in reconnaissance missions, UAV operator, navigator, who specializes in land and aerial navigation, and gimbal operator, who coordinates the sensor, batteries and information received by the UAV. Currently, experienced UAV operators are the most valuable force in the conflict (Halem, 2023). At a higher operational level, UAVs have been provided to military operational commanders in strategic positions as the SA significantly improves with aerial vision, reducing decision-making time (Roblin, 2023). However, these UAS would be for brigade, regiment, or battalion levels, using fixed-wing UAVs with greater range and flight time capabilities.

The difficulties felt by the Ukrainian forces still have much to reveal and changes to be had. President Volodymyr Zelenskiy on February 6, 2024, called for the creation of a separate branch of the Ukrainian armed forces dedicated to UAVs and their countermeasures (Reuters, 2024). Which became a reality on June 12 of this year. Becoming the first, but not last, country to create a new armed forces branch dedicated to uncrewed systems, called Uncrewed Systems Forces (Spray, 2024). The decision to form this branch was well received by the Ukrainian Defense Council and leaders within the Ukrainian armed forces, to produce one million UAVs this year, currently producing tens of thousands every month (Reuters, 2023).

In conclusion, there is a need to deploy them at the section or team level, with dedicated elements for countermeasures, UAV operators, and navigation. It also underscores the importance of employing these capabilities for leaders and decision-makers to enhance their situational awareness for better decision-making. Finally, there

is a need to evaluate the necessity of creating a separate branch or unit dedicated to the operation and destruction of UAS.

5.1.2. Russian UAS and C-UAS Employment

Russian forces initially faced some difficulties in adapting to the new dynamics of Drone warfare. They began the war with the expectation of a shorter duration but soon realized that more effort was needed than anticipated (Kunertova, 2023). The use of UAS in conflict initially emerged with the use of typically NATO Class II and above. It was only later that Russian forces began to utilize DIY FPV UAVs for combat and ISR purposes, adopting a similar approach to the Ukrainians as seen in Figure 50. These UAVs were equipped with intelligence fusion capabilities to transmit data to the rear lines for analysis and decision-making (Edmond & Bendett, 2023).

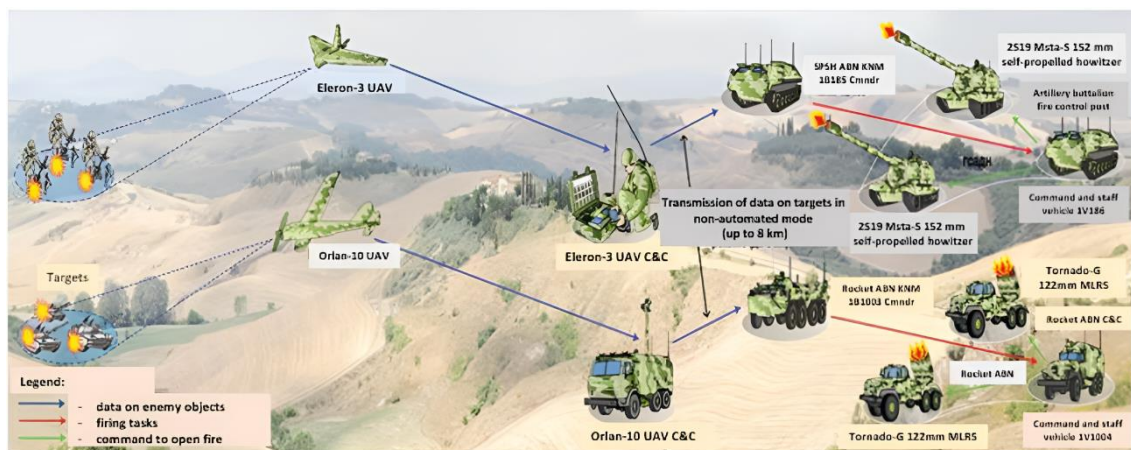


Figure 50- Russia's Chain of Command and Operational Organization⁴⁹

Until February 2022, before the conflict in Ukraine, the Russian military organized its UAS forces into companies, divided into platoons of equal size and UAV range, which facilitated C2 (command and control). This means that UAS and C-UAS forces were present throughout the military structure, including in armored vehicles, reconnaissance units, and even naval forces (Edmond & Bendett, 2023). It is believed that the Russian forces had approximately 2000 UAVs in their arsenal, which would represent one of the

⁴⁹ Figure taken from (Edmond & Bendett, 2023).

largest deployments of UAS in a military force in the world.

However, with the evolution of Drone Warfare and the need for quicker response times and decision-making, there was a necessity to adopt FPV UAVs and quadcopters, which were utilized at the battalion level or below (Edmond & Bendett, 2023). Samuel Bendett, an adviser for the Center of Naval Analysis and Center for New American Strategy, argues that these means should be integrated into combat and structured within the standard operational organization of the Russian forces.

The estimated operational organization of Russian forces is comparable to that of the Ukrainians, with at least three commercial drones at the team level, belonging to UAV reconnaissance squadrons integrated into air and mechanized brigades (Luzin, 2023). However, Russian forces face communication and flexibility challenges due to bureaucratic hurdles in training, utilization, and acquisition of these systems, creating disadvantages compared to Ukrainian forces. The lack of a defined and applied command and control structure between the operational and tactical levels, as seen in Ukrainian forces, is absent in the Russian case. This forces teams to act autonomously, giving operational decision-making authority to the tactical level, specifically to the team leader.

5.1.3. Serbian UAS and C-UAS Employment

To study UAS employment in Serbia is of interest due to their long influence by the soviet federation and by being a relevant actor in the “drones’ race”. The Serbian armed forces quickly identified the need to implement UAS and C-UAS in their operational organization and to formulate TTPs to address Drone Warfare. They recognized the tactical threat that these systems pose in armed conflicts, especially those that can be operated by a single individual and understood that a squad of shooters is capable of operating NATO Class I UAVs and their countermeasures (Žnidaršič & Radovanović, 2020).

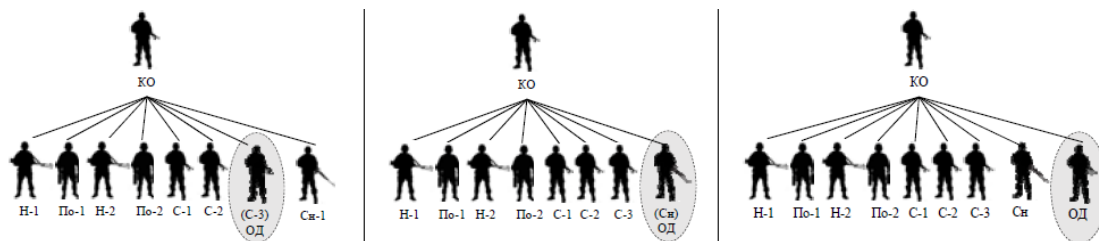


Figure 51- Models of the implemented UAV and counter-UAV operator duty in the rifle section organization.⁵⁰

In Figure 51, different modalities for the deployment of the UAV operator and countermeasures operator are observed. The first model, on the left, shows a member belonging to the section, an ordinary rifleman that would accumulate functions as UAV operator. The second model also depicts a member belonging to the section, this time, a designated rifleman, benefiting from the detachment from the battlefield and the equipment they typically carry. Lastly, there is an additional member outside the section, a UAV, and countermeasures specialist, totaling a 10 men section.

Among the options presented above, the first and third are the most appreciated. In the first option, a rifleman belonging to the section, without any leadership function but solely as an assistant, could serve the section leader in a team of three elements. This would allow the section leader to have situational awareness and control over the UAV's objectives. However, this would require another team to lose a member in their action, and the section leader would have an additional responsibility.

The third option seems to be the most efficient, despite adding one more man to the section. This change would necessitate modifications in the section's tactical action, including its efficiency, formations, and functioning. However, it would not cause organizational disruption and could, in parallel with the section leader, provide coverage, ISR, and increase combat power to the section.

Serbian Armed Forces show, again, that the use of UAV systems should remain in a low echelon, in this case, section level. It is recommended the addition of specialist on Drone Warfare to an already 9 man nominal section formation, becoming a 10 man

⁵⁰ Figure taken from (Žnidaršič & Radovanović, 2020)

section with various capabilities that could be divided in two teams of four and section leader assisted by a Drone Warfare operator for combat, reconnaissance and awareness capabilities, as recommended in Figure 52.

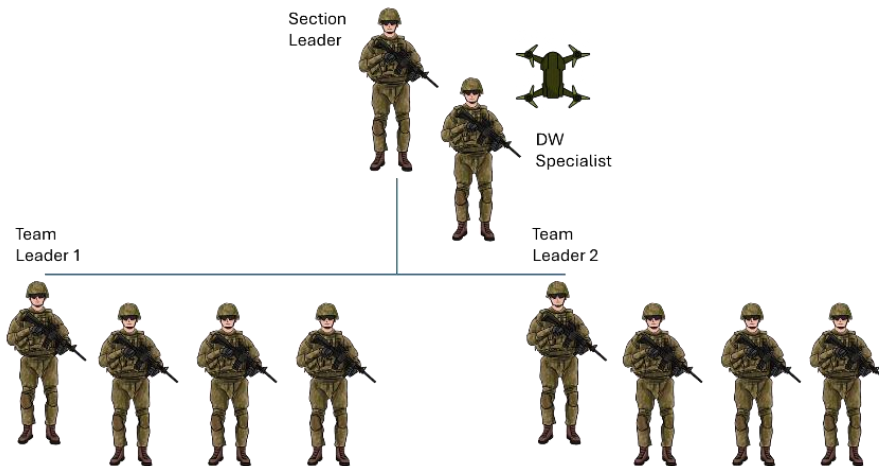


Figure 52- Recommended Serbian Operational Organization

5.1.4. United States of America UAS and C-UAS Employment

The United States Armed Forces were the first to use UAS and C-UAS and understand their potential, especially in counterterrorism actions. What was initially used for ISR operations at the operational and strategic level, such as the MQ-9A Reaper, has evolved towards surgical actions using increasingly smaller UAVs like the RQ-11 Raven. The US military quickly realized the potential of these assets in combat in places like Syria and Mosul, where extremist groups were using commercial UAVs to gain an advantage, (Gusterson, 2016). Therefore, the US Army recognized the need to develop its Drone Warfare capabilities, which remain relevant today.

Currently, there is a need for each force to have at least two quadcopters per platoon in addition to the existing RQ-11 Raven, (Broman, 2018). As it is argued that the quadcopter UAV has considerable advantages over most fixed-wings UAVs available in the market today. A quadcopter has greater agility, hovers in stationary flight, and enters tight and heavily protected areas such as urban or wilderness areas, all at a general low price. The robustness of a quadcopter is higher, and highly modifiable, with a bigger range of applicable sensors and cameras. The efficiency of these UAVs has been

constantly reported to be advantageous, in urban warfare (Hussaini, 2024) .

In February 2018, the Navy and Marine Corps Small Tactical Unmanned Aircraft Systems Office ordered 800 InstantEye quadcopters, four years before the conflict in Ukraine, to integrate them into the operational organization of sniper teams (Broman, 2018). For their use, units with two or three men per platoon are required, trained specifically as UAV operators and countermeasures operators, as done in Ukraine and one of the variants in Serbia. Each platoon should be equipped with two quadcopter UAV, however, each UAV should be of the responsibility of the platoon commander to make better use of mission command⁵¹ (Broman, 2018).

5.1.5. Israel UAS and C-UAS Employment

Israel is a country of high interest in the study of Drone Warfare and the employment of UAVs and countermeasures, as it is on par with the United States of America in the “drones’ race”. This position was demonstrated in the conflict with Gaza after the attack of October 7, 2023.

This conflict is different in several environmental aspects, such as the various surrounding tunnels in the combat zone, its high urbanization, and enemy infrastructure, which led to a different application of UAVs on the battlefield (Frantzman, 2024). Like the Russian forces, Israel applies Drone Warfare units in mechanized brigades, however it is employed liaison officers who assist in the communication between chiefs, commanders and the drone units (Frantzman, 2024). Liaison officers offer better coordination and integration of Drone Warfare units into nominal brigades, thus maximizing the effectiveness of these units.

The Israeli Defense Forces (IDF) have a unique operational organization for their drone units. The drones used by the ground forces are smaller and easier to operate, with the main functions of reconnaissance, such as NATO Class I drones (Reuters, 2022).

⁵¹ Mission Command “is the exercise of authority and direction by the commander’s intent to empower agile and adaptive leaders in the conduct of Unified Land Operations.” (Deployable Training Division Joint Staff J7, 2020)

However, the drones of the air force are larger and more complex, reaching NATO Class II and III, being more strategic with a longer range (Bob, 2023). Drones such as Heron 900, Heron TP, and Hermes 450 are some examples of Israeli drones that perform these capabilities, as well as engage enemy drones (Borg, 2021). The teams operating these drones consist of an operator and a commander, each with a 6-month specialization course.

In conclusion, the IDF presents an operational organization quite different from the one currently used in the other armed forces. It has similarities in the use of NATO Class I drones for lower echelons and Class II and III for higher echelons, but the teams are composed of only two elements and operate in parallel with air force brigades and in integrated coordination with mechanized brigades through liaison officers, as can be observed in Figure 53.

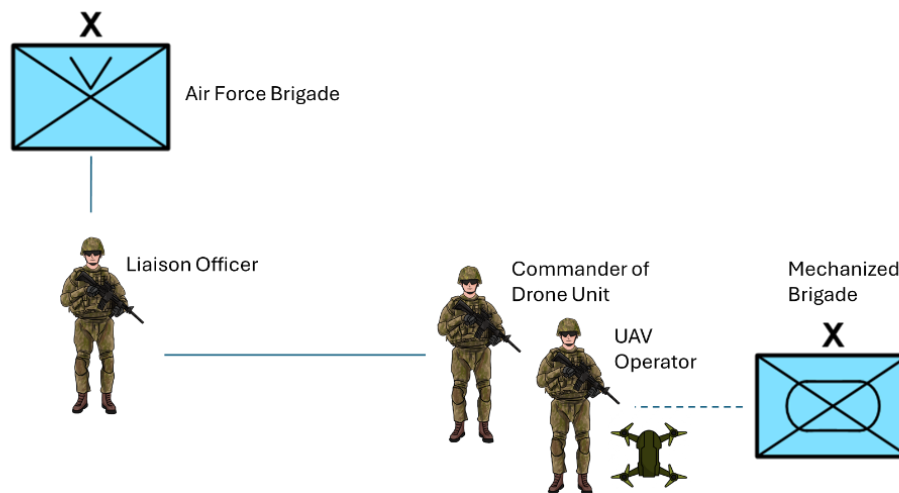


Figure 53- IDF Operational Organization

5.2. Portuguese UAS and C-UAS Recommendations

Types of Drone Warfare Operational Organizations

Ukraine	Russia	Servia	USA	Israel
ISR Unit with NATO Class II+ UAV.	Mobile command posts.			
Employment of Drone Warfare specialized units integrated in battalions, with NATO Class I UAVs.	Employment of Drone Warfare specialized units integrated in battalions, with NATO Class I Small UAVs	Each nominal section of a platoon employs a Drone Warfare specialist with countermeasures and NATO Class I UAV.	Each section of a platoon employs a reconnaissance NATO Class I UAV.	Each Drone Unit is consisted of two operators with NATO Class I or II UAVs.
Orders from Battalion commander.	Orders from Battalion commander.			Unit works in parallel with the brigade. Orders come through Liaison Officer from Air Force.
Mobile countermeasures as an air defense barrier in frontline.	Mobile countermeasures for ground forces and command posts.			

Figure 54- Types of Drone Warfare Operational Organization

With the study of different operational organizations for Drone Warfare adopted by foreign countries, as seen in Figure 54, it is possible to evaluate and recommend an operational organization of Drone Warfare for the Portuguese Marine Corps.

Despite the “Light and Fast” Concept being recent and lacking in doctrine and still in the experimental and testing phase, it is possible to have an operational organization designed for it with the inclusion of forces dedicated to Drone Warfare. In the new concept, the UAV operators and their countermeasures are referred to as SANT (*Sistemas Aéreos Não Tripulados*, uncrewed aerial systems) belonging to the UAC. The Portuguese Marine Corps will be divided into two Units, UPF and UAC, the former divided in three detachments and the later in one. It is envisaged that each marine detachment in the UPF will have three Combat Groups, each of them with an ISR team consisting of two UAS elements, one NW (Networking Warfare⁵²) element, and one Reconnaissance element (Alves C. F., 2023). In this way, each detachment would have a

⁵² Networking Warfare or Network-Centric Warfare is “a military doctrine or war theory that seeks to translate an information advantage, enabled in part by information technology, into a competitive advantage through the robust computer networking of well geographically informed dispersed forces.” (Demirci, 2021)

total of 97 men, including the chief's staff, each Combat Group 31 men, of which 4 men are allocated for reconnaissance, with one UAV operator and one C-UAS operator, as shown in the Table 22.

	GRUPO DE COMBATE 02 (31PAX)			
	Nº	CAT	FUNÇÃO	OBS.
ELEMENTO DE COMBATE 01	01	OFICIAL	CO GC02	
	02	SARGENTO	CO ELCOMB 01	
	03	PRAÇA	ATIRADOR/MANOBRAS	
	04	PRAÇA	ATIRADOR/MANOBRAS	
	05	PRAÇA	ATIRADOR/MANOBRAS	
	06	PRAÇA	ATIRADOR/MANOBRAS	TC3
	07	PRAÇA	ATIRADOR/MANOBRAS	
	08	PRAÇA	ATIRADOR/MANOBRAS	
	09	PRAÇA	ATIRADOR/MANOBRAS	
	10	PRAÇA	MORTEIROS	
	11	PRAÇA	MORTEIROS	
	12	SARGENTO	ACAR	Pode ser Oficial
	13	PRAÇA	ACAR	CG 84 MM
	14	PRAÇA	ATIRADOR ESPECIAL	
ELEMENTO DE COMBATE 02	16	SARGENTO	CO ELCOMB 02	
	17	PRAÇA	ATIRADOR/MANOBRAS	
	18	PRAÇA	ATIRADOR/MANOBRAS	
	19	PRAÇA	ATIRADOR/MANOBRAS	
	20	PRAÇA	ATIRADOR/MANOBRAS	TC3
	21	PRAÇA	ATIRADOR/MANOBRAS	
	22	PRAÇA	ATIRADOR/MANOBRAS	
	23	PRAÇA	ATIRADOR/MANOBRAS	
	24	PRAÇA	MORTEIROS	
	25	PRAÇA	MORTEIROS	
	26	PRAÇA	ACAR	CG 84 MM
	27	PRAÇA	ACAR	
	28	PRAÇA	ATIRADOR ESPECIAL	
APOIO EL.COMB. (ISR)	29	PRAÇA	SANT	
	30	PRAÇA	SANT	
	31	PRAÇA	NETWORKING WARFARE	
	32	PRAÇA	RECON	

Table 22- Combat Group, “Light and Fast” Concept. ⁵³

According to the Operational Organization of the concept “Light and Fast”, the

⁵³ Table taken from (Alves C. J., 2023)

considerations are as follows:

- The employment of a UAV and C-UAS specialized unit is necessary, but in alignment with the “Light and Fast” concept. Therefore, a formulation of a company-level unit is unnecessary and impractical. A Combat Group of 31 men seems to be optimal for UAV employment.
- The current use of two specialist elements for operating and neutralizing UAVs aligns with all current changes and updates in foreign operational organizations. It is much more useful and efficient to use specialized SANT elements in the field than individuals with multiple roles.
- The utilization of only two SANT elements in the operational organization of a combat group, in nominal terms like a platoon, aligns with what is implemented in the armed forces of USA and Israel, where two UAS per platoon are used. However, Russia, Ukraine, and Serbia agree that using only two UAS per platoon is insufficient for ISR, combat, and the SA of the Combat Group or Element leader. Ukraine employs independent UAS teams with 4 elements, including a dedicated navigator and elements for UAV operation and neutralization, which is not observed here. Russia, unlike Ukraine, does not separate UAV teams from the rest of its forces, but applies dedicated elements with a larger number of personnel, with a minimum of 3 UAS per team. For Portugal, it would be a total of 12 UAS per combat element. Serbia aligns with Russia, keeping UAS elements integrated with combat elements, however, they consider 1 UAS per section of 9 men sufficient. Which would result, for the Portuguese Marine Corps, in 2 UAS per combat element.
- The use of UAV and C-UAS means should also be addressed. The USA and Serbian forces show interest in Quadcopters, as does Ukraine with a DIY aspect. However, one should not overlook the capability of NATO Class II or III MALE fixed-wing UAVs for more critical ISR situations at the

company and battalion levels, which quadcopter UAVs cannot satisfy.

- The ISR Unit must work solo and in coordination with the Combat Group. This ISR unit would employ larger and higher NATO Class UAVs for reconnaissance and target destruction verification. This unit would work directly with the higher command and in coordination with the combat group.
- The employment of EW mobile systems, such as used in Ukraine and envisaged by the NATO Council, is also recommended, in order to have an electromagnetic wall to secure a line where enemy forces cannot physically or “cyberly” surpass.

In conclusion, the current Portuguese Marine Corps operational organization shows certain advantages and disadvantages that require modification and are subject to some recommendations. Currently, the application of dedicated and specialist elements to Drone Warfare in the operational organization of a Combat Group is necessary. However, having only two elements in a group of 31 men is insufficient, as it would mean 1 UAV per combat element consisting of 14 men, meaning that the UAV would only accompany the element leader and no section leader would have SA control over the UAS, as you can see in Figure 55 .

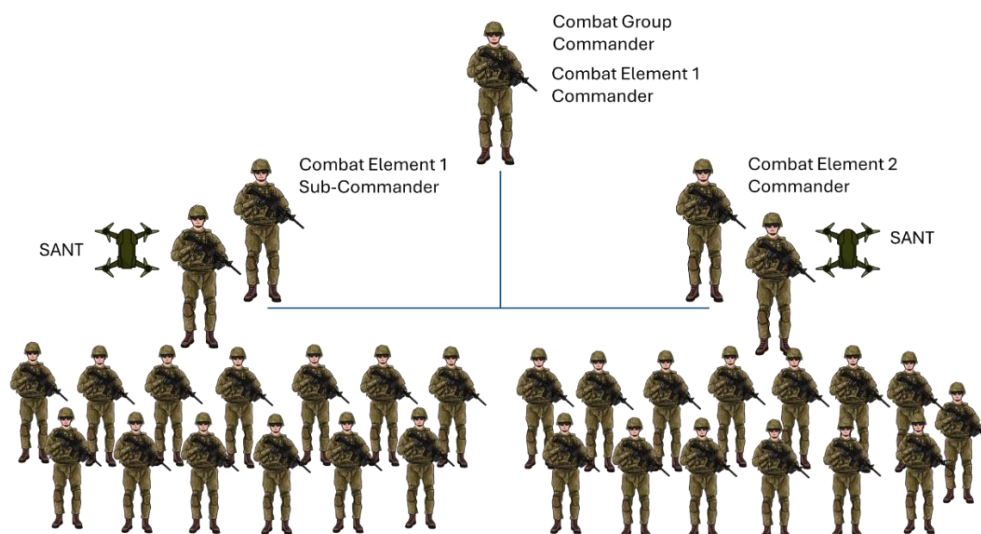


Figure 55- Combat Group “Light and Fast” Operational Organization

This problem also persists in defense against UAVs: if defense is only provided for 14 men at most, there will be a decentralization problem, meaning the element leader cannot divide his element into sections as he will not have C-UAS protection in one of the sections. It is recommended to employ two additional UAS and C-UAS elements to align with Serbian and American doctrine to have one UAV and C-UAS per section of 10 elements with the SANT element integrated. This way, all section leaders will have improvements in SA in their tactical actions. For the Combat Group leader and higher-ranking elements, a flexible and parallel strategy should be used to coordinate with their sections and the higher echelon, which will use higher-class UAS, as you can see in Figure 56. Finally, the UAVs used by the SANT element should be Quadcopters, as they have the best agility, while the higher echelon should use, Class III MALE (Medium Altitude Long Endurance) or Class II UAV, for medium-range ISR capabilities.

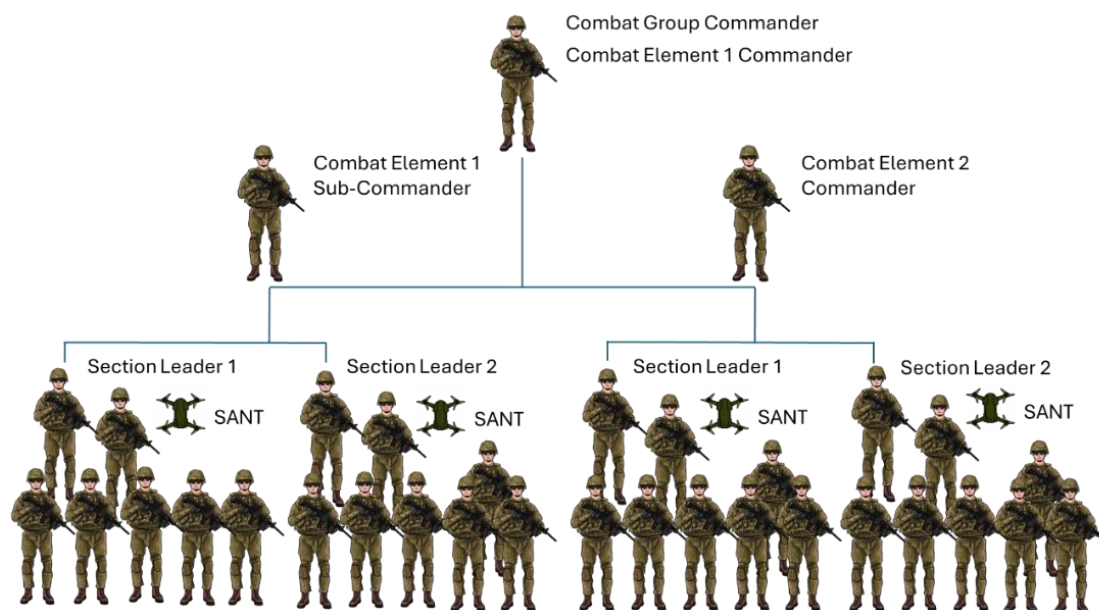


Figure 56- Recommended Operational Organization

Equipping and employing only NATO Class I UAVs is a disadvantage since they are limited in range and capabilities, therefore, a differentiated unit that works directly to the operational command and in coordination with the Combat Group is needed. As seen previously in the Ukraine Forces, in Figure 49, it is employed a unit separate to the main effort that uses larger UAVs with longer ranges for target identification and

reconnaissance of the battlefield. Therefore, in Figure 57, is presented a possible Unit that would work in coordination with the Combat Group constituted by four elements.

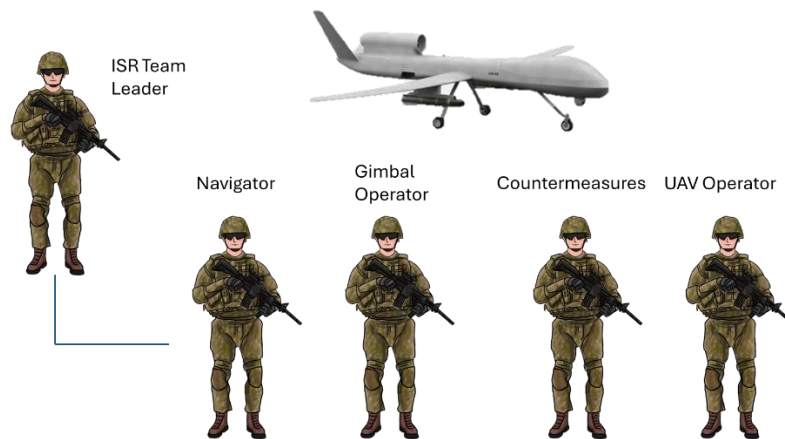


Figure 57- Recommended ISR Unit

5.3. Training

Ukraine can be seen as an example of training UAV operators, as they were forced to train more than 10,000 UAV operators per year during their conflict (Kullab, 2023), wanting to spend over 1 billion euros on UAV efforts. In addition, Ukraine, developed during the conflict period, a drone piloting training center called "Dronarium" with courses ranging from 12 to 42 hours for numerous purposes (Dronarium Academy, 2023), having already trained 7000 graduates, both civilians and military personnel. In addition to this effort, several civilian drone enthusiasts joined the war effort, some of whom became part of their training cadre.

The Russian forces, despite seeking more specialized means such as NATO Class II UAVs, realized their significant disadvantage due to the lack of quadcopters in their platoons, which led to the establishment of the first commercial UAV training facility in Donetsk, in May 2022 (Chávez, 2023).

Like Russia, China has sought to update itself with the difficulties demonstrated in the conflict in Ukraine by also developing its training program for UAV operators and

countermeasures. It was observed in the training of the Chinese armed forces a focus on FPV UAVs with TTPs like those used in the Russia-Ukraine war. Their training would include various obstacles that UAVs should pass through with immense speed and agility to accustom operators to the adversities of the urban environment. Another training exercise would involve hitting pre-designated moving targets to simulate the impact of kamikaze UAVs (Satam, 2024). With these new procedures, and as studied in the previous chapter, specialization in UAV control and its countermeasures seems interesting and feasible.

Following the possible specialization of military personnel in UAV operations, the US seeks to establish a branch of the armed forces dedicated to UAVs, as envisaged in the Ukrainian armed forces. In January 2024 the US Navy created a new unit, Task Group 59.1, commonly known as “The Pioneers” with the main focus of “the operational deployment of unmanned systems teamed with manned operators to bolster maritime security across the Middle East Region.” (The Maritime Executive, 2024). The US military demonstrates the need to train professional soldiers in UAV operations to create its branch that would be linked to land, sea, air and space, each with its own systems (Solano, 2024). The need for experts in machine learning, mechanics, and operators is evident. To address this need, the US forces have incorporated UAVs into their training for ammunition delivery and security purposes. Additionally, they have opened a school for training UAV operators and C-UAS at Fort Sill, Oklahoma (Saballa, US Army opens Drone Fighting School, 2023), the goal is to train up to 1000 men per year. Plans include the utilization of virtual, augmented, mixed, and extended reality for Drone Warfare training, such as the VBS 3 (Virtual Battle System 3) used by NATO forces to train their personnel (Antal J. , How to Train for the Coming Drone Wars, 2022).

Portugal, however, finds itself alongside the United States of America, in the “drones race” with the creation of Unit X31 on March 27, 2023, created a year before “The Pioneers”, which aims at managing SANT (*Sistemas Aéreos Não Tripulados*, uncrewed aerial systems), specialized training of fighters, and formulation of doctrine for the use of these assets in future missions, offering support to aerial, maritime, and

land domains (X31, 2024) , just like the new branch created by Ukrainian forces and the unit envisioned by the North American forces.

The X31 unit is the unit of the Portuguese Navy that provides specialized training in Drone Warfare, empowering fighters to operate drones from different NATO classes and instructing them in the innovations and technological challenges of the discipline. The training offered by the X31 unit follows the flight training provided by the ARPRA qualification using a MAVIC PRO type drone (Reuss & Pedro, 2024), which includes theoretical classes on US, pre-flight, in-flight, and post-flight preparations, and the execution of flights including evasive maneuvers, characteristic of complex and close quarters environments (Reuss & Pedro, 2024), as can be seen in Figure 58.

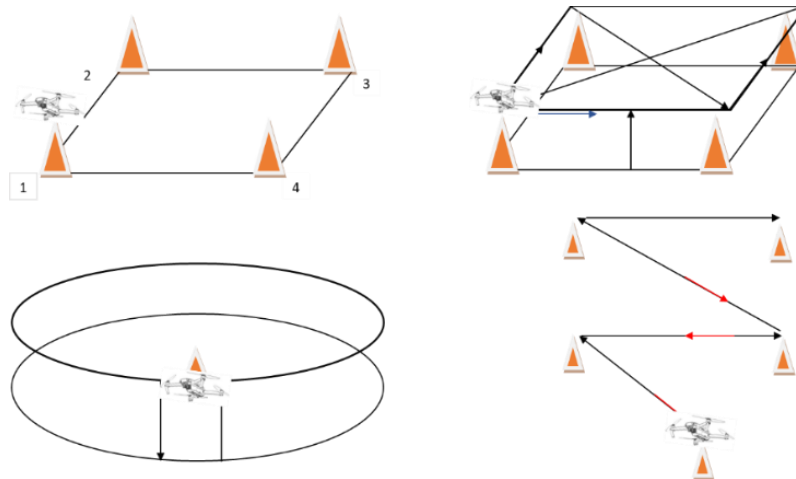


Figure 58- UAV Operation Course Provided by X31⁵⁴

However, the training falls short in comparison with other current courses offered by the Ukrainian and Chinese armed forces, which utilize buildings, windows, obstacles, and targets that simulate the current employment and capability of UAVs in the world of Drone Warfare. In addition to drone flight practice and theoretical knowledge, it is also recommended to use virtual reality systems such as VBS3 (Virtual Battle Simulator 3), which allows the application of lessons learned during training in virtual reality, practicing surgical actions and reconnaissance with the assistance of drones of various capabilities and NATO classes. In a study conducted in 2017 by the

⁵⁴ Table taken from (Reuss & Pedro, 2024)

Czech Republican, Jan Drozd and Zdenek Flasar simulated an operation with a section of combatants integrating a UAV operator. The UAV used was a commercial DJI Phantom Pro 4, and considerable success was noted in both planning and execution of the mission (Drozd & Flasar, 2017), as you can see in the Table 23. Hence, it would be an asset for Unit X31 and the Portuguese Marines to apply and simulate the current adversities observed in contemporary conflicts.

Followed values	Without drone	With drone	The percentage decline
Movement to LD duration (with obstacle)	16,2	13,6	-16,049%
Attack duration (from LD to ENY destruction)	44,1	37,2	-15,646%
Overall duration (include area securing)	70.1	57,3	-18,26%
Losses of lives	2,2	1,1	-50%
Number of wounded	1	0,8	-20%
Material losses (BMP2)	0,7	0,3	-57,143%
TLP duration	24	18,4	-23,333%

Table 23- UAS Employment Impact in a Simulated Operation.⁵⁵

NATO has a training doctrine made for UAS pilots in four different levels that UAS pilots must achieve to grant those levels and be capable of piloting a UAS. Those requirements can be seen in Annex B- Training Requirements for UAS (North Atlantic Treaty Organization, 2019). For C-UAS operators, NATO offers a training requirement as well, aiming the training for unit and subunit training that can be used in the Portuguese Marine Corps C-UAS training (North Atlantic Treaty Organization, 2023). It can be seen in Annex C- Training Requirements for C-UAS.

In conclusion, there is a considerable investment being made by various international armed forces seeking to adapt and update to the new realities, which the Portuguese Marine Corps should evaluate and consider, such as:

- The integration of civilian-donated equipment or expertise into military forces, as seen in Ukraine. Integrating civilian drone enthusiasts into the

⁵⁵ Table taken from (Drozd & Flasar, 2017)

armed forces saves on personnel costs, recruitment, and training. Requesting donated or charitable equipment like commercial UAVs is also a possibility, as utilized by Ukraine, which has garnered thousands of UAVs for battlefield use. An example is the Ukrainian Angry Birds unit, which has a dedicated page for public donations and recruitment inquiries to assist in the war effort., (Hero of Ukraine, 2023). Portugal should adopt these measures, seeking financial, personnel, and mechanical assistance from the civilian world, as it offers specialized capabilities and inherent motivation.

- The establishment of a branch or unit within the three branches of the armed forces dedicated to autonomous systems and countermeasures is necessary to centralize efforts, knowledge, and training. To achieve this, the Portuguese Marine Corps should also establish a school or training center to train future UAV operators for the new realities and environments or improve the formation provided by X31.
- Training for UAV operators within the Portuguese Marine Corps should include the creation of obstacle courses for UAV control and the use of virtual reality with programs like VBS 3 to simulate operations with FPV UAVs and quadcopters.

5.4. Tactical Considerations

Drone Warfare brings a new dynamic to combat, requiring the adoption and formulation of new TTPs to face the new challenges posed by agile and robust FPV UAVs, which have proven to be reliable and effective in various environments. With the conflict in Ukraine, especially, both Russian and Ukrainian forces have used Telegram and other encrypted social media networks to disseminate lessons learned from Drone Warfare and to contact the civilian world more quickly and fluidly, using civilian means for ISR and financing.

5.4.1. Uncrewed Aerial Systems Flight Considerations

Through the study of Russian Telegram channels, it is possible to draw some conclusions on how to survive and act in Drone Warfare, which will be useful for knowledge and application within the Portuguese Marine Corps, not only to understand the new challenges of military theaters but also how to use UAVs to one's advantage and how to neutralize them. The Center for Naval Analyses (CNA), a nonprofit organization that studies current theaters of operations, released an article studying Drone Warfare in the current Ukrainian conflict, conducting an intensive study on Russian telegram channels to draw lessons on how to act in the new dynamics of warfare (Edmond & Bendett, 2023). The results were as follows:

- Do not launch UAVs from assembly points or attack bases or patrols, as in the case of spoofing, the enemy will know and visualize the position.
- UAV landing site must be different to launching site and must not be repeated.
- Turn radio equipment off.
- Each combat UAV must be accompanied by another ISR UAV to confirm the target and its neutralization.
- Use Class I mini-UAVs to test enemy EW fields, seeking to understand the range of enemy jamming.
- Seek cover or shelter where the operator should be located before the flight.

The information shown above can be seen in its original version in Annex D- Russian TTPs on Drone Warfare. In addition to this, the Russian forces have developed a tactical doctrine for UAV operation before, during, and after flight, respectively found in Annex D- Russian TTPs on Drone Warfare, from (Edmond & Bendett, 2023).

Before flight:

1. Determine points of interest for operational information and reconnaissance forces.
2. Determine a covered and sheltered location for the UAV operator with direct visibility of 250 to 450 meters from the flight.
3. Locate a safe takeoff point for the UAV 150 to 200 meters from the operator, free from obstacles, in a flat area of 7 by 7 meters.
4. Familiarize yourself with the terrain and identify conspicuous points to maintain UAV control in case of jamming or spoofing.
5. Clear the UAV's memory before the flight.
6. Coordinate with the C-UAS unit regarding the friendly UAV's flight.
7. The assistant moves the UAV to the takeoff point.
8. Before the flight, turn on the flight mode on the phone or disable GPS, WI-FI Mobile Network.
9. Enter the quadcopter's route with the connected phone/tablet.
10. Assistant holds the copter at takeoff point, installs the battery.
11. Turn on the copter, place it on a flat surface.
12. After takeoff, the assistant must immediately return to the shelter.

During flight:

1. Raise the UAV to 250 meters above ground level.
2. Identify and analyze the sound of the quadcopter's propellers.
3. Continue flight up to 350 meters.

4. Monitor the signal.
5. Monitor the UAV's speed.
6. Monitor battery life and ensure the UAV has sufficient battery for return, typically requiring 60% of available battery for return flight.

After flight:

1. Mobilize the UAV for Return to Home (RTH).
2. Change mode to manual for parking at 1 km.
3. Bring the UAV to 250 meters above ground level, 500 meters from the parking point, and descend to 120 meters above ground level.
4. Perform a visual check of the UAV up to 20 meters away from the parking point, which is a flat and secure area.
5. Retrieve the UAV as quickly as possible by the assistant and turn it off immediately.

Apart from the lessons learned in the Ukraine conflict and the already mentioned TTPs for UAS missions, in the work, NATO states that to maximize the efficiency, control and speed of NATO class I UAVs, UAV operators must (North Atlantic Treaty Organization, 2023):

- Fly at low level and upwards to utilize the environment for protection and dissimulation and to minimize sound detection.
- Make series of false take-offs while approaching target.
- Use erratic movement for enemy deterrence and difficult observation and neutralization.
- Mask the UAV using the sun and clouds.

- Utilize sport flying mode to increase speed and agility.
- Utilize Swarms to confuse and deceive the enemy.
- Fly a pre-programmed flight to minimize UAV loss.

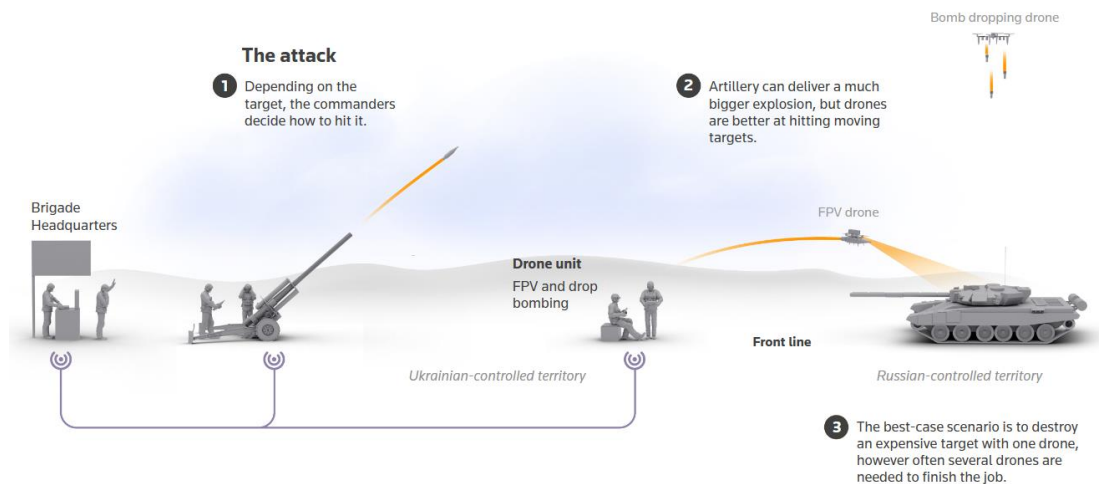


Figure 59- Ukrainian Forces TTPs⁵⁶

As stated earlier, it is recommended that a fluid, flexible, and fast C2 (Command and control) between the higher and lower echelons to speed up decision-making and technical procedures on the terrain. Three steps are necessary: Reconnaissance, Acquisition, Decision Making. Where communications between the assault UAV teams on the ground must find enemy targets through ISR, follow them, and then unleash information quickly so commanders may decide in useful time to neutralize enemy threats, as can be seen in Figure 49 and Figure 59. A communication link direct from the team to the operational command must be done. The decision to destroy the enemy through UAV or artillery means is an operational level choice but, in each case, a NATO Class II or III UAV is always necessary to maintain eyes on target on the enemy and to kill confirm.

5.4.2. Uncrewed Aerial Systems Detection Considerations

The United States Army has also idealized special doctrine for Counter-Uncrewed

⁵⁶ Figure taken from (Reuters, 2024)

Aerial Systems in August 2023 with the publication of ATP 3-01.81 (Headquarters, Department of the Army, 2023). In the publication, it is employed several tactics to survive enemy UAVs through camouflage, disguise, C-UAS and the dissemination of information of the enemy UAVs for upper echelons. To prevent enemy attacks for uncrewed aerial vehicles, the US army defends the scanning of the sky through three different methods: 20°, vertical scan method and horizontal scan method.

The 20° degrees estimating methods defends that enemy UAVs normally operate above 20 degrees of the ground which is approximately the size of a soldier's hand (Headquarters, Department of the Army, 2023), as seen in Figure 60.

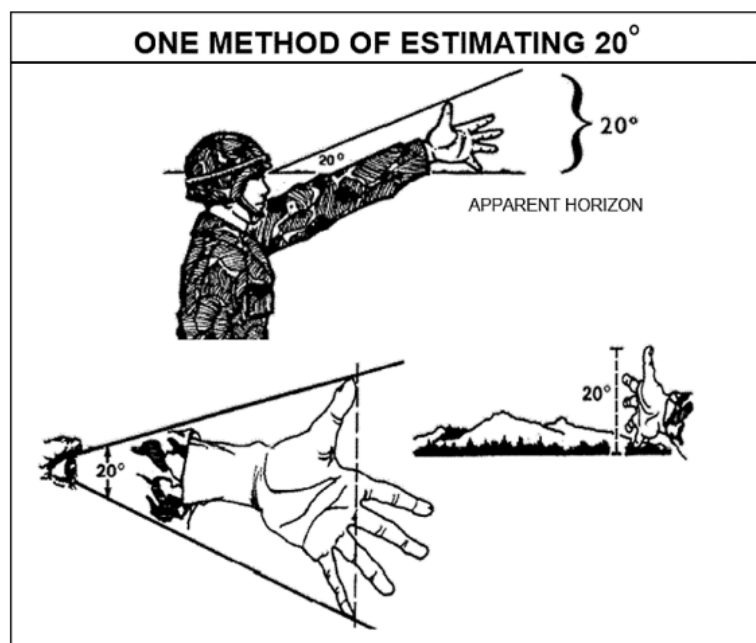


Figure 60- 20° Estimating UAV Scanning Method⁵⁷

The vertical and horizontal scan methods can be seen in Annex E- Vertical and Horizontal UAV Scan Detection Method. Both incorporate a scan of the sky, glancing at it vertically or horizontally in repeated and circular motions.

For a positive scan detection for an enemy UAV, a SALUTE format message must be made and redacted for upper echelons and future decision-making for neutralization of detected drone, the detection report can be seen in the Table 24 (Headquarters,

⁵⁷ Figure taken from (Headquarters, Department of the Army, 2023)

Department of the Army, 2023).

SALUTE UAV Report

	SALUTE					
	SIZE	ACTIVITY	LOCATION	UNIT	TIME	EQUIPMENT
INFORMATION	Number Size Formation	Direction of Movement	Where How Coordinates	NATO Class Type	When	Payload Sensors Weapons
		Hostile Action Spot of Detection Flight Movement		Wingspan Number of Rotors Operational Altitude Lights Distinctive Marks		

Table 24- SALUTE UAV Report⁵⁸

5.4.3. **Reconnaissance Considerations**

NATO is far behind in the formulation and utilization of UAS and C-UAS dedicated doctrine, with its implementation only to be successful in the end of 2024 (Gosselin-Malo, 2023). Current NATO doctrine for UAS tactics, techniques and procedures are the NATO standards ATP-3.3.8.2 and ATP-117, which, even short and outdated, are still in development and with lessons of interest such as planning reconnaissance missions and weather considerations.

Reconnaissance is defined as “a mission undertaken to obtain, by visual observation or other detection methods information about the activities and resources of an enemy or potential enemy, or to secure data concerning the meteorological, hydrographic, or geographic characteristics of a particular area.” (North Atlantic Treaty Organization, 2020). This is the primogenital mission of UAS, and NATO provides a categorization of reconnaissance missions with each its own characteristics (North Atlantic Treaty Organization, 2020). The different reconnaissance missions are the following:

- Route Reconnaissance: Obtain information of a specified route. With continuous vigilance through the flanks and rear, providing ambush and overwatch.

⁵⁸ Table taken from (Headquarters, Department of the Army, 2023)

- Zone Reconnaissance: Obtain information of all routes, obstacles, terrain and enemy forces present in the restrictive zone of reconnaissance. Used mostly for planning considerations when knowledge is limited.
- Area Reconnaissance: Obtain information of the permissive zone of reconnaissance.

For the defined reconnaissance missions, NATO advises the use of a reconnaissance mission checklist which is in the Annex F- Reconnaissance Mission Checklist. For the general UAS missions independent of the aim, objective and function of the UAV, NATO also suggest a UAS mission planning checklist that can be found in Annex G- Checklist for UAS Missions Planning.

The doctrine for Drone Warfare is a daily and recent input against new and advanced technological difficulties that enhance the necessity for its implementation in today's army. CEPA (Center for European Policy Analysis), has identified the necessity for doctrine, UAS and C-UAS proliferation for NATO members (Borsari & Jr, An Urgent Matter of Drones, 2023), with the integration of UAS into wider military ecosystem. With a demanding task to rejuvenate current UAS capabilities, the current Alliance Ground Surveillance and the limited sensor payloads and capabilities (Borsari & Jr, 2023).

To improve Drone Warfare knowledge in the Portuguese Marine Corps and the recent utilized TTPs in modern conflicts, a Drone Warfare Manual was made so the future Portuguese Marine Combatants can be prepared for future technologically advanced adversities. It can be seen in Appendix J- Drone Warfare Manual.

5.5. Drone Warfare Manual

The Drone Warfare manual is a manual of techniques, tactics, and procedures created as part of a master's dissertation and aimed as a thesis objective. The manual aims to compile TTPs drawn from various armed forces that apply to the recent and current conflicts involving Drone Warfare.

The manual addresses an existing gap in the Portuguese Marine Corps regarding doctrine dedicated to Drone Warfare. Therefore, with the completion of the dissertation, the UAC requested the author of the dissertation to prepare the document with a view to utilizing the lessons learned from various conflicts after studying the operational context of Drone Warfare.

The manual is intended for use by marine forces in the field, who, through checklists, risk analysis, and images, can identify enemy UAVs, assess the danger and protection they have against enemy UAVs, and safely conduct UAV operations and countermeasures, thereby surviving Drone Warfare.

5.5.1. Objectives and Purposes

- The objectives of the Drone Warfare manual identified by the UAC and the author of the present dissertation are as follows:
- Provide checklists before, during, and after UAV flights so that operators have a list to follow and minimize errors in UAV operation and safety.
- Provide lists of UAVs from competing armed forces such as Russia, China, and Iran to recognize their capabilities, functions, and forms to report their location to higher echelons in reconnaissance functions.
- Demonstrate risk considerations and analyses that combatants can perform to verify their protection against aerial threats.
- Highlight meteorological analyses for UAV operations so that operators recognize the impact of the atmosphere on system operation.
- Implement planning and mission checklists for leaders to lead and plan with UAS operations and countermeasures.

With the objectives established, the purpose of the manual is demonstrated, which should follow the following guidelines:

- The manual should be robust, waterproof, short, and A5-sized so that combatants can carry it in the field as an aid.
- The manual should be in Portuguese and easy to understand.
- The manual should include a bibliography and be subject to modifications and updates.

5.5.2. Results

The manual is in Appendix J- Drone Warfare Manual, A5 size, and contains 30 pages of necessary, practical, and important information for Portuguese combatants to use in the field and survive future technological adversities of Drone Warfare. Currently, the manual has been submitted and is under review by the UAC's doctrine department.

6. Conclusion

*“History shows that what matters most in periods of **technological disruption** is not getting a new technology first or even having the best technology but finding the best ways of using it.”*

Paul Scharre

The research conducted and the scientific study carried out have allowed the development of a comprehensive and detailed understanding of the current state of Drone Warfare, its consequences, and applications in UAS, C-UAS, and future technologies such as AI and Swarm. The sudden technological advancement associated with autonomous systems and their use in military environments was demonstrated through the work presented, justifying the need to adopt strategies both in the acquisition of countermeasures and their tactical application within the Portuguese Marine Corps.

6.1. Results

Analyzing and summarizing the results obtained through the different sections, the conclusions are as follows:

- **Knowledge:**
 - The current classification of UAVs is outdated and poorly regulated. By analyzing several UAV classifications from different armed forces, a current classification adapted to emerging technologies in the range of autonomous systems was developed with the inclusion of the following categories: autonomy, Artificial Intelligence, and energy sources.
 - The current legal framework related to the use of UAS and C-UAS is outdated. A need was identified to create a unanimous international framework for the use of UAS and C-UAS in the civilian environment, with a dedicated frequency band for UAVs and a broader, well-studied legal spectrum for resolving civil

conflicts. It was proven that Portugal is well-positioned regarding the legal aspect of using these means. Additionally, the need to form a legal framework for AI and Swarm technologies, which the European Union has yet to publish, is increasingly necessary. In the military environment, compliance with legal frameworks driven by the International Criminal Court is challenging. However, establishing a framework to integrate these new means into the Geneva Convention and identifying their legal application, especially with the use of AI and Swarm systems, is also necessary.

- UAVs are extremely versatile, with diverse capabilities that increase with the technology implemented in them. The trend observed is a decrease in size and cost, an increase in payload, operational altitude, range, speed, sensor and camera quality and a reduction in noise and electromagnetic presence.
- Non-kinetic C-UAS, as the best and most used method against enemy UAS, have evolved in accordance with the technological advancements of the latter. There has been a significant increase in the war effort placed by various armed forces in acquiring these systems to neutralize enemy UAS non-kinetically. The three different types of C-UAS and their required capabilities were demonstrated, proving that the best means depend on the area they defend, the combat power they enhance, and the objective they aim to achieve. In summary, the following was proven:
 - For defending large, fixed areas, a fixed system is recommended, typically of higher price value, that allows for 360° protection with detection, identification, acquisition, and neutralization capabilities, all fully autonomous. These systems are optimal for military bases and naval units.

- For defending large mobile units, such as military convoys, patrol bases, forward operational bases and for barrier line defense, mobile systems are excellent as they move with the unit, offering 360° protection. They are cheaper and more versatile than fixed systems but usually lack identification capabilities and battery limitation.
- For defending low-echelon tactical forces, such as special or reconnaissance forces, portable systems are considered most appropriate due to their low cost, lighter weight, and greater precision. They typically do not offer omnidirectional protection, have a reduced battery life, and are not autonomous, only capable of neutralization and, some, detection.
- **Protection:**
 - C-UAS may affect the combatant by the electromagnetic energy emitted by the antenna, therefore it was proven that the ballistic plate used by the Portuguese Marine Corps should be used while operating these systems, since it protects the combatant and increases the countermeasure's efficiency.
 - The PITBULL WINGMAN system is extremely effective for a small, dismounted force as it enhances combat power without replacing the primary weapon of the combatant, unlike the SWATTER system. This system is autonomous and omnidirectional, with active detection capabilities, making it a more complete system than the SWATTER, and lighter. However, it is expensive compared to other systems and less accessible than the SWATTER.
 - The SWATTER system, in the absence of the PITBULL

WINGMAN system, is a good alternative as it meets the range and efficiency requirements. However, it is considerably heavy, weighing 6kg, and would replace the combatant's primary weapon, resulting in reduced combat power. However, using the PITBULL WINGMAN systems for naval unit protection is inefficient, and a solution like the SWATTER would be more appropriate due to its accessibility and greater directional precision. It was demonstrated that if the SWATTER system is acquired, it should replace the PITBULL WINGMAN system in search and rescue missions and equip more vessels with it.

- **Employment:**

- The Portuguese Marine Corps is aware of the new challenges through the implementation of the “Light and Fast” concept. However, changes must be made to use UAVs as support systems for all three levels of the armed forces. Primarily for the operational level, using a dedicated ISR Unit employing NATO Class II or III MALE systems. And at the platoon level, the employment of Class I UAVs, with at least one system per team with combat and reconnaissance capabilities.
- The Marine Corps should invest in quadcopters due to their versatility, maneuverability, and agility and seek to develop AI and Swarm technologies dedicated to these systems.

- **Doctrine:**

- The Marine Corps should improve its training dedicated to UAV and countermeasures operators, aligning with what is practiced in real combat, adapting operators to trench and urban environments with high-speed loitering munitions

UAVs.

- The Marine Corps should understand and analyze current conflicts and learn lessons from them to develop doctrine and TTPs dedicated to Drone Warfare, enabling UAV teams to fight and survive, as well as adopt the formulated Drone Warfare Manual present in the dissertation.

The verification and acquisition of knowledge in Drone Warfare for the Portuguese Marine Corps was not solely autonomous work, it also involved a series of conversations, interviews, and idea exchanges with personnel specialized in Drone Warfare, ranging from legal experts to military theorists. The conducted interviews and the questions posed are detailed in Appendix K- Interview Guides, for readers interested in the identities of the interviewees and the scope of their inquiries.

For a more in-depth learning experience on the topic of Drone Warfare , both for the readers of this work and for any military personnel specialized or interested in Drone Warfare , a guide to courses on the subject of the dissertation has been prepared and is presented in Appendix L- Drone Warfare Courses Guide.

The dissertation is primarily targeted at the Portuguese Marine Corps and, consequently, to the Portuguese Navy. However, the topic explored in the dissertation is of global interest and significant knowledge for any armed force. Therefore, the author tried to publish articles to spread awareness, opinions, and knowledge on the subject, disseminating the lessons learned and the work of the dissertation. The articles are included in the following appendices: Appendix A- Article Submitted to the , Appendix M- Article Submitted to the Revista da Armada; Appendix N- Article Submitted to the ; Appendix O- Article Submitted to the RUSI Journal.

6.2. Validation of Hypothesis

The dissertation's results validate the previously formulated hypotheses through rigorous experimentation and analysis:

Knowledge-**H1**: The study of Drone Warfare will gather information necessary and important which will significantly reduce skepticism and increase understanding among Portuguese Marines.

R1: It was gathered updated, necessary and critical information about Drone Warfare through exploratory interviews and document research that, through the publication of the dissertation, will significantly reduce skepticism and increase understanding among Portuguese Marines.

Protection-**H2**: non-kinetic countermeasures, such as Spoofing and Jamming, effectively neutralize unauthorized UAVs without causing harmful effects to operators.

R2: Through the simulated and semi-controlled experimentation, it was demonstrated that, with the ballistic plate, no harm was done against the combatant while operating countermeasures. The countermeasures tested demonstrated levels of effectiveness in neutralizing enemy UAVs, accessibility for the operator and capabilities, which will be adopted by the Portuguese Marine Corps.

Employment-**H3**: Through the study of different operational organizations for Drone Warfare, it will be possible to implement a recommended operational organization for the Marine Corps.

R3: It was possible to analyze different operational organizations adopted by Russia, Ukraine, Israel, Serbia and United States of America which led to recommend and formulate an operational organization dedicated to C-UAS and UAS for the Portuguese Marine Corps.

Doctrine-**H4**: Through the study of different TTPs adopted by armed forces in current and recent conflicts, it will be possible to formulate and deliver a Drone Warfare Manual, which will improve combat readiness and response times against enemy or unauthorized UAVs.

R4: It was formulated a Drone Warfare Manual with updated TTPs, checklists and UAV lists for reconnaissance that was delivered to the UAC for analysis in the Portuguese

Marine Corps.

6.3. Research Limitations

During the completion of the master's dissertation, some limitations were faced, which are as follows:

L1 - The experimental research was limited due to simulated and semi-controlled experimentation not equating to the reality in which these systems will be employed.

S1 - The solution for limitation 1 is, within availability, to test the systems in military exercises to simulate as closely as possible the environment in which the systems will be employed and thus evaluate them more rigorously.

L2 - The comparative study was limited to two systems, which reduced and limited the conclusions drawn.

S2 - The solution for limitation 2 is to have other types of systems, preferably fixed and mobile, to perform a richer comparison and obtain more rigorous quantitative data.

In conclusion, this dissertation provides valuable insights into the current state of Drone Warfare and the effectiveness of C-UAS. The findings and recommendations presented offer a solid foundation for the Portuguese Marine Corps to develop and implement effective C-UAS strategies, ensuring their preparedness to counter the evolving threat of uncrewed aerial vehicles in modern military conflicts.

6.4. Future Work

*“Artificial intelligence is the future, not only for Russia, but for all humankind. It comes with colossal opportunities, but also threats that are difficult to predict. **Whoever becomes the leader in this sphere will become the ruler of the world.**”*

Vladimir Putin

Drone Warfare is a new, current, and dynamic discipline, with daily technological evolutions and advancements, which necessitates keeping up with its progress and

conducting future work, after the master's dissertation, for the benefit of the Portuguese Navy and Marine Corps.

The future work within the discipline of Drone Warfare intended for the Marine Corps, Marine School, and Portuguese Navy is as follows:

- Adopt, formulate, and conduct dedicated Drone Warfare training in urban operations within the Marine Corps. Military operations in urban environments are increasing, and this type of environment will be the nature of future conflicts (King, 2021), leading to the need to train Marines against the adversity of combat in built-up areas from a Drone Warfare perspective.
- Adopt, formulate, and conduct dedicated countermeasure training in the Marine Corps. Just like the "Dronariums" created with the Ukraine conflict, it becomes necessary to adopt dedicated training for countermeasure operators in the Marine Corps, as well as to test more and varied systems in military exercises.
- Adopt and understand "Masking." As discussed in chapter 3.3.7, John Antal envisions the need to evade enemy UAV sensors that are evolving daily. Through this, efforts should be made to protect Marines from enemy UAVs by adopting the Drone Warfare Manual and systems, as seen in Figure 61 that allow for the "invisibility" of combatants across various acoustic, electromagnetic, seismic, and thermal spectrums.
- Implement and apply new technologies such as autonomy, artificial intelligence, and swarm in autonomous systems within the Marine Corps and Portuguese Navy to prepare combatants for a future technological and algorithmic conflict.
- Conduct the various courses and training identified in Appendix L- Drone Warfare Courses Guide to foster and enhance knowledge in the discipline

of Drone Warfare.

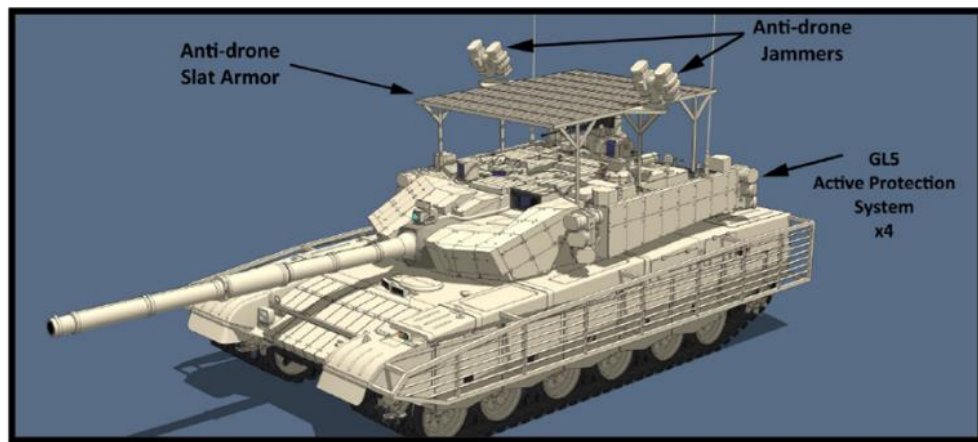


Figure 61- Kallisto Shield Masking⁵⁹

⁵⁹ Figure taken from (AI, 2024)

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8. Appendixes

8.1. Appendix A- Article Submitted to the RUSI Journal

The purpose of the article referenced below, submitted to the RUSI Journal, aims to eliminate an identified gap in the current state of the art regarding Drone Warfare. The identified gap is the lack of quantitative evidence that references and demonstrates the much-discussed proliferation of drones, from the acquisition of UAVs by various countries over time, as well as their use in armed conflicts and their growth. Therefore, an exploratory data analysis was conducted using data extracted from open-source databases of proven origin that demonstrate values which, when tabulated and graphed, show the increased use of UAVs in armed conflicts, their importance in military forces, and their destruction.

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Drone Warfare: An Exploratory Data Analysis on the Ukraine War

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Teixeira da Costa is an aspiring Marine Officer of the Portuguese Marine Corps, currently in the final year of the officer's course in the Navy. He is writing a master's dissertation entitled "Drone Warfare: Operational Context, Countermeasures, and Tactical Insights for the Portuguese Marine Corps." His research focuses on the operational organization, countermeasures, and tactical applications of drone warfare, aiming to enhance the preparedness and capabilities of the Portuguese Marine Corps in future conflicts.

Brito Araújo is a Lieutenant in the Portuguese Marine Corps, serving as the second commander of the Combat Support Unit and the Chief of the Communications Service in the Marine Corps. His extensive experience in military operations and communications provides valuable insights into the strategic and operational aspects of drone warfare. His collaboration in this research brings a practical perspective to the study, ensuring its relevance and applicability to real-world military scenarios.

Drone Warfare: An Exploratory Data Analysis on the Ukraine War

The study provides an in-depth exploratory analysis of drone warfare in the ongoing Ukraine conflict, highlighting the significant role of unmanned aerial systems (UAS) in modern military operations. The analysis reveals a substantial increase in the deployment and subsequent destruction of Russian drones by Ukrainian forces, underscoring the growing reliance on these technologies by both sides. Drones have emerged as the most frequently utilized and destroyed Russian aerial asset, accounting for nearly 99% of all downed Russian aircraft.

Key findings indicate that the most used Russian drones are the Shahed and Orlan-10 models, with the former specializing in loitering munitions and the latter in reconnaissance. This dual focus on offensive and intelligence-gathering capabilities reflects the strategic priorities of the Russian military. Additionally, the study highlights the significant contribution of Iranian-manufactured drones to the Russian arsenal, pointing to a strategic partnership between the two nations.

The analysis also reveals an increasing efficiency in Russian drone operations, evidenced by a widening gap between the number of drones launched and those destroyed by Ukrainian defenses. This trend suggests a pressing need for Ukraine to bolster its air defense systems to mitigate the evolving threat posed by Russian drone.

Overall, this study underscores the pivotal role of drones in the Ukraine conflict, illustrating their impact on the dynamics of modern warfare. The findings emphasize the importance of continued research into drone warfare to inform future military strategies and technological advancements, ensuring preparedness for the evolving landscape of armed conflict.

Keywords: Exploratory Data Analysis, Drone Warfare, Russia, Ukraine

Introduction

Drone Warfare is the military discipline that studies and analyses the use of drones in armed conflicts (Gusterson, 2016). Its relevance began in 1849 where unmanned hot air balloons were used by the Austrian forces against San Marco Republic, (Seharwat, 2021), since then, the study, development and proliferation of drones in armed conflicts increased to a defined Second Drone Age characterized by the proliferation of Commercial Off-The-Shelf (COTS) and Do-It-Yourself (DIY) Drones in armed conflicts, due to their low cost and low risk, minimizing expenses on artillery pieces and human resources. However, their capabilities are increasing as rapidly as their implementation, as they are becoming stealthier, smaller, faster, and more lethal, effectively replacing heavier and more expensive drones, (Council, 2020). A clear representation of the second drone age and bigger and better implementation of drones in armed conflicts is the Ukraine conflict.

The conflict in Ukraine began with Russia's invasion of Ukraine on February 24, 2022, intended to last between 4 to 5 days, to enable annexation by August 2022. Despite Russia's numerical strength, they failed to achieve the desired end state due to limited planned courses of action, and Ukraine managed to mobilize using various means, including unmanned aerial systems (UAS), to halt the Russian advance, (Kunertova, 2023). The use of UAVs in the conflict has proven that drones are an asset of destruction of critical positions and enemy morale and will, (Watling, 2023). Drones demonstrated a relevant demoralizing capability as they are difficult to detect and increase anxiety due to their stealthiness and efficiency, (Lowther & Siddiki, 2023). Quadcopter UAVs DIY or military grade drones such as the Punisher UCAV have demonstrated the enormous and important capabilities that such means represent, (Lowther & Siddiki, 2023), capable of destroying big artillery pieces worth thousands of dollars with an expense of six hundred dollars on a commercial drone.

Therefore, it was proven in the Ukrainian conflict, that drone warfare came to change the dynamic of warfighting, with an employment of NATO Class I drones for all sorts of missions and functions, from combat to reconnaissance and reaching all military levels from strategic to the tactical level, (Borsari & Jr, 2023). Thus, a complex and thorough investigation on the Ukraine War with a Drone Warfare lenses must be done in order to find its applicability, influence and importance. Hence and exploratory data analysis on the Ukraine war, through and analysis of open-source databases on drone strike sin the war, is necessary and of interest of study.

The Databases

To conduct an analytical, comprehensive, and critical study, it was necessary to use three different databases to have the most extensive dataset with the most information and to draw the greatest number of relevant conclusions for the study. Therefore, through Table 1, the databases used can be verified.

Table 1- Drone Warfare Databases

Drone Warfare: Databases			
Author	Database	Attributes	Source
Petro Ivaniuk	2022 Russia Ukraine War	19 Columns 836 Rows	2022 Russia Ukraine War (kaggle.com)
	Massive Missile Attacks on Ukraine	21 Columns 1103 Rows	Massive Missile Attacks on Ukraine (kaggle.com)
ACLED (Armed Conflict Location and Events Data)	Ukraine Conflict Map	7 Columns 100 653 Rows	Ukraine Conflict Monitor (acleddata.com)

The purpose of each database is as follows:

- The ACLED database provides an overall view of the Ukraine conflict, showing the total number of drone attacks carried out in the conflict and their geographical and temporal location, (ACLED, 2024).
- The Massive Missile Attacks on Ukraine database aims to demonstrate the types of drones used in the conflict, specifically the drones used by the Russians that were reported destroyed, launched and their capabilities, (Ivaniuk, 2022).
- The 2022 Russia Ukraine War database shows all types of Russian equipment destroyed by Ukrainian forces with temporal and quantitative information. Therefore, the purpose is to provide a temporal view of the number of drones destroyed and consequently identify the most used Russian drones and compare them with the rest of their war effort,

highlighting the importance of drone warfare and the use of drones in armed conflicts today, (Ivaniuk, 2022).

To understand the type of information they offer, Table 2 presents the values provided by the three databases.

Table 2- Drone Warfare Databases Values

Drone Warfare: Databases Values		
2022 Russia Ukraine War	Massive Missile Attacks on Ukraine	Ukraine Conflict Map
• Date • Day • Personnel • Prisoner of War (POW) • Aircraft • Helicopter • Tank • Armored Personnel Carrier (APC) • Multiple Rocket Launcher (MRL) • Field Artillery • Military Auto • Fuel Tank • Anti-aircraft warfare • Drone • Naval Ship • Mobile SRBM System • Vehicles and Fuel Tanks • Cruise Missiles • Direction of Greatest Losses	• Time start • Time end • Model • Launch place • Target • Carrier • Launched • Destroyed • Source • Destroyed details • Category • Origin • Type • Launch platform • Name • NATO name • Guidance System • Features • Unit Cost • Produced • Manufacturer	• Date • Violence Targeting Civilians • Air and Drone Strikes • Armed Clashes • Shelling Events • Ukrainian Forces Regain Territory • Russian/Pro-Russian Forces Overtake Territory
Represents the Russian Material Destroyed by Ukrainian Forces	Russian drones and missiles launched and destroyed by the Ukrainian Forces	Overall Conflict Geographical Map ^{nirio}

Here is an overview of all the attributes of the 2022 Russia Ukraine War:

- **Date:** Date of each reported destroyed Russian material.
- **Day:** Number of day since the beginning of war.
- **Personnel:** Number of Russian personnel killed.
- **Prisoner of War (POW):** Number of Russian POW.
- **Aircraft:** Number of Russian military planes destroyed.
- **Helicopter:** Number of Russian helicopters destroyed.

- Tank: Number of Russian tanks destroyed.
- Armored Personnel Carrier (APC): Number of Russian APCs destroyed
- Multiple Rocket Launcher (MRL): Number of Russian APC destroyed.
- Field Artillery: Number of Russian mortars and other stationary artillery destroyed.
- Military Auto: Number of Russian military vehicles, such as light vehicles destroyed.
- Fuel Tank: Number of Russian fuel tanks destroyed.
- Anti-aircraft warfare: Number of Russian air defenses destroyed.
- Drone: Number of Russian drones destroyed.
- Naval Ship: Number of Russian military ships destroyed.
- Mobile SRBM System: Number of Russian road-mobile short-range ballistic missiles systems destroyed
- Vehicles and Fuel Tanks: The sum of vehicles and fuel tanks attributes.
- Cruise Missiles: Number of Russian cruise missiles.
- Direction of Greatest Losses: Text data of Russian military objectives of each attack.

Here is an overview of all the attributes of the 2022 Russia Ukraine War:

- Time start: Date of the start of the attack.
- Time end: Date of the end of the attack.
- Model: Type of Russian drone
- Launch place: Geographical data on the launching site of missile or UAV.
- Target: Objective of each missile or UAV.
- Carrier: Mobile station or naval ship which launched a missile or UAV.
- Launched: Number of launches of each drone or missile.

- Destroyed: Number of Russian drones or missiles destroyed.
- Source: Textual data of the information origin.
- Destroyed details: Textual data of additional information on the destroyed equipment.
- Category: If the strike was a missile or drone.
- Origin: Country manufacturer of drone or missile.
- Type: Type of drone or missile.
- Launch Platform: Additional data to the Launch place attribute.
- Name: Popular name of the system.
- NATO name: NATO classified name of the system.
- Guidance System: Textual data of the guidance system of the drone or missile.
- Features: Textual data of the system's features.
- Unit cost: Cost of the system.
- Produced: Textual data of where the system was produced.
- Manufacturer: Company of the system's production.

The three databases use official reports from the General Staff of the Armed Forces of Ukraine, (ЗБРОЙНІ СИЛИ УКРАЇНИ, 2024) and the Ministry of Defence of Ukraine, (Ministry of Defence of Ukraine, 2024), as their sources of information. However, these sources may contain biases and present errors in the research due to their pro-Ukrainian nature and the lack of access to Russian data. Additionally, since the data only includes information on destroyed Russian equipment, it only accounts for the materials reported and disclosed by official sources, meaning the true quantitative value could be significantly higher.

Thus, by using software such as Orange, the Python programming language through Jupyter Notebook, and working with Excel, it will be possible to clean and organize the data for future analysis.

Cleaning and Organizing Data

For efficient data use, it was necessary to clean and organize the databases for future Exploratory Data Analysis (EDA).

Starting with the 2022 Russia Ukraine War database, all columns deemed unnecessary for the study and analysis were eliminated, including:

- Military Auto: Due to the study being focused on drones and not ground vehicles.
- Fuel Tank: Due to the study being focused on drones and not ground vehicles.
- Mobile SRBM System: Due to the study being focused on drones and not ground vehicles.
- Greatest Losses Direction: Due to high number of missing values.
- Vehicles and Fuel Tanks: Due to the study being focused on drones and not ground vehicles.
- Cruise Missiles: Due to the study being about drone warfare.
- Submarines: Due to the study being about drone warfare.
- Personnel: No direct relation do drone damage.
- POW: Not of interest to the study.
- Day: Date attribute already presents the necessary data.

These columns were removed as they were not specifically relevant to the study of Drone Warfare and had a high number of missing values.

Next, a set of missing values in special equipment was identified, and these values were filled with the last recognized value, which is 10.0. This prepared the database for analysis.

The Massive Missiles database had date problems and considered unnecessary columns. The following columns were eliminated:

- Time End: Not important for the study. Only necessary the initial date.
- Launch Place: Due to high number of missing values and for being textual data, therefore, not analyzable.
- Carrier: High number of missing values, textual data.
- Source: Textual data, not important for the study.
- Launch Platform: Textual data not analyzable and high number of missing values.
- Name: For military terms, NATO name is the most rigorous definition.
- Guidance System: High number of missing values.
- Features: High number of missing values.
- Unit Cost: High number of missing values, and throughout the study such information will be gathered through other sources.
- Produced: High number of missing values.
- Manufacturer: Not important to study since the country of origin is already presented.

The ACLED database did not need any treatment and organization since it is web-based interactable dataset.

Table 3- Databases after Data Treatment

2022 Russia Ukraine War

	A	B	C	D	E	F	G	H	I	J	K	L
1	date	day	aircraft	helicopter	tank	APC	field artillery	RPL	drone	naval ship	anti-aircraft warfare	special equipment
2	26/05/2024	825	357	326	7662	14903	12953	1083	13425	37		81.6 2111.0
3	25/05/2024	822	356	326	7650	14796	12929	1082	13414	37		81.6 2104.0
4	24/05/2024	821	356	326	7635	14775	12902	1080	13401	37		81.3 2103.0
5	23/05/2024	820	356	326	7622	14748	12880	1077	13381	37		81.3 2094.0

Massive Missile Attacks on Ukraine

	A	B	C	D	E	F	G
1	time_start	model	Category	Origin	target	Loss	destroyed
2	2022-09-28	Ordn-32	Reconnaissance	Russia	Ukraine	3.8	3
3	2022-09-29	Shahed-136/131	Labeling Maritime	Iran	Odessa oblast and Mykolaiv oblast	7.9	5
4	2022-09-30	Ordn-32	Reconnaissance	Russia	Ukraine	3.8	3
5	2022-10-01	Ordn-32	Reconnaissance	Russia	Ukraine	1.8	miro 1

This way, the database was prepared for a necessary, important, and thorough study of Drone Warfare, which could provide readers with advanced knowledge of the conflict, justify statements on the topic, and comprehend the evolution of the study object. Data treatment and cleaning end with two tables: the first titled "UAV" with 7 columns and 612 rows, and the second titled "Ukraine War" with 11 columns and 823 rows. The first five rows of each dataset can be seen in table 3.

Exploratory Data Analysis

To begin the EDA study of Drone Warfare in the Ukraine conflict, guiding lines must be established, from general to more detailed, aiming to achieve the following objectives:

- The quantity of drones used in the conflict and their importance.
- Their usage compared to other means.
- The most used types of drones.
- The most used drone capabilities.
- The origins of Russian drones.

With the objectives set, the development of the work begins, starting with the proliferation and current state of drone warfare.

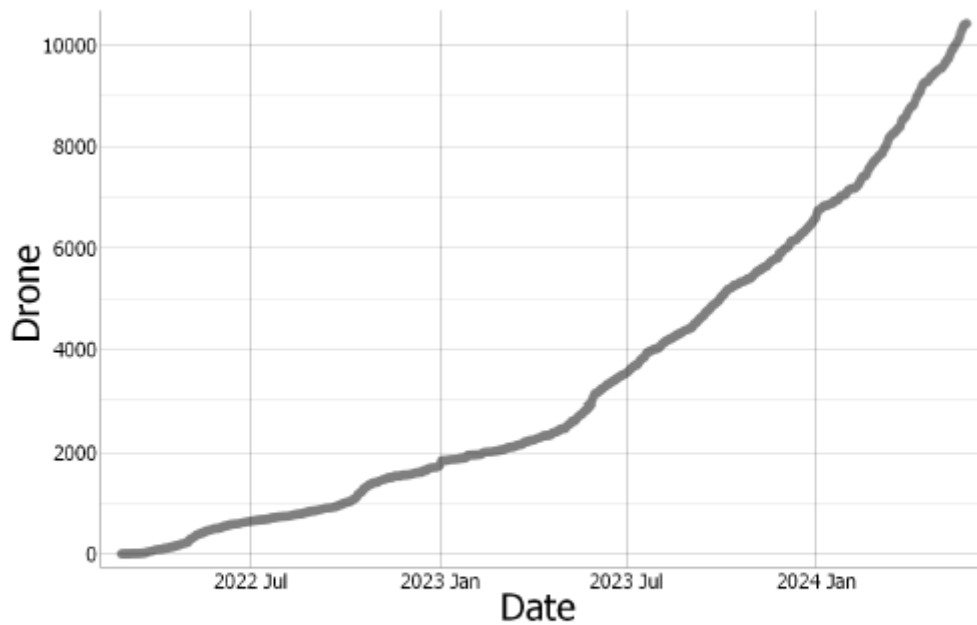


Figure 1- Drone Warfare throughout the Ukraine Conflict

As shown in Figure 1, the destruction of Russian drones by Ukrainian forces has been increasing quadratically, with the number of destroyed drones rising as the conflict progresses over time. A linear regression study shows that this trend evolves with an average slope of 0.96. This finding directly indicates that the use of drones has also followed a similar pattern, with increased deployment by both Russian and Ukrainian forces over the years, (Reuters, 2024). It is anticipated that these capabilities will continue to grow, as President Volodymyr Zelensky aims to produce 1 million drones in 2024 (The Straits Times, 2023). A similar trend is observed in the Russian government, which is making substantial investments in military drones, (Bendett, 2022).

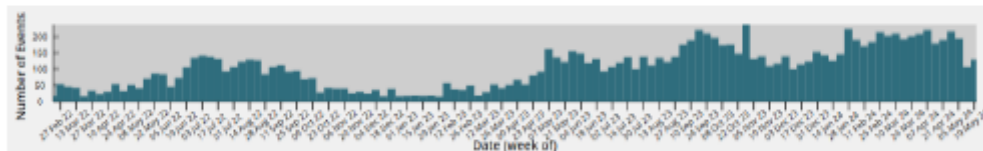


Figure 2- Drones Strikes in Ukraine Over Time

ACLED's data also gets the same conclusion of a visible increase in drone strikes in Ukraine, but with an outlier between October 2022 and April 2023 where there is a

considerable decrease in drone strikes in the conflict. That decrease can be justified for several reasons such as:

- Weather conditions: Between October 2022 and 2023 to April 2023 and 2024 there is always a decrease in the average yearly drone utilization due to the winter season that is characteristic of that time period. Cold temperatures can impact battery life and the drone mechanics, therefore decreasing its efficiency and employment, (Harward, Bailey, Evans, Hird, & W., 2023)
- Overall dedication for ground operations with less effort on drone warfare due to an improvement of air defenses by the Ukraine forces, (DW, 2023)

With the proven increase in the use of drones and their destruction during the conflict, a more detailed study can be conducted. While it is evident that the use of drones has been rising, it is important to understand their usage in comparison to other types of aerial assets.

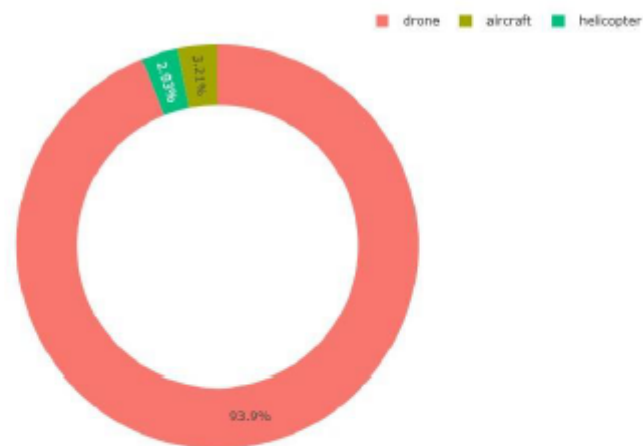


Figure 3- Percentage of Russian Aircrafts Destroyed

With Figure 3, it can be confirmed that, in addition to their increased use, drones are the most destroyed type of Russian aerial asset, and consequently, the most utilized

in comparison to aircraft and helicopters. Drones account for 98.9% of the destroyed Russian aerial assets during the conflict, demonstrating a significant and relevant Russian war effort in this domain. This expenditure in drone warfare by the Russian forces is justified by the cost-effectiveness of these systems and their high precision and adaptability, (Thompson, 2024). However, it should be noted that the destruction of a drone is easier than that of other aerial assets, and the higher their utilization and presence on the battlefield, the greater the likelihood of them being destroyed.

It is also important to study these aerial assets in relation to other land and maritime artillery to understand the overall expenditure on drone warfare across the different branches of the armed forces.

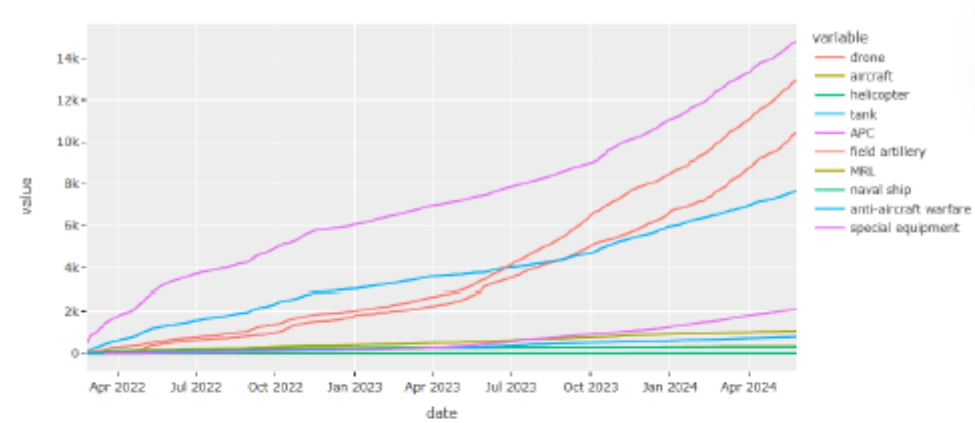


Figure 4- Russian Equipment Losses

With Figure 4, a general conclusion can be drawn regarding the context of drones within the spectrum of destroyed Russian assets. As of today, it is observed that drones have reached a total of 10,290 destroyed units, placing them just behind APCs (Armored Personnel Carriers) with 14,775 destroyed units, and field artillery (which includes mortars and other ground-based systems) with 12,395 destroyed units.

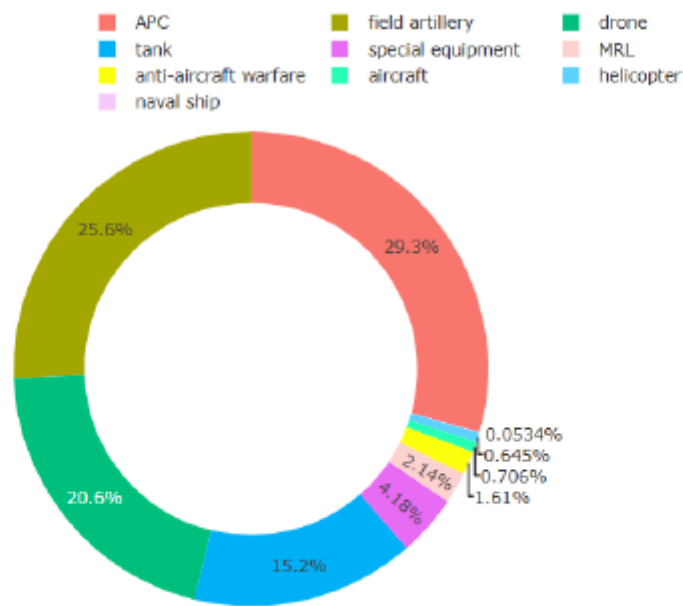


Figure 5-Russian Equipment losses Percentage

Another way to observe this result is through Figure 5, which more clearly demonstrates the component of drone warfare among destroyed assets, showing that drones account for 20.6% of the destroyed war effort. This makes drone warfare the third most invested area by the Russian forces.

By now analyzing the types of drones employed by the Russian forces, including their capabilities, functions, and the frequency of their deployment and destruction, the following conclusions can be drawn.

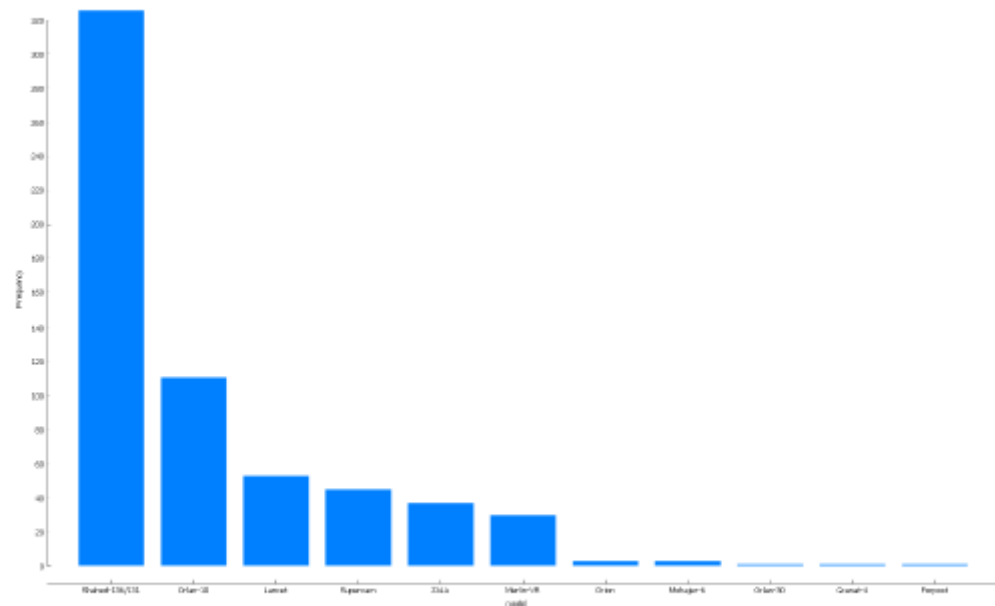


Figure 6- Russian Utilized Drones

According to Figure 6, the drones used by Russian forces are as follows:

- ZALA
- Supercam
- Shahed 136/131
- Lancet
- Orlan-30
- Orlan-10
- Orion
- Mohajer-6
- Merlin-VR
- Granat-4
- Forpost

The most frequently used drones by Russian forces are the Shahed drones, with 326 official reports, accounting for 53.36% of the drones used. Following the Shahed drones, the Orlan-10 has 111 reports, representing 18.17% of the utilization. In third place are the Lancet drones, with 53 reports and 8.67% of the usage in the drone category. This distribution justifies the types of drones employed by the Russian forces, highlighting that Shahed drones are the most utilized, (The Wall Street Journal, 2023).

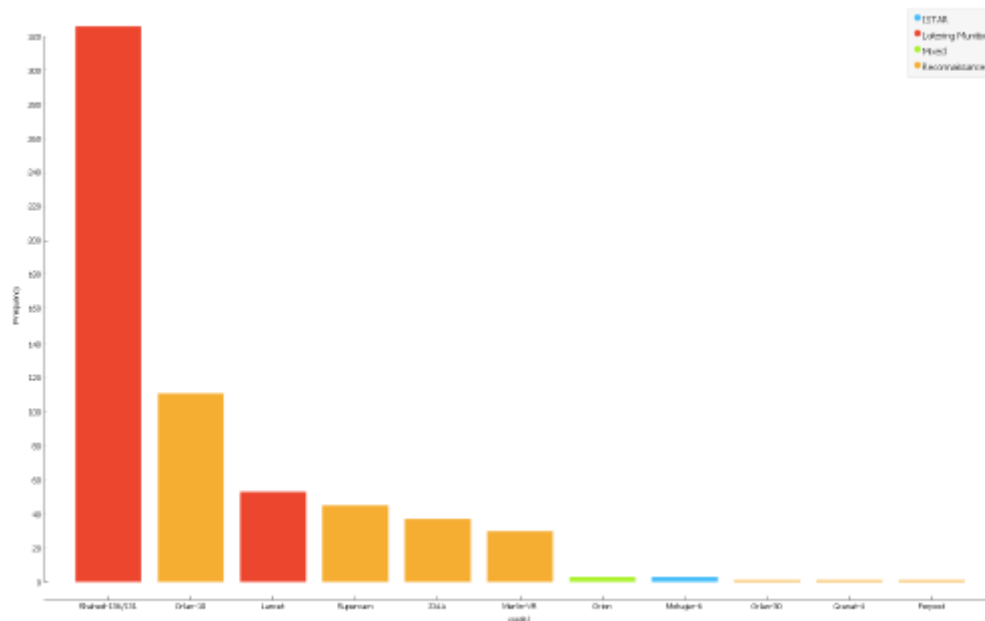


Figure 7- Russian Drones Capabilities

Considering the drones used by Russian forces, it becomes important to know their capabilities and try to understand why some drones are used more frequently than others. From Figure 7, it is evident that the Shahed and Lancet are loitering munition drones. Loitering munitions drones are “colloquially called kamikaze drones or suicide drones, provide small teams of soldiers with single-use small unmanned aerial systems, equipped to track and strike a target.”, (Eversden, 2022). Therefore, it can be concluded that loitering munition drones are drones that carry explosives, which can be activated on impact or dropped by the drone. Russian forces heavily invest in this capability, with two of the three most used drones supporting this capacity, (Luzin, 2023).

Next, the most invested capability is in reconnaissance, which includes the Orlan-10, Supercam, and Zala drones. However, it is important to know which capability is most heavily invested in by Russian forces.

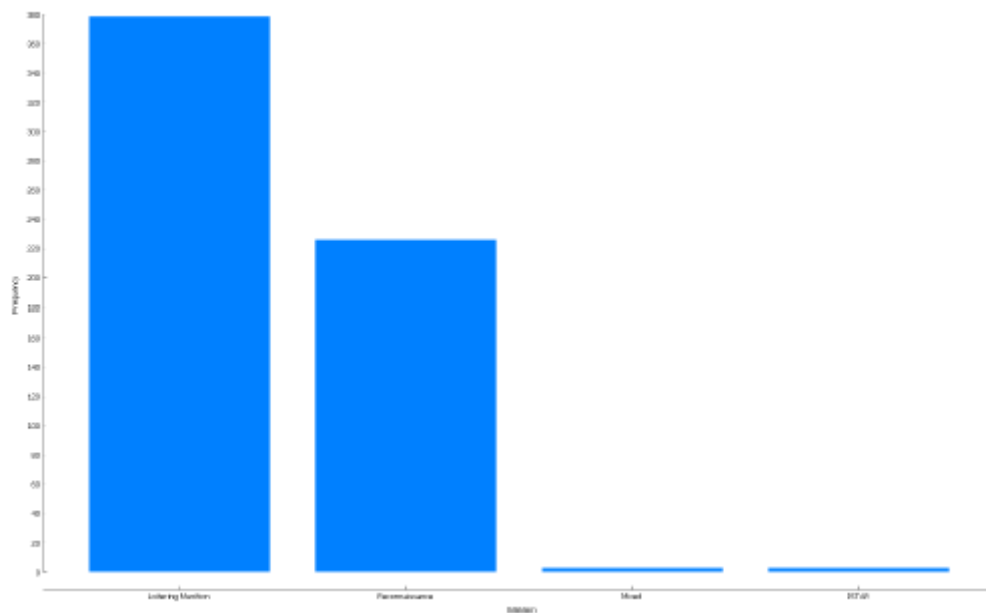


Figure 8- Russian Drones Capabilities

From Figure 8, it can be concluded that the most invested drone capability by Russian forces is loitering munition, with 62.03% of the capabilities embedded in the drones, followed by reconnaissance with 36.99%.

In addition to the Shahed and Lancet drones that perform loitering munition, the rest are used for reconnaissance, except for the Orion drone, which performs both reconnaissance and combat capabilities, and the Mohajer-6, probably the most advanced Russian drone as it performs ISTAR (Intelligence, Surveillance, Targeting, Acquisition, and Reconnaissance), making it a more complex, effective, and multifaceted drone.

Another analysis that can and should be carried out on Russian drone warfare capabilities is the origin of the manufacturers of these means.

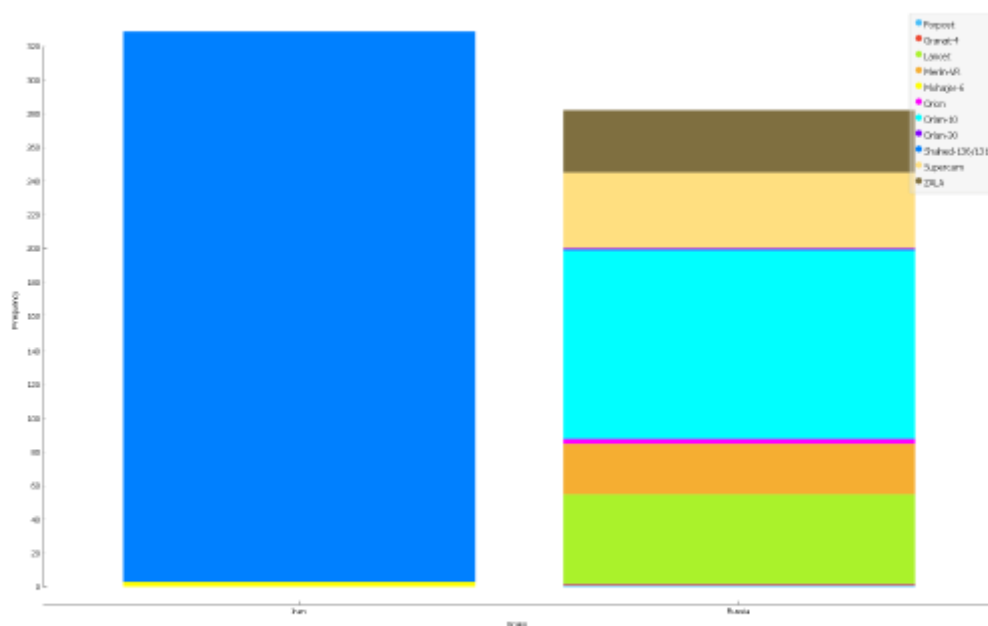


Figure 9- Russian Drones Manufacturers

From the visualization of Figure 9, it is evident that the drones can have either Russian or Iranian origins, with 53.85% of the drones being of Iranian origin, 99% of which are Shahed drones, and the remaining are Mohajer-6 drones. The remaining models, representing 46.15%, are of Russian origin. Therefore, it can be concluded that a significant part of the Russian drone warfare effort is financed by Iranian forces, (Sauvage, 2022).

Finally, it is pertinent to know the efficiency of the drones used by Russian forces by comparing the number of drone launches with those destroyed, which is illustrated in Figure 10.

From Figure 10, it can be concluded that as drones are employed, the higher the number of launches, the higher the number of drones destroyed. However, the gap between the two relationships has been increasing, which means that fewer drones launched are being destroyed by Ukrainian forces, translating into greater efficiency of Russian drones and a greater danger to Ukrainian forces. It was observed that in May 2024, about 1000 drones were launched, and only 600 were destroyed. Therefore, there

is a need for Russian forces to increase and improve their air defenses, (The Conversation, 2022).

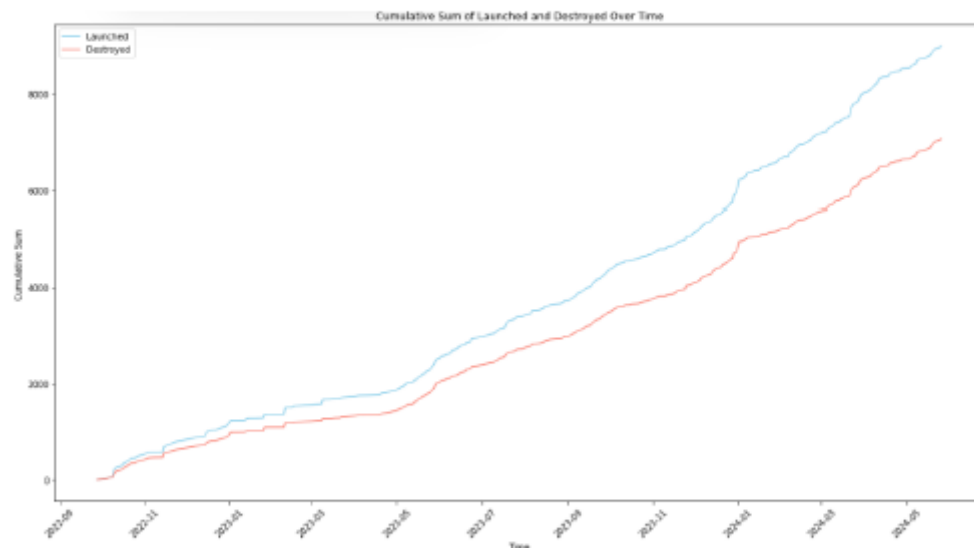


Figure 10- Launched and Destroyed Drones Comparison

To finalize the study of drone warfare in the Ukraine conflict, it is important to have a geographical understanding of the conflict and the recent drone attacks carried out on Ukrainian territory. Observing Figure 11, it can be concluded that to date, approximately 12,297 airstrikes, some of which were carried out by drones, have been conducted. A significant portion of these strikes occurred in urban centers, large metropolises, and capitals. However, there is a higher incidence along an eastern coastal area formed by drone strikes, which simultaneously demonstrates the advance of Russian forces into Ukrainian territory.

Additionally, several epicenters of drone strikes can be noted, such as:

- Kherson
- Zaporizhia
- Donetsk
- Odesa
- Mykolaiv

- Nikopol
- Luhansk
- Kharkiv

These areas have experienced a concentrated number of drone strikes, indicating strategic targets and significant conflict zones.

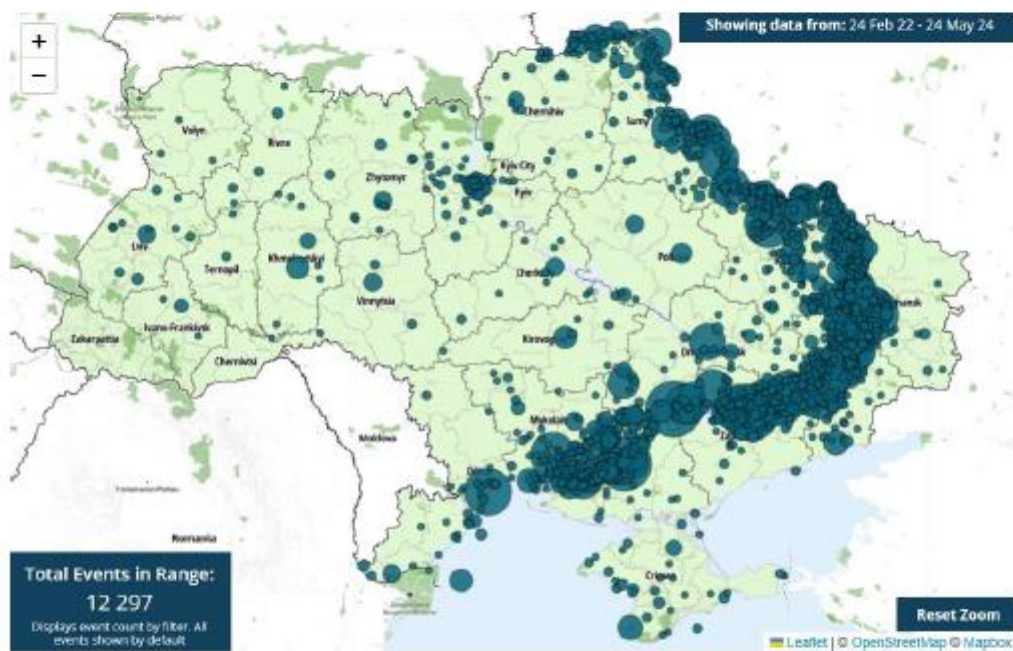
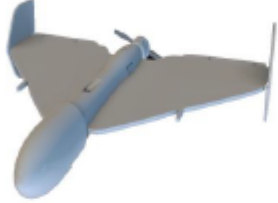


Figure 11- Drone Strikes in the Ukrainian Conflict

Russian Drone Capabilities

Based on the exploratory analysis of the Ukraine conflict, we have been able to understand and gain insights into the various drone capabilities presented by Russian forces. Table 4 demonstrates the different drones studied and their respective capabilities.

Table 4- Russian Drones List

Drone	Function	Capabilities
Shahed-136  (Army-Technology, 2023)	Weight: 200kg Wingspan: 2.5m Range: 2.500km Speed: 185km/h (Cheng, 2022)	Loitering Munition
Orlan-10  (Airforce-Technology, 2023)	Weight: 16.5kg Wingspan: 3.1m Range: 140km Speed: 150km/h (Sof, 2022)	Reconnaissance
Lancet  (Sof, 2023)	Weight: 12kg Wingspan: 2.4m Range: 40km Speed: 300km/h (Sof, 2023)	Loitering Munition
Supercam  (Panasovskyi, 2023)	Weight: 12kg Wingspan: 3.2m Range: 240km Speed: 120km/h (Supercam, 2024)	Reconnaissance

ZALA  (Airforce-Technology, 2017)	Weight: 29.5kg Wingspan: 5m Range: 150km Speed: 110km/h (Airforce-Technology, 2017)	Reconnaissance
Merlin-VR  (Defense Express, 2023)	Weight: UNK Wingspan: UNK Range: UNK Speed: UNK (Defense Express, 2023)	Reconnaissance
Orion  (Çetiner, 2021)	Weight: 1000kg Wingspan: 16m Range: 30km Speed: 200km/h (ArmyRecognition, 2021)	Mixed
Mohajer-6  (Global Security Organization, 2023)	Weight: 600kg Wingspan: 10m Range: 200km Speed: 200km/h (Global Security Organization, 2023)	ISTAR

Orlan-30  (Defense News Army, 2024)	Weight: 40kg Wingspan: 3.9m Range: 4km Speed: 150km/h (Defense News Army, 2024)	Reconnaissance
Granat-4  (Eastwood, 2022)	Weight: 30kg Wingspan: 3.2m Range: 70km Speed: 150km/h (Oliver, 2019)	Reconnaissance
Forpost  (Army Recognition, 2018)	Weight: 450kg Wingspan: 9.1m Range: 250km Speed: 200km/h (Army Recognition, 2018)	Reconnaissance

Conclusion

The exploratory data analysis on the use of drones in the Ukraine conflict has provided valuable insights into the evolving nature of drone warfare. The data shows a clear and exponential increase in the destruction of Russian drones by Ukrainian forces, indicating a growing reliance on these unmanned aerial systems by both sides. Drones have emerged as the most heavily utilized and destroyed Russian aerial asset, accounting for nearly 99% of all destroyed Russian aircraft.

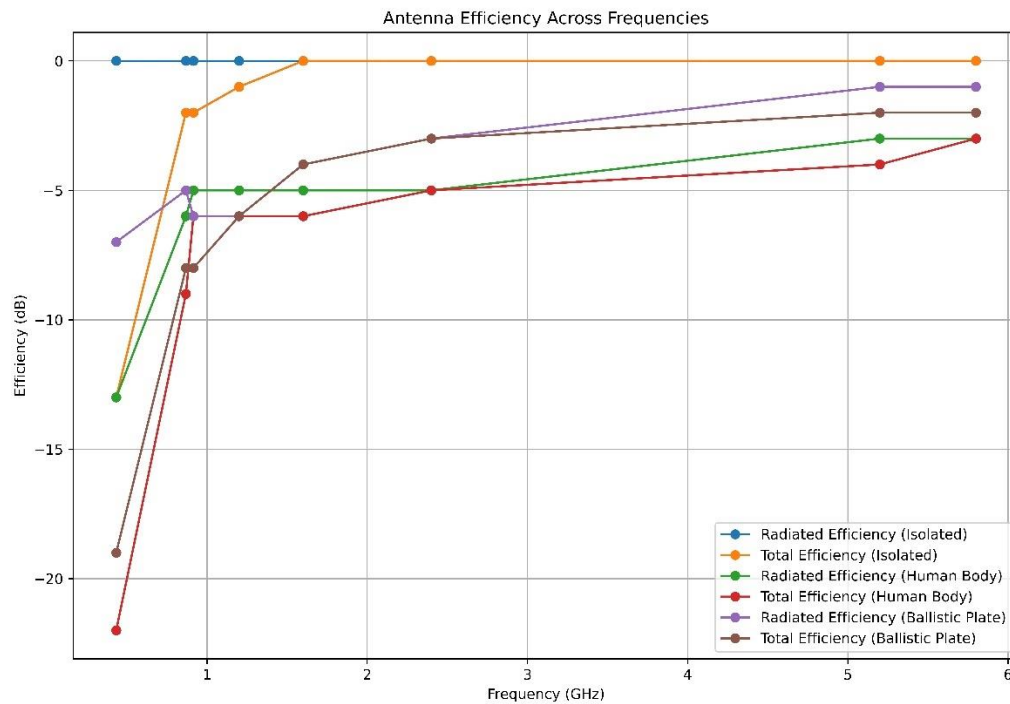
The analysis reveals that the most frequently used Russian drones are the Shahed and Orlan-10, with the former being a loitering munition drone and the latter a reconnaissance drone. This highlights the Russian military's focus on both offensive and intelligence-gathering capabilities. Furthermore, the data suggests that a significant portion of the Russian drone arsenal is of Iranian origin, underscoring the strategic partnership between the two nations.

The analysis also indicates that the efficiency of Russian drone usage is increasing, with a growing gap between the number of drones launched and those destroyed by Ukrainian forces. This trend suggests the need for Ukraine to enhance its air defense capabilities to counter the evolving threat posed by Russian drone warfare.

In conclusion, the exploratory data analysis has demonstrated the pivotal role of drones in the ongoing conflict in Ukraine. The data reveals the scale, evolution, and strategic importance of drone warfare, which has become a defining feature of modern military operations. As the conflict continues, the study of drone warfare and its implications will remain a critical area of research, with the potential to inform future military strategies and technological developments.

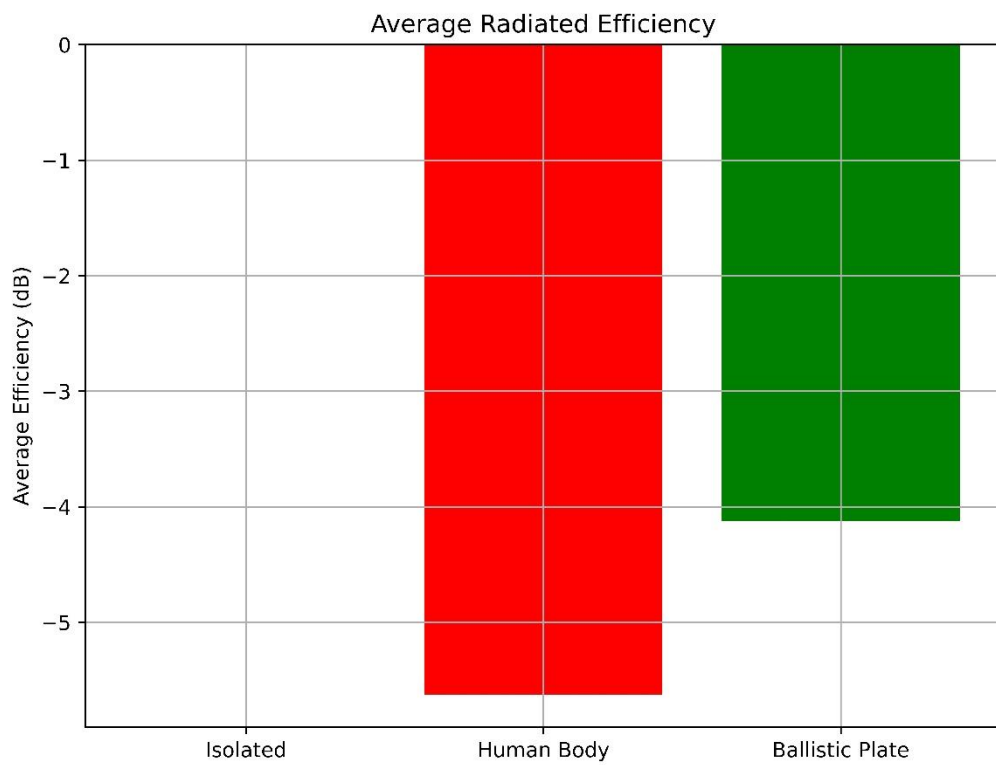
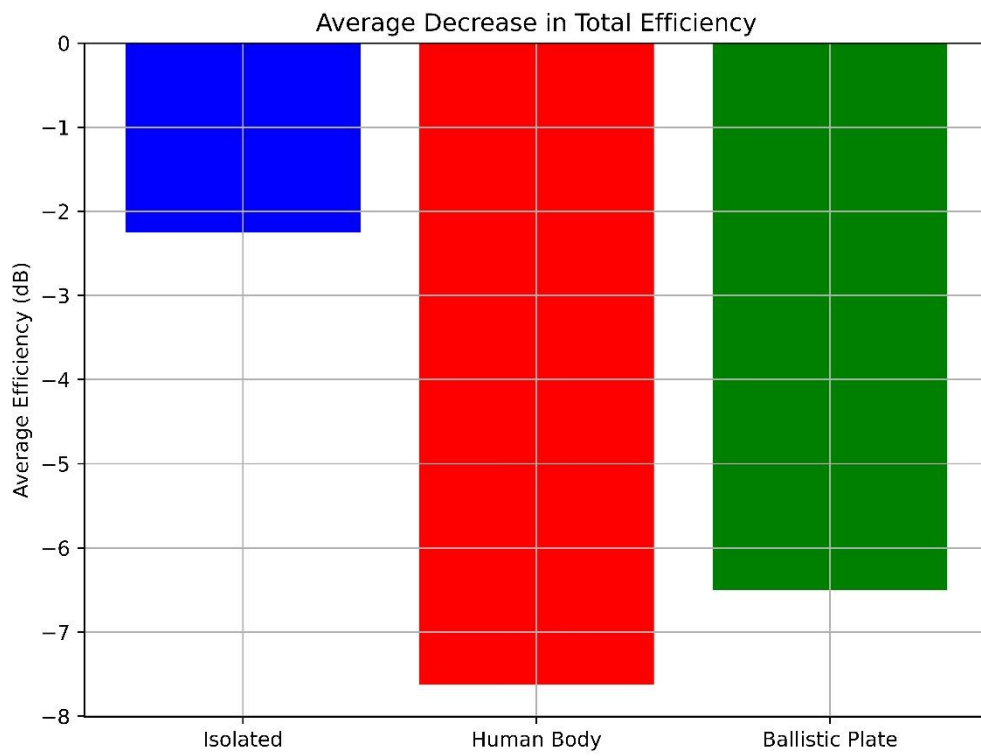
8.2. Appendix B- Efficiencies Analysis

The images referenced below are the result of a more applied study on the findings regarding the efficiency of the simulated countermeasure in the bulk of the work.



The image above demonstrates the efficiencies of the countermeasure (total and irradiated) in the three studied scenarios: isolated antenna, antenna plus human body, and antenna plus human body and ballistic plate. It concludes that with the insertion of the ballistic plate, there is an increase in the antenna's effectiveness.

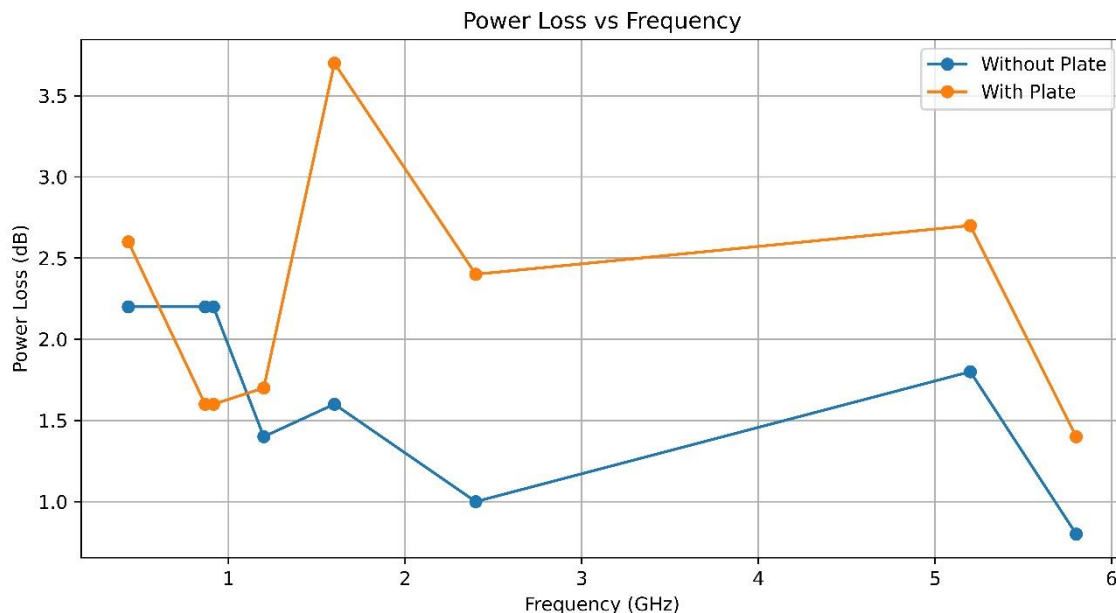
The images immediately below demonstrate a study of the average decrease in total effectiveness and irradiated effectiveness, respectively. This shows that, compared to the isolated antenna, the countermeasure always presents a smaller decrease in effectiveness with the ballistic plate.



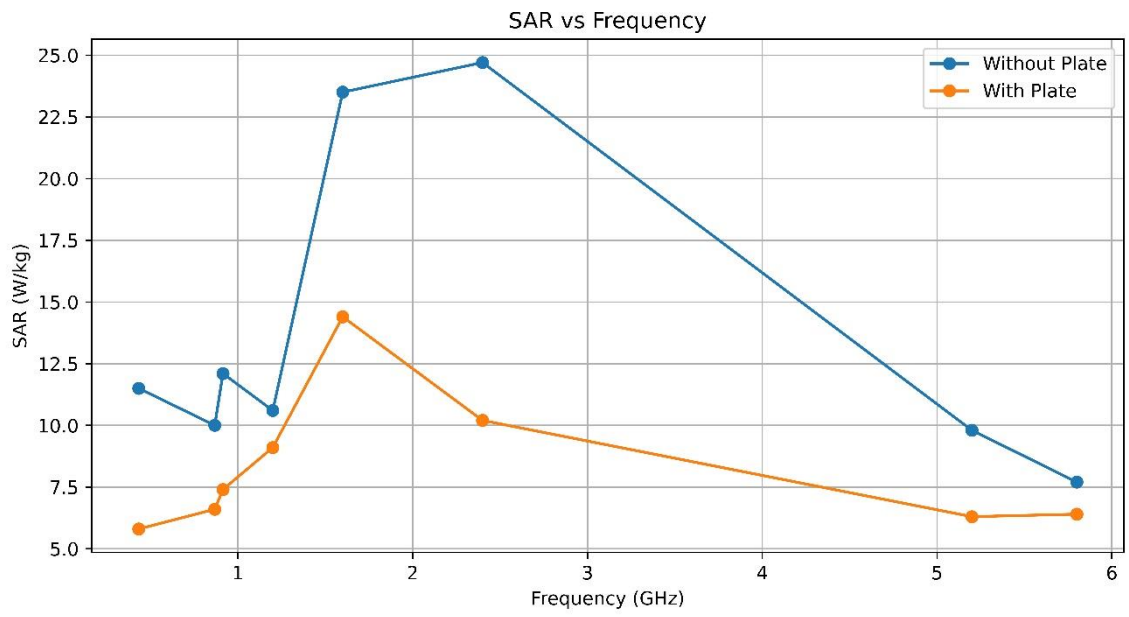
8.3. Appendix C- Power Loss and SAR Analysis

The images below demonstrate a comparative study of power loss vs. frequency and SAR vs. frequency, to identify the relationships both have with frequency.

With the power loss vs. frequency graph, it is observed that the energy lost by the countermeasure is greater with the ballistic plate than without it after the frequency of 1.2 GHz, inclusive. This occurs with the increase in frequency due to the shorter wavelength with lower absorption capacities. It also occurs due to the dielectric properties of the ballistic plate, which influence the energy lost through reflection effects.

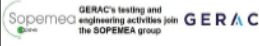


With SAR vs. Frequency, it is observed that the SAR values are significantly higher without the ballistic plate than with it, thus demonstrating that the ballistic plate acts as a shield for the combatant, reducing the energy absorption values by the operator. It is also noted that there is an increase in SAR at frequencies 1.2, 1.6, and 2.4 GHz, which are optimized by the countermeasure, making them more harmful to the combatant.



8.4. Appendix D- PITBULL WINGMAN Controlled Experiment

The experimentation demonstrated below is a test in a controlled environment, in an anechoic chamber, carried out in Toulouse on the PITBULL WINGMAN system (Development, 2019), which aims for the master's dissertation to validate results obtained in simulated and semi-controlled experimentation.

		Reference: 19T216-RE-01 Issue: – Page: 1 / 15
TEST LABORATORY OF TOULOUSE		
TEST REPORT		
EQUIPMENT DESIGNATION		
<i>Device Under Test:</i> PITBULL – PB100 & PB101 <i>Company:</i> JCPX DEVELOPMENT		
COMPOSITION OF THE DOCUMENT		Number of pages
Body of the document.....		15
Appendices.....		0
Total		15
VISAS		
Written by: Function: Test Performer Name: O. RINGUET Written on 11, October 2019	Checked by: Function: Laboratory Manager Name: A. BARREAU Checked on 14, October 2019	Approved by: Function: Laboratory Manager Name: A. BARREAU Signature numérique de Alain BARREAU Date : 2019.10.14 18:53:01 +02'00'
THE COPY OF THIS TEST REPORT IS ONLY PERMITTED WITH THE UNABRIDGED VERSION.		

The experimentation was conducted under the following conditions, as shown in the table below:

- Tests for the general and occupational public exposure.
- Testing with the system operating on its own battery.
- Testing at frequencies 2.4GHz, 5.2GHz, 5.8GHz, and 1.6GHz.

- Calculation of safety distances.

Band type	Device rotary dial position	Frequencies	RMS electric field strength (V/m) (general public)	RMS electric field strength (V/m) (occupational)
ISM 2.4 GHz only	2	2400 – 2483.5 MHz	61	137
ISM / WIFI 5.8 GHz only	3	5725 – 5875 MHz	61	137
WIFI 5.2 GHz only	4	5170 – 5250 MHz	61	137
GNSS only (PB101 only)	5	1562 – 1602 MHz	55	122

The results were the following:

2.4 GHz

Point	1	2	3	4	5	6	7	8	9	10	11	T	B	Max BS ⁽¹⁾
RMS electric field strength measured (V/m)	10	24	21	11	12	10	12	9	21	11	10	26	14	32
Maximal RMS electric field strength (V/m) (general public)	61													
Maximal RMS electric field strength (V/m) (occupational)	137													

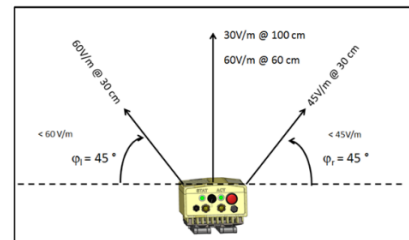


Figure 1: front side -2400 – 2483.5 MHz

5.8 GHz

Point	1	2	3	4	5	6	7	8	9	10	11	T	B	Max BS ⁽¹⁾
RMS electric field strength measured (V/m)	16	7	18	5	5	5	5	4	6	6	5	61 40 @ 5 cm	8	26
Maximal RMS electric field strength (V/m) (general public)	61													
Maximal RMS electric field strength (V/m) (occupational)	137													

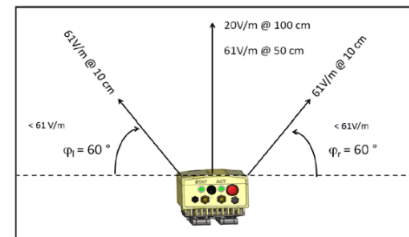


Figure 2: front side - 5725 – 5875 MHz

5.2 GHz

Point	1	2	3	4	5	6	7	8	9	10	11	T	B	Max BS ⁽¹⁾
RMS electric field strength measured (V/m)	14	10	8	5	4	5	7	3	4	3	5	56 30 @ 5 cm	9	16
Maximal RMS electric field strength (V/m) (general public)	61													
Maximal RMS electric field strength (V/m) (occupational)	137													

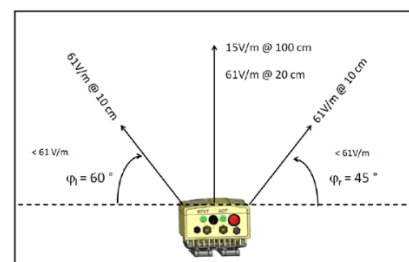


Figure 3: front side - 5725 – 5875 MHz

1.6 GHz

Point	1	2	3	4	5	6	7	8	9	10	11	T	B	Max BS ⁽¹⁾
RMS electric field strength measured (V/m)	45	31	26	44	32	45	47	28	79 55 @ 2 cm	30	30	98 61 @ 5 cm 55 @ 7 cm	66 55 @ 5 cm	55
Maximal RMS electric field strength (V/m) (general public)	55													
Maximal RMS electric field strength (V/m) (occupational)	122													

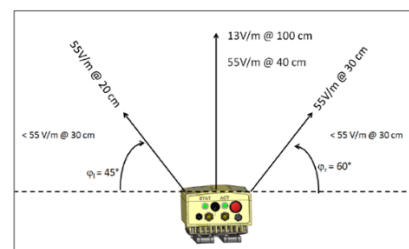
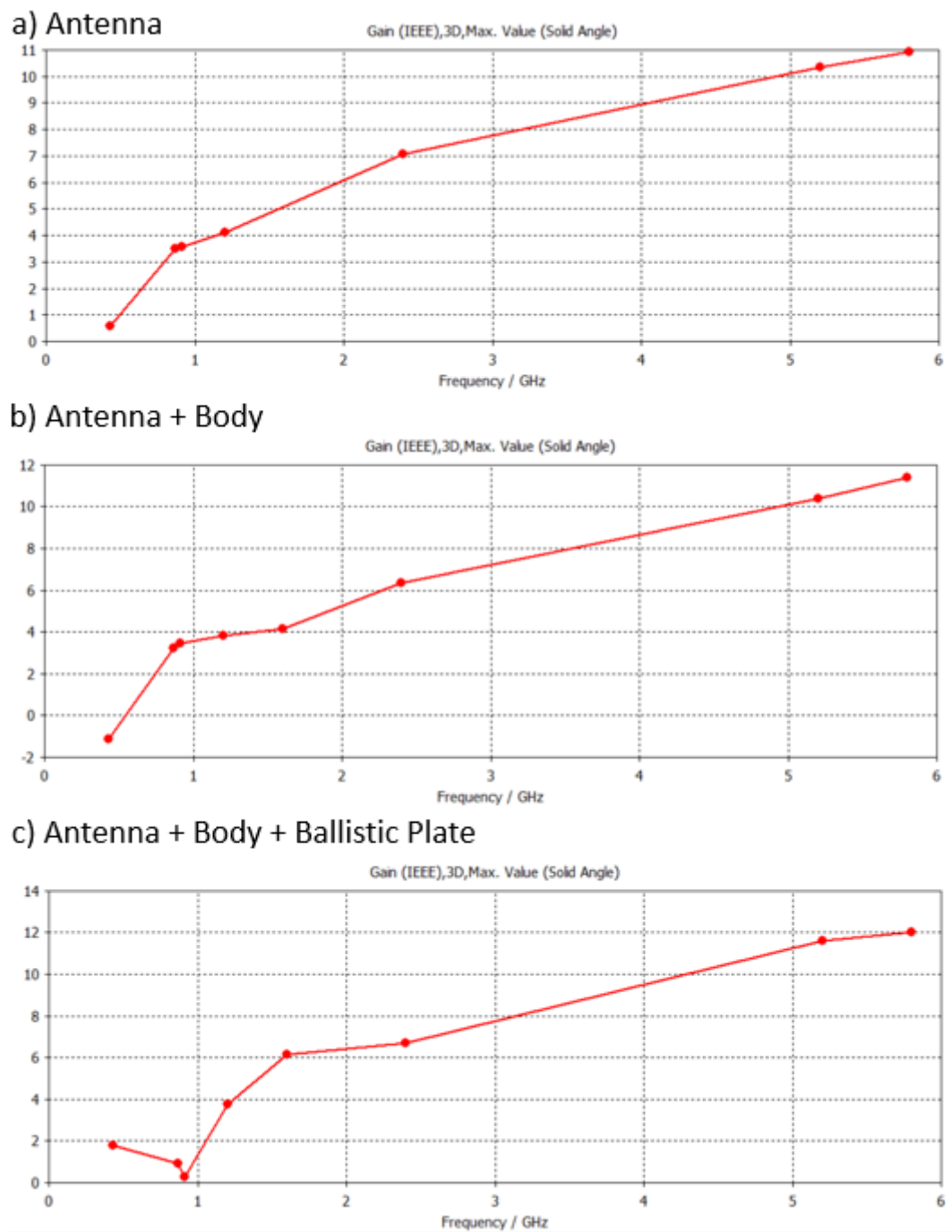


Figure 4: front side - 1562 – 1602 MHz

It is concluded, through experimentation in a controlled environment, that the system meets the general and occupational requirements for the frequencies 2.4GHz, 5.2GHz, and 5.8GHz. However, for 1.6GHz, it only meets the occupational requirements.

8.5. Appendix E- Gain Analysis

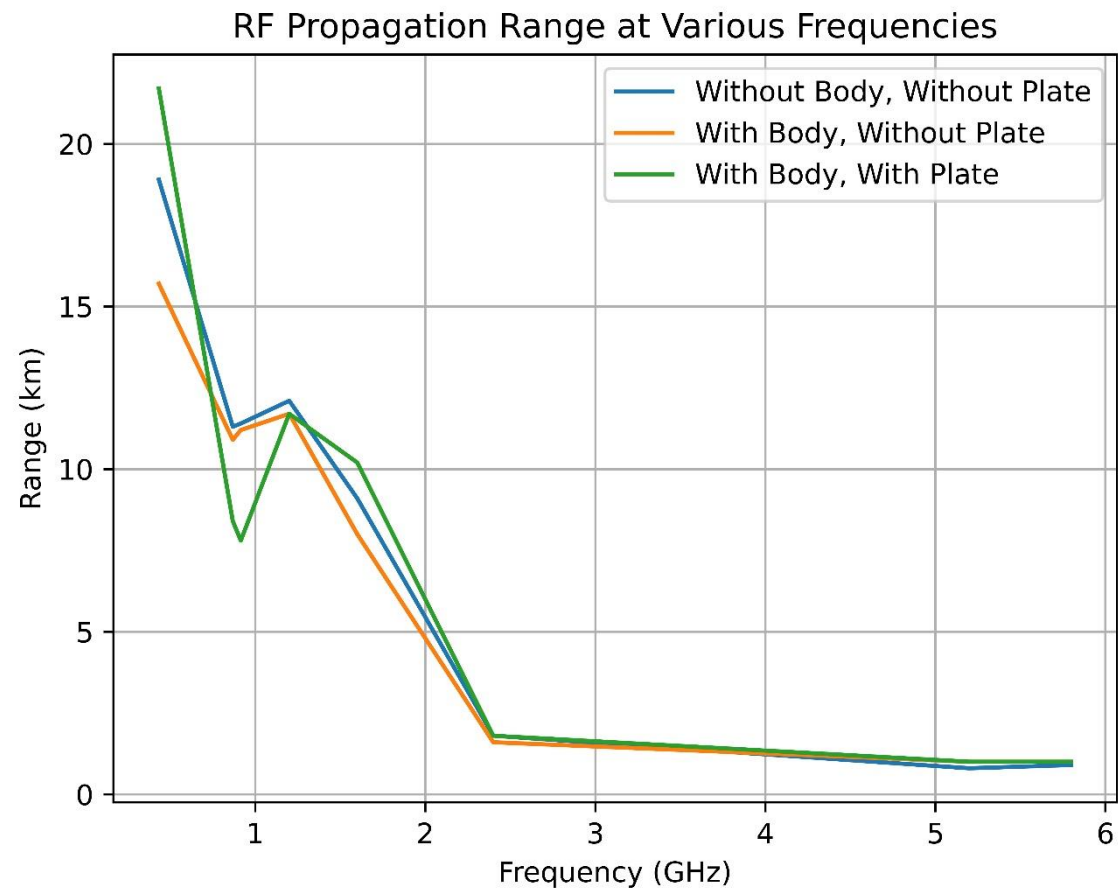
The image shown below references the various types of gains at different frequencies in the three situations under study. This gain will allow its use in calculating the Friis equation for formulating the range for each study format. The gain takes into account the influences of nature with the human body and ballistic plate.



What is concluded from the gain study is its increase with the insertion of the ballistic plate after the decrease with the human body, which leads to an increase in range with the ballistic plate worn.

8.6. Appendix F- Range Analysis

The image below demonstrates the set of ranges with the various situations studied in the dissertation, thus showing that the range increases with the insertion of the ballistic plate after its calculation with the Friis equation.



8.7. Appendix G- Friis Equation for Range Calculation Code

The code shown below is the calculation for the range using the Friis equation. The gain allowed for consideration of the use of the ballistic plate and human body and their effects. The power used was the maximum power of 10 W, and the received power was considered typical for current drones.

```
import numpy as np

def calculate_range(Pt, Gt_dB, Pr_nW, lambda_):
    Pt_watts = Pt

    # Convert received power from nanowatts to watts
    Pr_watts = Pr_nW * 1e-9

    # Convert gain from dB to linear scale
    Gt = 10 ** (Gt_dB / 10)

    # Friis Transmission Equation rearranged to solve for R
    R = np.sqrt((Pt_watts * Gt * (lambda_ ** 2)) / (Pr_watts * (4 * np.pi) ** 2))
    return R

Pt = 10
Gt_dB = 1.8
Pr_nW = 0.1
lambda_ = 0.7

# Calculate maximum range
max_range = calculate_range(Pt, Gt_dB, Pr_nW, lambda_)
print(f"The maximum range is approximately {max_range:.2f} meters.")
```


8.8. Appendix H- Energy Depth Penetration Distance Calculation Code

The code shown below is the calculation necessary to identify the values that each frequency presents that exceed 37% of the air/body barrier, approximately the common value considered by physics where signal attenuation occurs. If 37% is exceeded, it means that the energy has significantly penetrated the combatant's body. The average distance identified as this barrier was 423mm.

The code considers the calculation of the electric field magnitude using the Euclidean equation. Normalization is performed by dividing each value by the maximum value and subsequently multiplying by 100.

```
import pandas as pd
import numpy as np

file_path = '0.433n.txt'
column_names = ['x', 'y', 'z', 'ExRe', 'ExIm', 'EyRe', 'EyIm', 'EzRe', 'EzIm']
data = pd.read_csv(file_path, delim_whitespace=True, names=column_names)

data['Ex'] = data['ExRe'] + 1j * data['ExIm']
data['Ey'] = data['EyRe'] + 1j * data['EyIm']
data['Ez'] = data['EzRe'] + 1j * data['EzIm']

data['E_magnitude'] = np.sqrt(np.abs(data['Ex'])**2 + np.abs(data['Ey'])**2 + np.abs(data['Ez'])**2)

data['normalized_E'] = (data['E_magnitude'] / np.max(data['E_magnitude'])) * 100

# Define the threshold percentage
threshold_percentage = 37

min_z_value = data[data['normalized_E'] >= threshold_percentage]['z'].min()

print('Minimum z value where the electric field surpasses 37%:', min_z_value)
print('Data at this depth:')
print(data[data['z'] == min_z_value])
```


8.9. Appendix I- Energy Depth Penetration Values Calculation Code

The code shown below, like Appendix G, allows for the calculation of the average penetration value of the values that each frequency demonstrates, thus enabling the conclusion about which frequencies penetrate the combatant's body the most and are more harmful.

```
import pandas as pd
from pathlib import Path
import numpy as np

file_path = Path('5.8n.txt')

column_names = ['x', 'y', 'z', 'ExRe', 'ExIm', 'EyRe', 'EyIm', 'EzRe', 'EzIm'] # Replace ... with your column names

try:
    data = pd.read_csv(file_path, names=column_names, delimiter=r'\s+')
    print(data.head())
except Exception as e:
    print("Error occurred:", e)

    data['Ex'] = data['ExRe'] + 1j * data['ExIm']
    data['Ey'] = data['EyRe'] + 1j * data['EyIm']
    data['Ez'] = data['EzRe'] + 1j * data['EzIm']
data['E_magnitude'] = np.sqrt(np.abs(data['Ex'])**2 + np.abs(data['Ey'])**2 + np.abs(data['Ez'])**2)

# Normalize to the maximum field value
data['normalized_E'] = (data['E_magnitude'] / np.max(data['E_magnitude'])) * 100

# Define the threshold percentage
threshold_percentage = 37

if np.any(data['normalized_E'] > threshold_percentage):
    print("Electric field strength surpasses the threshold.")
else:
    print("Electric field strength is within the threshold.")

surpass_threshold_values = data[data['normalized_E'] > threshold_percentage]['normalized_E']

    if not surpass_threshold_values.empty:
        print("Values of normalized_E column that surpass 37%:")
        print(surpass_threshold_values)
    else:
        print("No values of normalized_E column surpass 37%.")

import pandas as pd

export_path = 'exported_dataframe.csv'

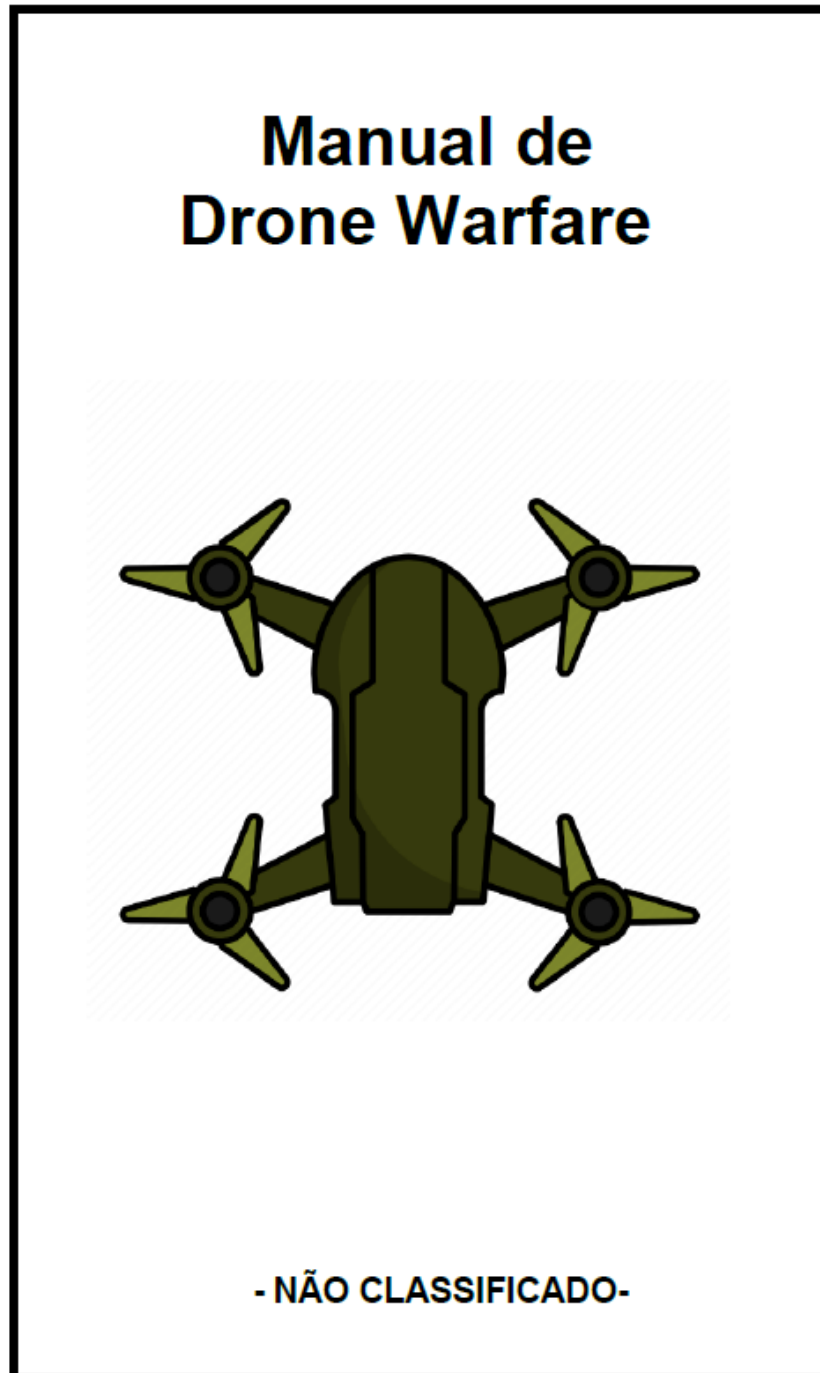
try:
    # Export the DataFrame to a CSV file
    data.to_csv(export_path, index=False)

    print(f"DataFrame exported to '{export_path}' successfully.")
except Exception as e:
    print("Error occurred:", e)

surpass_threshold_values.to_csv('threshold_exceeding_values.csv', index=False)
```


8.10. Appendix J- Drone Warfare Manual

The manual shown below is a provisional template created during the master's dissertation. The manual aims for its adoption and use by the Portuguese Marine Corps. The purpose is for operators in the field to have checklists and standards to survive and combat Drone Warfare.



Propósito

Com o aumento da proliferação e utilização de drones em conflitos armados, e outros avanços tecnológicos denotados e analisados em atuais guerras internacionais, verificou-se a necessidade de utilização de elementos especializados em sistemas aéreos não tripulados (SANT) no conceito "Light and Fast".

Os SANT têm se tornado uma ferramenta essencial em operações militares modernas devido à sua capacidade de realizar missões de reconhecimento, vigilância, e ataque com precisão e eficiência. A análise de conflitos recentes, como o conflito na Ucrânia, Gaza, Nagorno-Karabakh e Yemen, revelou a importância crítica dos drones no campo de batalha.

Este manual foi compilado com base em uma análise detalhada desses conflitos e visa fornecer um conjunto abrangente de ferramentas, técnicas, táticas e procedimentos para operadores de SANT e contramedidas. O objetivo é capacitar esses operadores a maximizar a eficácia de suas operações enquanto minimizam os riscos associados ao uso de drones no campo de batalha.

"Os combatentes continuarão a disputar guerras, mas a nova tecnologia dará aos militares, como sempre deu, maior distância do inimigo, maior capacidade de sobrevivência e letalidade"

Scharre, 2014

PROTEU- Regras para Drone Warfare

1. **Posição** de descolagem de SANT deve ser diferente de posição de aterragem. E nunca repetidos.
2. **Rádio** deve ser desligado antes de voo.
3. **Operador** deve procurar abrigo antes de começar voo.
4. **Trabalhar** sempre em binómio.
5. **Evitar** lançar SANTs a partir de pontos de reunião, bases ou posições de patrulha, ataque ou defesa. Pois em caso de spoofing o IN saberá a nossa posição.
6. **Utilizar** SANTs de Classe I NATO para identificar e testar campos elétricos inimigos. Verificando, capacidade e alcance do campo.

PROTEU- Deus Profético do Mar.
Analista da constante mudança da natureza do mar, dom da premonição e do destino.

PROCEDIMENTOS	Conhecimento Situacional	
	Reconhecer o alcance operacional de SANTs • Até 2km para longo alcance • Até 300 metros para curto alcance Manter comunicação constante com RECON com SANTs de ISR. Garantir comunicação permanente e oportuna com o Escalão Superior, transmitindo coordenadas, capacidades e movimentos dos SANT inimigos. Manter distância segura das linhas da frente • 2-5km para operação de SANT de curto-alcance. Utilizar máscaras, cobertas e abrigos para ocultação e camuflagem de vigilância de SANT inimigos. Preparar tomadas de decisões rápidas com base em dados obtidos por ISR de SANTs. Cada SANT de curto alcance com capacidades de combate ou ISR deve ser acompanhado por outro de longo alcance e maior altitude operacional para confirmação de alvo e destruição.	
Página 3 de 29		

Deteção de SANTs Inimigos

Em caso de deteção de SANT inimigo deve ser seguido um formato SALUTE e reportado ao escalão superior. Por eles será decidido as ações subsequentes e de que forma será neutralizado o SANT.

SALUTE	INFORMAÇÃO
SIZE	Quantidade Tamanho Formação
ACTIVITY	Movimento Hostilidade
LOCATION	Aonde Como Coordenadas
UNIT	Classe NATO Tipo Nº de Rotores Altitude Operacional Luzes Peculiaridades
TIME	Quando
EQUIPMENT	Carga Útil Sensores Armamento

Métodos de detecção SANT

Método da Mão:

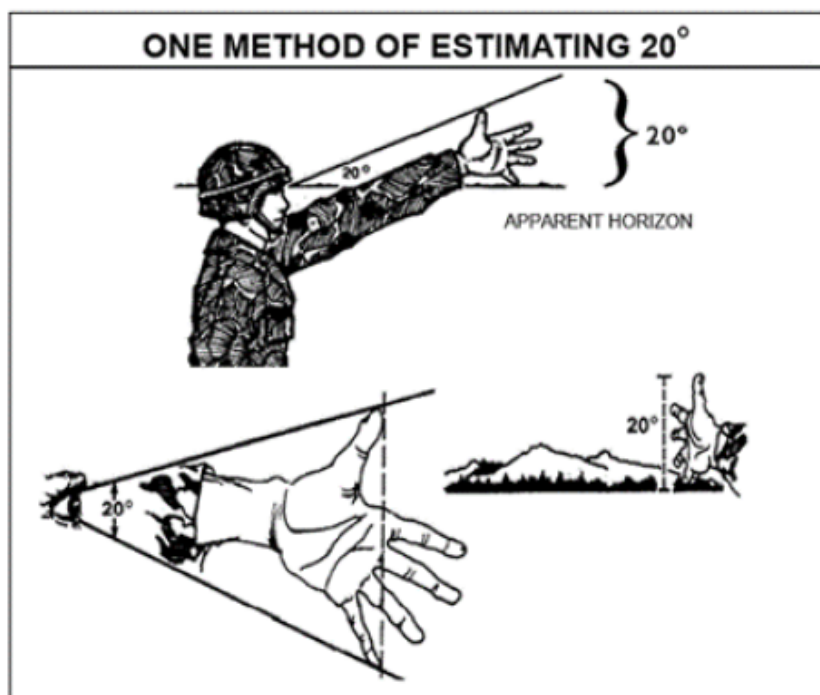


Figura retirada de (Headquarters, Department of the Army, 2023)

SANTs inimigos normalmente operam a 20° graus do chão, que é aproximadamente o tamanho da mão do combatente. Deve-se colocar a mão por cima da linha do horizonte e vigiar a zona envolvente por cima do polegar.

Métodos de detecção SANT

Método Vertical:

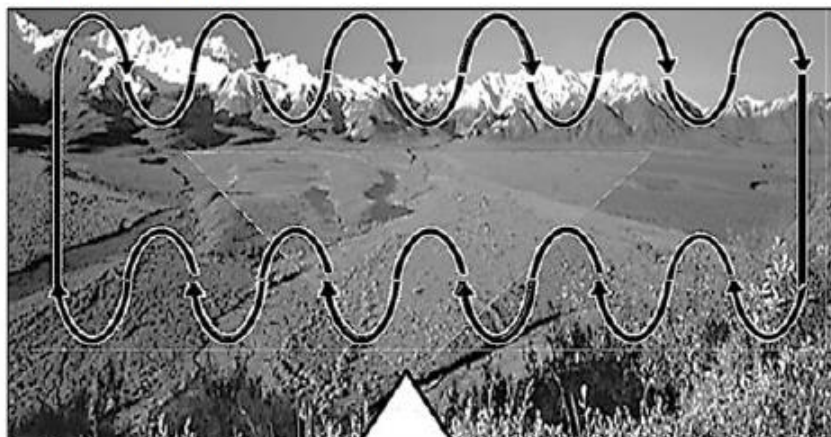


Figura retirada de (Headquarters, Department of the Army, 2023)

Método vertical visa a vigilância do campo de batalha através de uma observação circular vertical, tendo em conta os movimentos imprevisíveis dos SANT.

Métodos de detecção SANT

Método Horizontal:

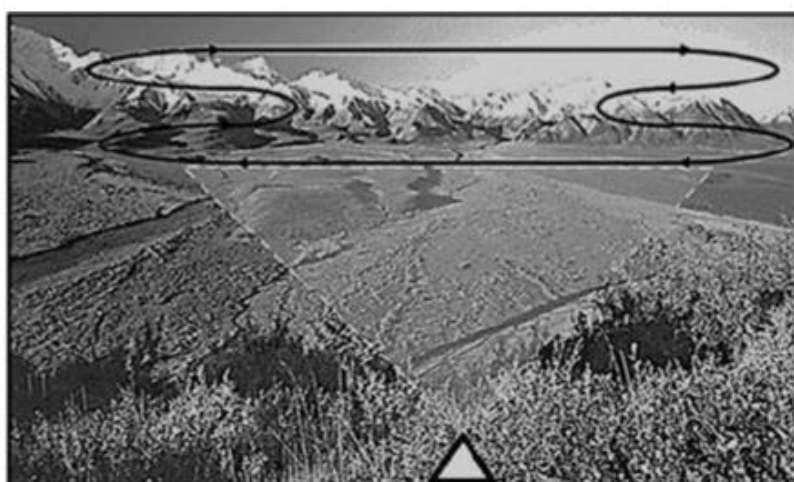


Figura retirada de (Headquarters, Department of the Army, 2023)

Método vertical visa a vigilância do campo de batalha através de uma observação circular horizontal, começando do céu ao horizonte.

Métodos de detecção SANT

Avaliação de Alvos e Tomada de Decisão:

- Avaliar Importância e o nível de ameaça dos alvos identificados
- Decidir sobre o método de ataque:
 - SANT:
 - SANTs FPV (First Person View) para alvos precisos
 - Alvos móveis onde a precisão é crucial
 - Artilharia
 - Para alvos estacionários ou maiores onde é necessário mais poder de fogo
 - SANT funciona como corretor de tiro
- Eficiência do Ataque:
 - Destruir alvos de maior valor com o menor uso de SANTs possível
 - Prepara ataques secundários para caso principal não seja eficiente
- Segurança e Evasão
 - Após executar ataque, relocalizar.

Monitorizar continuamente as COMMS inimigas e atividades SANT para antecipar retaliações

PROCEDIMENTOS

RECONHECIMENTO								
Se durante progressão, necessitar de pedir reconhecimento por meios SANT deve emitir um pedido de reconhecimento à unidade de SANT da seguinte maneira:								
<table><tr><td>Tipo de Reconhecimento necessário (Área, Zona, sensores necessários...)</td></tr><tr><td>Nome do Alvo</td></tr><tr><td>Localização do Alvo</td></tr><tr><td>Elementos de informação necessários</td></tr><tr><td>Informações para o reconhecimento</td></tr><tr><td>Perigo de detecção para o reconhecimento (Baixo, Médio, Alto)</td></tr><tr><td>Informações do espaço aéreo</td></tr></table>		Tipo de Reconhecimento necessário (Área, Zona, sensores necessários...)	Nome do Alvo	Localização do Alvo	Elementos de informação necessários	Informações para o reconhecimento	Perigo de detecção para o reconhecimento (Baixo, Médio, Alto)	Informações do espaço aéreo
Tipo de Reconhecimento necessário (Área, Zona, sensores necessários...)								
Nome do Alvo								
Localização do Alvo								
Elementos de informação necessários								
Informações para o reconhecimento								
Perigo de detecção para o reconhecimento (Baixo, Médio, Alto)								
Informações do espaço aéreo								
Tabela retirada de (North Atlantic Treaty Organization, 2020)								

ANÁLISE DE RISCO

A análise de risco permite calcular, rapidamente, o perigo da missão e contribuir para o conhecimento situacional do comandante e para as ações subsequentes. A análise é efetuada da seguinte maneira.

$$Risco = \frac{Ameaças \times Vulnerabilidades \times Impacto}{Contramedidas}$$

Ameaças são todos os tipos de ataque que a força pode sofrer em todos os domínios por meios de SANTs. Vulnerabilidades são fraquezas nas defesas aéreas, tanto nos sistemas como na área de defesa que oferecem. Impacto são os possíveis danos resultantes de ataques de SANTs inimigos.

Quanto mais e melhores os sistemas de contramedidas, menor é o risco e mais segura se encontra a nossa força de ataques aéreos inimigos. De acordo com os valores atribuídos a cada variável o resultado é avaliado da seguinte maneira:

Risco	Percentagem
Alto	>75%
Médio-Alto	61-75%
Médio	31-60%
Baixo	16-30%
Muito Baixo	1-15%

Tabela retirada de (Barnhart, Marshall, & Shappee, 2021)

PROCEDIMENTOS	METOC		
	As condições meteorológicas podem afetar e até impedir a utilização de SANTS durante a missão, logo deve-se conhecer as devidas limitações que o METOC pode incutir limitações na operação de SANTS, tanto no voo como nos seus sensores, comunicações e cargas.		
	METOC	SANT	SENSORES
	Gelo	Piores Condições de voo	Obstrução
	Ventos		Pior Recepção
	Chuva	Voo não aconselhado	Pior qualidade de imagem
	Névoa	Risco no decolar, aterragem e colisão	Pior Recepção
	Altas Temperaturas	Sobreaquecimento	Menor eficácia da penetração de luz
	Baixas Temperaturas	Redução da bateria	
	Tabela retirada de (North Atlantic Treaty Organization, 2020)		
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METOC

Bom Tempo	Altitude Operacional acima de 2500m, visibilidade de 5km. Ótimo para ISR.
Mau Tempo	Altitude Operacional até 2500m, visibilidade entre 1.5km a 5km. Dificulta direção e reconhecimento do SANT
Tempo Adverso	Altitude Operacional até 90m, visibilidade até 1.5km. Ataques limitados à distância visual.

Tabela retirada de (North Atlantic Treaty Organization, 2020)

PROCEDIMENTOS

PRÉ-VOO CHECKLIST	
TÁTICAS	1. Determinar pontos de interesse para informações operacionais e forças de reconhecimento. ☐
	2. Identificar um local coberto e abrigado para o operador do SANT com visibilidade direta de 250 a 450 metros do voo. ☐
	3. Localizar um ponto de decolagem seguro para o SANT a 150 a 200 metros do operador, livre de obstáculos, numa área de 7 por 7 metros. ☐
	4. Familiarizar-se com o terreno e identificar pontos conspícuos para manter o controlo do SANT em caso de interferência ou falsificação. ☐
	5. Limpar a memória do SANT antes do voo. ☐
	6. Coordenar com a unidade C-SANT sobre o voo do SANT amigo. ☐
	7. Ter um assistente para mover o SANT para o ponto de decolagem. ☐
	8. Após a decolagem, o assistente deve retornar imediatamente ao abrigo. ☐
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DURANTE-VOO CHECKLIST

1. Elevar o SANT a 250 metros acima do nível do solo.
2. Identificar e analisar o som das hélices do SANT.
3. Continuar o voo até 350 metros.
4. Monitorar o sinal.
5. Monitorar a velocidade do SANT.
6. Monitorar a vida útil da bateria e garantir que o SANT tenha bateria suficiente para o retorno, geralmente exigindo 60% da bateria disponível para o voo de retorno.

☐☐☐☐☐☐

TÁTICAS

PÓS-VOO CHECKLIST

1. Mobilizar o SANT para o Retorno à Casa (RTH). ☐
2. Mudar o modo para manual para aterragem de SANT a 1km da posição. ☐
3. Levar o SANT a 250 metros acima do nível do solo, a 500 metros do ponto de estacionamento, e descer para 120 metros acima do nível do solo. ☐
4. Realizar uma verificação visual do SANT até 20 metros de distância do ponto de estacionamento. ☐
5. Recuperar o SANT o mais rápido possível pelo assistente e desligá-lo imediatamente. ☐

PLANEAMENTO CHECKLIST																																																														
<table border="1"> <tr> <td colspan="2">Duty Assignments:</td> </tr> <tr> <td></td> <td>Critical skill specialties identified and on-hand</td> </tr> <tr> <td></td> <td>Additional personnel necessary for planned mission time</td> </tr> <tr> <td colspan="2">Enemy Situation:</td> </tr> <tr> <td></td> <td>Units / order of battle / uniforms-dress</td> </tr> <tr> <td></td> <td>Enemy unit locations plotted on map</td> </tr> <tr> <td></td> <td>Strengths / weaknesses</td> </tr> <tr> <td></td> <td>Most probable COA</td> </tr> <tr> <td></td> <td>Most dangerous COA</td> </tr> <tr> <td></td> <td>ADA threats (for each weapon system)</td> </tr> <tr> <td></td> <td>System Location plotted on map</td> </tr> <tr> <td></td> <td>Maximum/minimum range (threat rings plotted on map)</td> </tr> <tr> <td></td> <td>Minimum engagement altitude</td> </tr> <tr> <td></td> <td>Strengths</td> </tr> <tr> <td></td> <td>Weaknesses</td> </tr> <tr> <td></td> <td>Planned reaction</td> </tr> <tr> <td></td> <td>Night vision capability</td> </tr> <tr> <td></td> <td>EW threat</td> </tr> <tr> <td></td> <td>Meaconing, interference, jamming, and intrusion [MIJI] of UAS uplink/downlink</td> </tr> <tr> <td></td> <td>CBRN threats</td> </tr> <tr> <td colspan="2">Friendly Situation:</td> </tr> <tr> <td></td> <td>Overall mission/intent</td> </tr> <tr> <td></td> <td>Unit mission/intent</td> </tr> <tr> <td></td> <td>Maps or imagery of operating area</td> </tr> <tr> <td></td> <td>Friendly unit location plotted on map</td> </tr> <tr> <td></td> <td>Friendly manoeuvre graphics posted on map</td> </tr> <tr> <td></td> <td>UAS readiness status</td> </tr> <tr> <td></td> <td>Supported unit task/purpose</td> </tr> <tr> <td></td> <td>Adjacent unit task/purpose</td> </tr> <tr> <td></td> <td>Abort criteria</td> </tr> </table>		Duty Assignments:			Critical skill specialties identified and on-hand		Additional personnel necessary for planned mission time	Enemy Situation:			Units / order of battle / uniforms-dress		Enemy unit locations plotted on map		Strengths / weaknesses		Most probable COA		Most dangerous COA		ADA threats (for each weapon system)		System Location plotted on map		Maximum/minimum range (threat rings plotted on map)		Minimum engagement altitude		Strengths		Weaknesses		Planned reaction		Night vision capability		EW threat		Meaconing, interference, jamming, and intrusion [MIJI] of UAS uplink/downlink		CBRN threats	Friendly Situation:			Overall mission/intent		Unit mission/intent		Maps or imagery of operating area		Friendly unit location plotted on map		Friendly manoeuvre graphics posted on map		UAS readiness status		Supported unit task/purpose		Adjacent unit task/purpose		Abort criteria	MISSÃO
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Página 16 de 29																																																														

MISSÃO	PLANEAMENTO CHECKLIST		
		Other UAS units task/purpose	
		Other UAS units operations posted on map	
		Friendly aviation scheme of manoeuvre	
		Review site security	
		Additional equipment necessary for planned mission time	
		Evaluate all specified tasks from:	
		OPORD	
		WARNOs	
		FRAGOs	
		Verify ACO, ATO, SPINS requirements	
		ROZ locations/dimensions/frequency/call signs	
		Artillery position area locations plotted	
		Active routes/airspace control points plotted	
		Verify method of airspace control	
		Positive control measures	
		Procedural control measures	
		Verify H-hour	
		Spare UA procedures	
		Emergency procedures	
		Divert plan	
		Downed UA recovery plan	
		Weather decision time	
		Mission Planning:	
		Sensor selection/options	
		EO and IR imagery payload for day/night operations	
		Other sensors	
		Weapons load (if capable)	
		Map reconnaissance of mission area	
		Identify terrain that will interfere with LOS data link	
		NAIs	
		Grids defining NAIs	
		Heading and distance to NAI from launch point	
	Heading and distance between NAIs		
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PLANEAMENTO CHECKLIST

	Identify/mark natural and manmade hazards to flight
	Local hazards
	Sectionals
	Alternate route (ingress and egress)
	Threats plotted along route
	Weather
	Clouds
	Precipitation
	Wind
	Visibility
	Temperature / thermal crossover
	Illumination
	Launch/takeoff and recovery/landing area identified
	Flight route outside threat engagement rings
	Route time
	Loiter time
	Verify grids
	Check all altitudes, azimuths, and distances
	Navigational systems check/accuracy
	Times submitted to higher headquarters
	Waypoint card printed
	Air control points plotted on map
	Primary/alternate routes plotted on map
	Contingency actions
	Fuel planning:
	Availability and on-hand stock age of fuel (AVGAS/MOGAS/JP-8)
	Availability and on-hand stock age of batteries
	Availability and on-hand stock age of ammunition
	Estimated fuel burn rate
	Estimated battery usage rate
	Minimum fuel at departure
	Bingo fuel
	Communication plan:

MISSÃO

MISSÃO	PLANEAMENTO CHECKLIST	
Tabela retirada de (North Atlantic Treaty Organization, 2020)		
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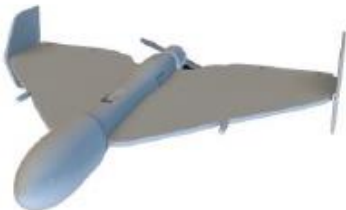
Classificação SANT

NATO UAS CLASSIFICATION						
Class	Category	Normal Employment	Normal Operating Altitude	Normal Mission Radius	Primary Supported Commander	Example Platform
Class III (> 600 kg)	Strike/Combat *	Strategic/National	Up to 65,000 ft MSL	Unlimited (BLOS)	Theatre	Reaper
	HALE	Strategic/National	Up to 65,000 ft MSL	Unlimited (BLOS)	Theatre	Global Hawk
	MALE	Operational/Theatre	Up to 45,000 ft MSL	Unlimited (BLOS)	JTF	Heron
Class II (150 kg - 600 kg)	Tactical	Tactical Formation	Up to 18,000 ft AGL	200 km (LOS)	Division, Brigade	Watchkeeper
Class I (< 150 kg)	Small (>15 kg)	Tactical Unit	Up to 5,000 ft AGL	50 km (LOS)	Battalion, Regiment	Scan Eagle
	Mini (<15 kg)	Tactical Sub-unit (manual or hand launch)	Up to 3,000 ft AGL	Up to 25 km (LOS)	Company, Platoon, Squad	Skylark
	Micro ** (<66 J)	Tactical Sub-unit (manual or hand launch)	Up to 200 ft AGL	Up to 5 km (LOS)	Platoon, Squad	Black Widow

Figura retirada de (North Atlantic Treaty Organization, 2019)

Lista de SANTs

RÚSSIA

	<u>SHAHED-136</u> Peso-200kg Comp-2.5m Alc-2.500km Vel-185km/h	Drone Kamikaze
	<u>ORLAN-10</u> Peso-16.5kg Comp-3.1m Alc-140km Vel-150km/h	ISR
	<u>LANCET</u> Peso-12kg Comp-2.4m Alc-40km Vel-300km/h	Drone Kamikaze

Lista de SANTs

	<u>SUPERCAM</u> Peso-12kg Comp-3.2m Alc-240km Vel-120km/h	ISR
	<u>ZALA</u> Peso-29.5kg Comp-5m Alc-150km Vel-110km/h	ISR
	<u>MERLIN-VR</u> Peso-UNK Comp-UNK Alc-UNK Vel-UNK	ISR

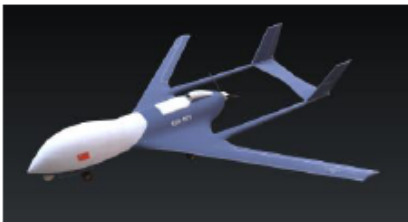
ANEXO B

ANEXO B	Lista de SANTs	
		<u>ORION</u> Peso-1000kg Comp-16m Alc-30km Vel-200km/h ISTAR
		<u>MOHAJER-6</u> Peso-600kg Comp-10m Alc-200km Vel-200km/h ISTAR
		<u>ORLAN-30</u> Peso-40kg Comp-3.9m Alc-4km Vel-150km/h ISR
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Lista de SANTs

	<u>GRANAT-4</u> Peso-30kg Comp-3.2m Alc-70km Vel-150km/h	ISR
	<u>FORPOST</u> Peso-450kg Comp-9.1m Alc-250km Vel-200km/h	ISR

ANEXO B

Lista de SANTs		
ANEXO B	<u>CHINA</u>	
		<u>WING LOONG II</u> Peso-4200kg Comp-20.5m Alc-1000km Vel-370km/h ISTAR
		<u>CH-4</u> Peso-345kg Comp-18m Alc-2000km Vel-435km/h ISTAR
		<u>BZK-005</u> Peso-1200kg Comp-19m Alc-UNK Vel-180km/h ISR
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Lista de SANTs

	<u>DJI PHANTOM 4</u> Peso-1.3kg Comp-0.3m Alc-5km Vel-56km/h	Drone Kamikaze
	<u>DJI MAVIC 3</u> Peso-0.8kg Comp-0.2m Alc-15km Vel-76km/h	Drone Kamikaze
	<u>DJI MATRICE</u> Peso-5kg Comp-0.9m Alc-15km Vel-82km/h	Drone Kamikaze Ou Logístico

ANEXO B

SANTs COMMS RF

ANEXO C

**TABLE 1 : STANDARD DEFINITIONS
OF RADIO SPECTRUM SEGMENTS**

Name	Frequency range	Applications
Low frequency (LF)	30 to 300 kHz	Navigation, time standards
Medium frequency (MF)	300 kHz to 3 MHz	Marine/aircraft navigation, AM broadcast
High frequency (HF)	3 to 30 MHz	AM broadcasting, mobile radio, amateur radio, shortwave broadcasting,
Very high frequency (VHF)	30 to 300 MHz	Land mobile, FM/TV broadcast, amateur radio
Ultra high frequency (UHF)	300 MHz to 3 GHz	Cellular phones, mobile radio, wireless LAN, PAN
Super high frequency (SHF), millimeter-wave range	3 to 30 GHz	Satellite, radar, backhaul, TV, WLAN, 5G cellular
Extremely high frequency (EHF)	30 to 300 GHz	Satellite, radar, backhaul, experimental, 5G cellular
Terahertz , tremendously high frequency (THF) or far infrared (FIR)	300 GHz to IR	R & D, experimental

Tabela retirada de (Nichols, Mumm, Lonstein, Ryan, & Carter, 2019)

TABLE 2: MICROWAVE LETTER BAND DESIGNATIONS

Band	Frequency range	Applications
L	1 to 2 GHz	Satellite, navigation (GPS, etc.), cellular phones
S	2 to 4 GHz	Satellite, SiriusXM radio, unlicensed (Wi-Fi, Bluetooth, etc.), cellular phones
C	4 to 8 GHz	Satellite, microwave relay, Wi-Fi, DSRC
X	8 to 12 GHz	Radar
K _u	12 to 18 GHz	Satellite TV, police radar
K	18 to 26.5 GHz	Microwave backhaul
K _a	26.5 to 40 GHz	Microwave backhaul, 5G cellular
Q	30 to 50 GHz	Microwave backhaul, 5G cellular
U	40 to 60 GHz	Experimental, radar
V	50 to 75 GHz	New WLAN, 802.11ad/WiGig
E	60 to 90 GHz	Microwave backhaul
W	75 to 110 GHz	Automotive radar
F	90 to 140 GHz	Experimental, radar
D	110 to 170 GHz	Experimental, radar

Tabela retirada de (Nichols, Mumm, Lonstein, Ryan, & Carter, 2019)

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8.11. Appendix K- Interview Guides

Below are the various exploratory interviews conducted during the dissertation with the aim of collecting valuable information data for drawing conclusions and gathering important information for future work.

The interview guides allow the reader to understand the various interviewees, their roles and specializations, and the questions asked about the various topics surrounding Drone Warfare.

The interviewees were as follows:

- Commander Faias Martins, commander of unit X31.
- Representative of ANACOM, general department of information and innovation.
- Ms. Marilia Frias, managing associate of Vieira de Almeida Enterprise, legal expert in the use of drones in civilian environments.
- Commander Jesus Alves, commander of the Force Projection Unit of the Portuguese Marine Corps.
- Dr. James Patton Rogers, NATO Country Director of the Full Spectrum of Drone Warfare Project, expert in Drone History.
- Samuel Bendett, Adviser with CNA and CNAS Strategy, specialist in Drone Warfare.
- Colonel (Retired) John Antal, specialist in Future Warfare.

Interview Guide		
Date: 031030MAY24	Interviewer: ASPOF FZ Teixeira da Costa	Interviewee: CFR M Faias Martins Occupation: X31 Unit Commander
Objectives	Questions	
Drones utilized by the Portuguese Navy and Marine Corps	1. What is the purpose of the X31 unit? 2. What is the employment of the drones in the Portuguese Navy? 3. How is the integration of drones in naval operations? 4. Which drones does the Portuguese Navy operate? 5. What are their advantages?	
Drone modification, AI and Swarm implementation in drones	1. Is there an effort in implementing AI in drones? 2. Is the Portuguese Navy experimenting Swarm technology? 3. How do you see the autonomy evolution in drones in the future? 4. Do you believe in a possibility of prohibition of drones in armed conflicts?	
Drone employment in the Light and Fast concept	1. How are drones employed in the Light and Fast concept of the Portuguese Marine Corps? 2. Who trains the drone operators and what course is given?	
Portuguese Navy's C-UAS	1. In addition to the PITBULL WINGMAN system does the Portuguese Navy have any other C-UAS?	

Interview Guide		
Date: 081200MAY24	Interviewer: ASPOF FZ Teixeira da Costa	Interviewee: ANACOM Representative Occupation: General Department of Information and Innovation
Objectives	Questions	
Legal bases of the utilization of the electromagnetic spectrum in the civil environment	1. What are the laws and what convention explores the electromagnetic spectrum in a national level? 2. What is the legal definition of a jammer and spoofer? 3. Is it legal for a civilian to perform jamming? If it is, in what situations? 4. What are the frequency bands permitted and prohibited? 5. Is it legal to obtain or construct jammers?	

Interview Guide		
Date: 131500MAY24	Interviewer: ASPOF FZ Teixeira da Costa	Interviewee: Sra. Marília Frias Occupation: Managing Associate of Vieira de Almeida Enterprise
Objectives	Questions	
Legal questions of drone utilization in civil and military environments	1. What are the main legal considerations in drone utilization in military and civil environments? 2. Has the case of drone accidents and related injuries been increasing? 3. What has been done to decrease the accidents? 4. What is the Portugal position in the european regulation in drone utilization?	
Legal considerations in the utilization of the eletromagnetic spectrum in drone countermeasures	1. What are the legal considerations in the utilization of the eletromagnetic spectrum? 2. What are the legal concerns in it's use in armed conflicts? 3. What is the international regulation to drone and anti-drone utilization in military and civil conflicts?	
Artificial Intelligence associated to Swarming development	1. Is there an european regulation for AI and Swarm technologies?	
Drone prohibition in armed conflicts	1. Do you believe in a possibility of prohibition of drones in armed and civil conflicts?	

Interview Guide		
Date: 201400MAY24	Interviewer: ASPOF FZ Teixeira da Costa	Interviewee: CFR FZ Jesus Alves Occupation: UPF Unit Commander
Objectives	Questions	
Generalities about the Light and Fast concept of the Portuguese Marine Corps	1. What is the purpose of the Light and Fast Concept implementation in the Portuguese Marine Corps? 2. What was the thought process behind and it's objectives? 3. What has been the difficulties in implementing the concept?	
Drone, drone operators and countermeasures employment in the Light and Fast Concept	1. How are drone operators and countermeasures idealized in the operational organization of the Light and Fast concept? 2. What systems, weapons and material do they carry? 3. What training do the drone operators go through to be established as drone specialists? Who or what unit provides the training?	

Interview Guide		
Date: 171800JUN24	Interviewer: ASPOF FZ Teixeira da Costa	Interviewee: Dr. James Patton Rogers Occupation: NATO Country Director of the Full Spectrum of Drone Warfare Project
Objectives	Questions	
The Drone Ages, Definitions and Classifications	1. How do you define the first and second drone ages, and do you agree that the second drone age started earlier, perhaps during the second Nagorno-Karabakh war? 2. What do you believe will define the third drone age? 3. How do you define a drone in a military context? Could you elaborate on your statement that a drone's essence lies in its loitering capability, with reconnaissance being its primary function? 4. Is there an international agreement on the definition and classification of drones, and do you believe current UAV classifications are outdated?	
Current and Future Capabilities of C-UAS	1. What do you believe is the most effective method for destroying enemy UAVs, considering the weaknesses of current systems? 2. You mentioned the NATO curtain wall against Russian UAV forces and its flaws. What improvements can be made?	
Drones Ethical and Legal Considerations on Military and Civil Conflicts	1. Do you believe an international framework for drones in civilian environments is necessary? Are initiatives like U-SPACE sufficient? 2. Regarding military drones, do you believe existing frameworks need updating to address new technologies? 3. Do you believe the use of armed drones could be classified as a war crime in the future? 4. Do you see the EU's regulation of AI in military systems as an advantage or a limitation? Considering Russia and China's lack of regulation, do you think they have an edge in development? 5. How do you think these regulations will impact the autonomy of military systems, and what are the ethical and legal implications?	
The Impact and Evolution of Drone Warfare in Conflicts	1. What are the key lessons learned from recent conflicts regarding drone warfare? 2. Do you believe drones will continue to decrease in size while increasing in range, potentially making HALE and larger drones obsolete? 3. What are the lessons of these conflicts in AI and Swarms? 4. Do you think that 5G in the IoT of drones will be the next step?	
Development and Dissemination of Doctrine and TTPs for Drone Warfare	1. What do you believe are the most important TTPs formulated by the recent conflicts? 2. Do you believe that drones should become an integral part of tactical echelon? 3. Do you have any input for training personnel in Drone Warfare?	
NATO	1. As the director of the Full Spectrum Drone Warfare Project, what are NATO's future projects in drone warfare, and what advice would you give to allies for future drone conflicts? 2. A new doctrine on drone warfare is expected this year. What key aspects do you think it should cover? 3. In your 2017 work, you predicted the use of small drones by state actors. Looking at the current state of drone warfare, has it evolved as you expected? 4. What is NATO's position in the drone race compared to China and Russia?	

Interview Guide		
Date: 071330JUL24	Interviewer: ASPOF FZ Teixeira da Costa	Interviewee: Samuel Bendett Occupation: Adviser with CNA Strategy
Objectives	Questions	
Impact and Evolution of Drone Warfare	1. What would you characterize the evolution of drone warfare from the second Nagorno Karabakh war to now in Ukraine, Gaza and Yemen? 2. Do you think there was a lack in development and implementation of drones and anti-drone systems in most armed forces? 3. Do you believe that, as Ukraine established, a creation of a drone branch is the next step for international armed forces? 4. As a countermeasure, should armed forces employ a Drone Wall, as NATO and Ukraine are employing with a barrier of EW?	
Development and Dissemination of Doctrine and TTPs for Drone Warfare	1. How are military doctrines and TTPs evolving to incorporate the use of drones in modern warfare? 2. What are some key differences in how various countries are developing their drone warfare doctrines? 3. How is the training of military personnel adapting to include drone operations?	
Current and Future Capabilities of C-UAS	1. What are the most effective current technologies in C-UAS? 2. How do different C-UAS approaches (kinetic vs. non-kinetic) compare in effectiveness? 3. What are some emerging trends in C-UAS technology that you find promising?	
Future Challenges and Technological Advancements in Drone Warfare	1. What do you see as the biggest challenges facing drone warfare in the next 5-10 years? 2. What role do you anticipate for autonomous drones in future conflicts?	

Interview Guide		
Date: 200900JUL24	Interviewer: ASPOF FZ Teixeira da Costa	Interviewee: Col. Ret. John Antal
Objectives	Questions	
Lessons Learned from Nagorno-Karabakh and recent conflicts.	1. Looking back, do you believe that Ukraine, Russia and Israel, learned with the first robotized conflict? 2. What lessons could be taken by the recent conflict in Yemen by Houthis? 3. In a possible confrontation between China and Taiwan, what should their armies adopt to survive modern warfare and drone warfare?	
Advantages, limitations and disadvantages of C-UAS	1. In a world with ever developing and evolving drones, how can C-UAS be kept in pace? 2. Is Masking the silver bullet? Or the Silver Shield? 3. What is the best way to neutralize drones? 4. What are some emerging trends in C-UAS technology that you find promising?	
Employment of Masking and Countermeasures	1. How do you believe Drone Warfare will affect operational organization, doctrines and TTPs? 2. What is the best way to implement masking in a reconnaissance unit? 3. What should be done to Command Posts of decentralized, low echelon forces for distributed operations	
Further Questions	1. What do you see as the biggest challenges facing drone warfare in the next 5-10 years? 2. What role do you anticipate for autonomous drones in future conflicts? 3. How can we upgrade battle schools and wargaming?	

8.12. Appendix L- Drone Warfare Courses Guide

Below is a guide to courses and training that combatants can undertake to prepare for the technological challenges of Drone Warfare. The guide includes courses for C-sUAS and UAV operators.

Drone Warfare Course Guide			
Objective	Course	Host	Area
C-UAS Data	Joint Knowledge Online (JKO) C-sUAS (Counter Small Unmanned Aircraft Systems) community page	United States Army	C-UAS
	Center for Army Lessons Learned (CALL)		
	Joint Lessons Learned Information System		
C-UAS Mission Planning	The Joint C-sUAS Operator Course (9ESIU5/ ASIU5/920-ASIU5) The Joint C-sUAS Planner Course (9ESIU1/ ASIU1/920-ASIU1) Joint Installation Protection Course (current non-ATTRS)	United States Army	C-UAS
C-UAS Training	JCO Policy Training Module: Basic C-sUAS Awareness Training Basic C-sUAS Familiarization Training Basic C-sUAS Installation Training Basic C-sUAS Tactics, Techniques, and Procedures		
UAS Training	Basic UAS Qualification Combined Mission Qualification SOF-SO-35555: Drone Exploitation Course	NATO	UAS
	ARPRA- IB Mavic Pro	X31 (Portuguese Navy)	

8.13. Appendix M- Article Submitted to the Revista da Armada

Below is the article submitted to the Revista da Armada. The Revista da Armada is a journal of the Portuguese Navy to which an article was submitted by the author of the dissertation, featuring original content and opinions on future technologies dedicated to Drone Warfare that could completely change the way modern combat is conducted.

Drone Warfare: Tecnologias do Presente e Futura Implementação

Em 1849, com o uso de balões de ar quente não tripulados pelas forças austríacas na batalha com a República de São Marco, surgiram os primeiros veículos aéreos não tripulados (Seharwat, 2021). No entanto, foi apenas em 1935 que surgiu o termo "Sistemas Aéreos Não Tripulados" ou, popularmente, "Drones", com a construção da "Queen Bee". Este era um biplano não tripulado (Markaria & Staniforth, 2021), que desde então inspirou a construção e proliferação de drones para serem usados em conflitos armados, marcando o início da disciplina de Drone Warfare (Gusterson, 2016).

Drone Warfare pode ser dividido em duas eras distintas, cada uma caracterizada pelos seus avanços tecnológicos e desafios. A primeira era dos drones é considerada pelos especialistas atuais como o uso abundante de drones pelas forças dos Estados Unidos da América durante o período após o 11 de setembro (Rogers, 2021). Os drones eram usados principalmente para funções de Intelligence Surveillance and Reconnaissance (ISR) ou destruição cirúrgica de High Value Targets (HVT). Os MQ9A-Reapers e os MQ-1 Predators foram fenómenos com imensa precisão e capacidade de destruição. Até então, os drones eram grandes unidades tecnológicas com elevada altitude operacional, resistência e alcance. Mas o paradigma mudou com a Segunda Era dos Drones.

A Segunda Era dos Drones, para alguns, é definida como a proliferação generalizada e global de Sistemas Aéreos Não Tripulados (SANT) e de drones comerciais armados, utilizados não apenas pelas forças armadas tecnologicamente mais avançadas, mas também por forças rebeldes não convencionais (Rogers, 2021). O baixo custo e

ampla oferta de drones no mercado levaram à sua adoção e modificação para uso na guerra e no mundo civil, levando a uma verdadeira Quarta Revolução Industrial, impulsionada pela Inteligência Artificial (IA) e pela Internet of Things (IoT) (Ross & Maynard, 2021). Para outros, e para os autores, acredita-se que a Segunda Era dos Drones começou com a Segunda Guerra de Nagorno-Karabakh, considerada a primeira guerra a ser disputada, principalmente, pelos sistemas robóticos autónomos mais avançados, até então, no campo de batalha (Antal, 2022). A Segunda Era dos Drones é caracterizada pela proliferação de Drones Comerciais Off-The-Shelf (COTS) e Do-It-Yourself (DIY) em conflitos armados, devido ao seu baixo custo e baixo risco, minimizando despesas em peças de artilharia e recursos humanos. No entanto, as suas capacidades estão a aumentar tão rapidamente quanto a sua implementação, uma vez que estão a tornar-se mais furtivos, mais pequenos, mais rápidos e mais letais, substituindo eficazmente drones mais pesados e mais caros (Council, 2020).

O impacto destes novos drones comerciais no campo de batalha é facilmente reconhecido nos conflitos da Ucrânia e Gaza. Ambos são caracterizados e estudados especificamente pelo uso abundante de drones do tipo DJI e Autel para infligir danos consideráveis às forças inimigas apeadas e móveis. Os quadricópteros conquistaram facilmente as mentes dos combatentes e são considerados os drones mais capazes no terreno devido à sua agilidade, estabilidade e capacidade de carga (Broman S. C., 2018).

A dinâmica da guerra mudou com a utilização de drones altamente modificados. O mesmo drone pode realizar funções de ISR, ações de targeting e aquisição, tornando-se um verdadeiro Drone Kamikaze, destruindo ou imobilizando colunas militares e veículos de combate designados. Mykhailo Fedorov, Primeiro-Ministro da Ucrânia, reconhece e celebra o impacto dos drones no exército ucraniano e seu efeito ofensivo sobre as forças russas, de tal forma que tentou angariar doações de drones do mundo civil (Pong, 2022) e 128 milhões de dólares de países estrangeiros aliados para adquirir mais drones First-Person View (FPV) para enfrentar a Rússia (Martin, 2024). 300.000 drones foram produzidos no último ano por empresas ucranianas com capacidades e funções táticas cada vez mais aprimoradas (Balmforth, 2024).

O conflito em Gaza pode ser visto como um campo de testes para Drone Warfare. O conceito de “Swarm”, ou “Enxame”, definido como "a group of at least 50 individual, self-organized, homogenous unmanned air vehicles that perform a mission through local interactions" (Giles, 2022), acompanhado por inteligência artificial, provou ser uma arma furtiva e extremamente capaz para a qual as atuais defesas antiaéreas não estão preparadas. Há também um uso extremo de drones suicidas tanto pelas forças do Hamas como pelas forças israelitas, o que permitiu a prolongação do conflito devido à sua elevada eficiência e capacidade de destruição (Ling, 2023). O uso de pequenos drones comerciais permitiu ao Hamas penetrar o Iron Dome que, combinado com mísseis de cruzeiro e forças de infantaria, iniciou o conflito em 7 de outubro de 2023 (Goudarzi, 2023).

No entanto, Drone Warfare ainda se encontra nos seus primórdios. Estima-se que até 2047 os drones sejam capazes de tomar decisões autonomamente em poucos nanossegundos (Decoeur, 2012). O Departamento de Defesa dos Estados Unidos da América investiu 30,8 bilhões de dólares neste esforço (Union, 2013). A Comissão da União Europeia estima que dentro de 20 anos, o setor de drones empregará mais de cem mil pessoas e terá um impacto económico de 10 bilhões de euros por ano (Hartmann, Jueptner, Matalonga, Riordan, & White, 2023). É uma certeza, não uma teoria ou possibilidade, que os drones vieram para ficar e não apenas para modificar os estilos de vida civis, mas também as dinâmicas da guerra militar. Portanto, é importante teorizar e analisar os aspetos nos quais Drone Warfare se irá concentrar nos próximos anos e os pilares do seu desenvolvimento. Do ponto de vista dos autores, esses pilares serão a Inteligência Artificial, a Autonomia e os Swarms.

A Inteligência Artificial, o primeiro pilar, será o auge da quarta revolução industrial. O seu crescimento no desenvolvimento e utilizadores alcançou recordes sem precedentes (McKinsey and Company, 2023). A sua implementação na indústria e academia tem aumentado consideravelmente, com o setor de defesa não ficando para trás. Com a aparente inevitabilidade da implementação de IA em armas, vários cientistas e filantropos têm-se oposto a isso, procurando negar o uso de IA em drones porque:

“Once developed, they will permit armed conflict to be fought at a scale greater than ever, and at timescales faster than humans can comprehend. These can be weapons of terror, weapons that despots and terrorists use against innocent populations, and weapons hacked to behave in undesirable ways. We do not have long to act. Once this Pandora’s box is opened, it will be hard to close” (An Open Letter to the United Nations Convention on Certain Conventional Weapons, 2018),

No entanto, é tarde demais, uma vez que o seu emprego já está presente no conflito na Ucrânia, com a sua aplicação em drones que, em caso de perda de ligação com o operador devido a jamming ou spoofing, mantêm o conhecimento da sua posição geográfica e identificam o seu alvo recorrendo a ferramentas de inteligência artificial (Hudson, 2023). O mesmo pacote de IA foi utilizado no avião não tripulado Cessna que destruiu uma fábrica de drones russa em 2 de abril de 2024 (Axe, 2024). O mesmo aplica-se ao conflito em Gaza, com o uso de IA para o desenvolvimento de Swarms mais capazes e eficientes (Hambling, 2021), e para a identificação de alvos durante ações de ISR (Brumfiel, 2023). A Inteligência Artificial serve como a pedra angular de uma estrutura que abrange a autonomia e o Swarming no domínio de Drone Warfare.

A Autonomia, o segundo pilar de Drone Warfare do futuro, é uma consequência da Inteligência Artificial. Atualmente, nenhum drone é verdadeiramente autónomo. Atualmente, sistemas autónomos significa sistemas semi-autónomos onde a interação entre o operador e o sistema existe na identificação e destruição do alvo (CloudFactory, 2021). Um sistema verdadeiramente "Human-Off-the-Loop" (Union, 2013) ainda está em experimentação e a sua utilização em conflitos armados ainda é mínimo devido a restrições legais, éticas e morais que ainda estão em desenvolvimento. Um sistema completamente autónomo só será possível com inteligência artificial, possibilitando capacidades de planeamento, movimentação e execução sem interação entre o humano e o drone. No entanto, um quadro internacional deve ser formulado porque a morte humana por "máquinas" sem qualquer decisão consciente prévia humana parece inaceitável e distante (Boyle, 2020). Sistemas verdadeiramente autónomos só serão

adotados e aplicados quando for aceitável para um humano prescindir da sua vida por uma "máquina", e quando isso acontecer, exércitos robóticos serão a norma, mais baratos e menos dolorosos para a vida humana (Watling, 2024).

Os Swarms, o terceiro pilar, serão o maior e mais desafiante inimigo do combatente, a sua imprevisibilidade, velocidade e capacidade destrutiva representarão um problema drástico para os objetivos operacionais e táticos de qualquer força armada (Scharre, 2014). Segundo Paul Scharre, Swarms pode ser definido como:

“Just as Swarms of insects, which individually, can nevertheless collectively perform complicated tasks, a cloud of tiny drones could similarly be used in novel and inventive ways. “Smart clouds” of 3D printed drones could flood a building, locating and identifying enemy combatants and civilians, or could even be airdropped over a wide area to find enemy personnel and material” (Scharre, 2014)

É fácil imaginar o poder de combate de um Swarm de drones autónomos, cada um com capacidade de IA e a transmitir informações integradas e sistemáticas extraídas do campo de batalha pelos seus sensores sofisticados para um "drone rainha". As informações recebidas e filtradas pelo "drone rainha", que simultaneamente atua como um repetidor protegendo seu "enxame" de ataques não cinéticos, são enviadas a um único operador humano (Boyle, 2020). Swarming será o próximo grande passo em Drone Warfare, assim como os carros de combate e os couraçados foram na Primeira Guerra Mundial, os aviões de caça e veículos anfíbios na Segunda Guerra Mundial (Boussel, 2023). O impacto tático e operacional de Swarms no campo de batalha representa apenas uma parte do problema. Na verdade, diversos estudos desde a Primeira Era dos Drones têm demonstrado o impacto psicológico e moral dos drones em conflitos armados, representando uma fonte considerável de Perturbação de Stress Pós-Traumático (PSPT) nos operadores desses sistemas sofisticados (Phelps, 2021). Esses problemas têm piorado com a Segunda Era dos Drones devido ao aumento do uso de drones comerciais no campo de batalha. O conhecido "buzz" dos drones no horizonte e o seu significado aumentaram exponencialmente os casos de PSPT nas forças de ambos

os conflitos de Gaza e Ucrânia (The conversation, 2022), tais preocupações e impactos só aumentarão com a implementação do conceito de Swarm nos conflitos futuros.

Estes são os três pilares de Drone Warfare que a sustentarão nos próximos anos. Várias e numerosas forças armadas têm-se preparado para enfrentar as novas dificuldades apresentadas por Drone Warfare. O Presidente Volodymyr Zelensky, a 6 de fevereiro de 2024, convocou a criação de um ramo separado das forças armadas ucranianas dedicado a sistemas aéreos não tripulados e contramedidas (Reuters, 2024). As forças dos EUA abriram uma academia para treinar operadores de UAVs e sistemas C-UAS em Fort Sill, Oklahoma (Saballa, 2023), e a China tem-se focado em treinar combatentes para operar FPV Unmanned Aerial Vehicles (UAV) com táticas, técnicas e procedimentos (TTP) aplicados no conflito na Ucrânia (Bajak, 2024).

A Marinha Portuguesa não tem ficado para trás. O Sr. Almirante Chefe do Estado-Maior da Armada Gouveia e Melo, tem acompanhado de perto os desenvolvimentos na guerra contemporânea e implementou mudanças significativas na Marinha Portuguesa para enfrentar os desafios colocados por Drone Warfare.

Seguindo o exemplo estabelecido na Ucrânia, o Almirante CEMA não criou um ramo separado dedicado a drones, mas implementou, sim, a Unidade X31 a 27 de março de 2023, que visa a gestão de Sistemas Não Tripulados (SNT), a formação especializada dos combatentes e a formulação de doutrina para o uso desses ativos em futuras missões, oferecendo auxílio aos domínios aéreos, marítimos e terrestres. A criação da unidade considera-se mais rentável e produtivo à Marinha do que a criação de um único ramo diferenciado devido às limitações financeiras e humanas. No entanto, seria uma possibilidade criar um ramo de drones que pudesse coordenar esforços entre os três ramos atuais das Forças Armadas.

O conceito ““Light and Fast””, uma nova organização e tipologia de emprego dos Fuzileiros, não é nada mais que o resultado de lições aprendidas de conflitos recentes e em curso. Com o novo conceito, perspetiva-se a utilização de combatentes especializados em Drone Warfare, mais especificamente, dois elementos para operação

de SANT e um elemento para Electronic Warfare (EW) num grupo de combate de 32 combatentes no total. Esta mudança é fundamental em todos os três níveis militares, uma vez que a inclusão de drones afetará positivamente o planeamento e a execução. Verificou-se em vários estudos e exercícios que a inclusão de um simples drone comercial com ações de ISR para fins de planeamento levou a uma descida acentuada do tempo de decisão, e que na execução da tarefa resultou em uma descida considerável de vidas perdidas, feridos e duração de missão (Drozd & Flasar, 2017).

Os drones são uma mais-valia para o combatente, e a sua utilização deve ser feita cautelosamente. Vários países efetuaram o mesmo paradigma, as forças ucranianas empregam drones comerciais em equipas de 4 elementos compostos por um navegador, um operador de SANT, um elemento de reconhecimento e um operador de gimbal (Halem, 2023), que integram companhias mecanizadas que adquiram alvos por reconhecimento, informam o escalão superior e efetuam a destruição do alvo de acordo com a decisão superior (Reuters, 2024). As forças russas rapidamente compreenderam o *modus operandi* ucraniano e procuram inovar, diariamente, a doutrina de forma a responder às novas dificuldades (Edmond & Bendett, 2023). As forças dos Estados Unidos da América são quem mais se aproxima da atual organização operacional do conceito ““Light and Fast”” com a utilização de 2 ou 3 drones por pelotão de 32 homens (Broman S. C., 2018).

A Marinha Portuguesa está na vanguarda da “drones race” com muitos outros países que rapidamente perceberam a natureza dos futuros conflitos. Assim, restará à Marinha desenvolver os seus meios e doutrinas de acordo com os três pilares de Drone Warfare e de que modo as empregará operacionalmente e com que meios se deverá guarnecer. A Marinha Portuguesa deve-se atualizar e desenvolver, rumo a uma guerra tecnologicamente avançada, composta por marinheiros de carbono, que são os humanos, e marinheiros de silício, que são os drones.

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8.14. Appendix N- Article Submitted to the Journal of Critical Military Studies

Below is an article submitted to Critical Military Studies. The article is similar to the article presented in Appendix M- Article Submitted to the Revista da Armada but with an adaptation to the international world.

Future Technologies of Drone Warfare

It was in 1849 with the use of unmanned hot-air balloons by the Austrian forces in the battle with the Republic of San Marco that the first unmanned aerial systems emerged (Seharwat, 2021). However, it was only in 1935 that the term "Unmanned Aerial Systems" or, popularly, "Drones" appeared with the construction of the "Queen Bee". This was an unmanned biplane (Markaria & Staniforth, 2021), which since then has inspired the construction and proliferation of drones to be used in armed conflicts, marking the beginning of the discipline of Drone Warfare (Gusterson, 2016).

Drone Warfare can be divided into two distinct eras, each with its technological advances and challenges. The first Drone Age is considered by current theorists as the abundant use of drones by the United States forces during the period following 9/11 (Rogers, 2021). Drones were primarily used for ISR (Intelligence Surveillance and Reconnaissance) functions or surgical destruction of HVTs (High Value Targets). MQ9A-Reapers and MQ-1 Predators were technological phenomena with immense precision and destruction capabilities. Until then, drones were large technological units with high operational altitude, endurance, and range. But the paradigm changed with the Second Drone Age.

The Second Drone Age, for some, is defined as the widespread and global proliferation of Unmanned Aerial Systems (UAS) and armed commercial drones used not only by the most technologically advanced armed forces but also by non-conventional rebel forces (Rogers, 2021). The low cost and wide availability of drones in the market have led to their adoption and modification for use in warfare as well as in the civilian world, leading to a true Fourth Industrial Revolution, empowered by Artificial Intelligence and the Internet of Things (Ross & Maynard, 2021). For others, as in the

author's opinion, it is believed that the Second Drone Age began with the Second Nagorno-Karabakh War, considered to be the first war shaped and fought by the most advanced autonomous robotic systems used on the battlefield (Antal, 2022). The Second Drone Age is characterized by the proliferation of Commercial Off-The-Shelf (COTS) and Do-It-Yourself (DIY) Drones in armed conflicts, due to their low cost, low-risk engagement, minimizing costs in artillery pieces and human resources. However, their capabilities are increasing as rapidly as their deployment, since they are becoming stealthier, smaller, faster, and more lethal, effectively replacing heavier and more expensive drones (Council, 2020).

The impact of these new commercial drones on the battlefield is easily acknowledged in the conflicts in Ukraine and Gaza, currently underway. Both are specifically characterized and studied for the abundant use of DJI and Autel type drones to inflict considerable damage on enemy infantry and mobile forces. Quadcopters have easily won over the minds of combatants and are considered the most capable drones due to their agility, hovering, and payload capabilities (Broman, 2018).

The dynamics of war have changed with the deployment of highly modified drones. The same drone can perform ISR functions, targeting and acquisition actions, becoming a true Kamikaze Drone, destroying, or immobilizing military columns and designated combat vehicles. Mykhailo Fedorov, Ukraine's Prime Minister, recognizes and celebrates the impact of drones in the Ukrainian army and their offensive effect on Russian forces, calling for "Drone Donations" from the civilian world (Pong, 2022) and for 128 million€ to allied foreign countries to acquire more FPV drones to face Russia (Martin, 2024). 300,000 drones were produced in the last year by Ukrainian companies with increasingly tactical capabilities and functions (Balmforth, 2024).

The conflict in Gaza can be seen as a testing ground for Drone Warfare. This is where the concept of Swarm first emerged, defined as "a group of at least 50 individual, self-organized, homogenous unmanned air vehicles that perform a mission through local interactions" (Giles, 2022), which, accompanied by Artificial Intelligence, has proven to be a stealthy and extremely capable weapon for which current anti-aircraft defenses are

unprepared. There is also an extreme use of suicide drones by both Hamas and Israeli forces, which have allowed a prolongation of the conflict due to their high efficiency and destruction capacity (Ling, 2023). The use of small commercial drones allowed Hamas to penetrate the Iron Dome which, combined with cruise missiles and infantry forces, initiated the conflict on October 7, 2023 (Goudarzi, 2023).

However, modern Drone Warfare is just beginning. It is estimated that by 2047 drones will be capable of autonomously making decisions in a few nanoseconds (Decoeur, 2012). The US Department of Defense invested 30.8 billion€ in this effort (Union, 2013). The European Union Commission estimates that in 20 years, the Drone Sector will employ more than a hundred thousand people and have an economic impact of 10 billion euros per year (Hartmann, Jueptner, Matalonga, Riordan, & White, 2023). It is a certainty, not a theory or possibility, that drones have come to stay and not only modify civilian lifestyles but also the dynamics of military warfare. Therefore, it is important to theorize and analyze the aspects on which Drone Warfare will focus in the coming years and the pillars of its development. From the author's perspective, these pillars will be Artificial Intelligence, Autonomy, and Swarms.

Artificial Intelligence will be the pinnacle of the fourth industrial revolution. Its growth in development and users has reached unprecedented records (McKinsey and Company, 2023). Its implementation in industry and academia has been considerably increasing, with the defense sector not being left behind. With the seeming inevitability of AI deployment in weapons, several scientists and philanthropists have opposed it, seeking to deny the use of AI in drones because:

“Once developed, they will permit armed conflict to be fought at a scale greater than ever, and at timescales faster than humans can comprehend. These can be weapons of terror, weapons that despots and terrorists use against innocent populations, and weapons hacked to behave in undesirable ways. We do not have long to act. Once this Pandora’s box is opened, it will be hard to close” (An Open Letter to the United Nations Convention on Certain Conventional Weapons, 2018).

However, it was too late as its employment is already present in the conflict in Ukraine, with its application in drones that, in case of loss of connection with the operator due to jamming or spoofing, maintain knowledge of their geographical position and identify their target using Artificial Intelligence tools (Hudson, 2023). The same AI package was used in the Cessna unmanned plane that destroyed a Russian drone factory on April 2, 2024 (Axe, 2024). The same applies to the Gaza conflict with the use of AI for the development of more capable and efficient Swarms (Hambling, 2021), and for target identification during ISR actions (Brumfiel, 2023). Artificial Intelligence serves as the cornerstone of a structure encompassing autonomy and Swarms in the realm of Drone Warfare.

Autonomy, the second pillar of future Drone Warfare, is a consequence of Artificial intelligence. Now, no drone is truly autonomous. When we talk about autonomous systems, we are referring to semi-autonomous systems where interaction between the operator and the system exists in target identification and striking (CloudFactory, 2021). A truly "Human-Off-the-Loop" system (Union, 2013), is still in experimentation, and its use in armed conflicts is still minimal due to legal, ethical, and moral restrictions that are still under development. A fully autonomous system will only be possible with Artificial Intelligence capable of planning, moving, and executing without human-drone interaction. However, until then, an international framework must be formulated because human death by "machines" without any previous human judgment and conscious decision seems unacceptable and distant (Boyle, 2020). Truly autonomous systems will only be adopted and applied when it is acceptable for humans to give their lives for "machines", and when that happens, robotic armies will become the norm, cheaper and less costly to human life (Watling, 2024).

Swarms, the third pillar, will be the greatest and most challenging enemy of the combatant, their unpredictability, speed, and destructive capability will pose a drastic problem for the operational and tactical objectives of any armed force. According to Paul Scharre, Swarm can be defined as:

"Just as Swarms of insects, which individually, can nevertheless collectively

perform complicated tasks, a cloud of tiny drones could similarly be used in novel and inventive ways. “Smart clouds” of 3D printed drones could flood a building, locating and identifying enemy combatants and civilians, or could even be airdropped over a wide area to find enemy personnel and material” (Scharre, 2014)

It is easy to imagine the combat power of a Swarm of autonomous drones, each connected by Artificial Intelligence and transmitting integrated and systematic information extracted from the battlefield by their sophisticated sensors to a “queen drone”. The information received and filtered by the “queen drone”, which simultaneously acts as a repeater protecting its "Swarm" from non-kinetic attacks, is sent to a single human operator (Boyle, 2020). Swarming will be the next major step in Drone Warfare, like how tanks and dreadnoughts were in World War I, fighter planes and amphibious vehicles in World War II (Boussel, 2023). The tactical and operational impact of Swarms on the battlefield represents only one part of the problem. In fact, various studies since the First Drone Age have demonstrated the psychological and moral impact of drones in armed conflicts, representing a major source of PTSD (Post Traumatic Stress Disorder) in operators of these sophisticated systems (Phelps, 2021). These problems have gotten worse with the Second Drone Age due to the increasing use of commercial drones on the battlefield. The well-known "buzz" of drones on the horizon and its significance has exponentially increased cases of PTSD in the forces of both the Gaza and Ukraine conflicts (The conversation, 2022), such concerns and impacts will only increase with the concept of Swarm.

These are the three pillars of Drone Warfare that will sustain it in the coming years. Numerous armed forces have prepared themselves to confront the new difficulties presented by Drone Warfare. President Volodymyr Zelensky on February 6, 2024, called for the creation of a separate branch of the Ukrainian armed forces dedicated to UAVs and their countermeasures (Reuters, 2024). US forces have opened a school for training UAV operators and C-UAS at Fort Sill, Oklahoma (Saballa, 2023), and China has focused on training combatants to operate FPV UAVs with TTPs like those used

in the conflict in Ukraine (Bajak, 2024).

The Portuguese Navy has been approaching and seeking to adapt and update itself to these concepts with the “Light and Fast” concept in the Portuguese Marine Corps and the creation of the X31 unit. Both seek to employ specialized personnel in Drone Warfare in the field, as well as to create a different unit that specializes in Drone Warfare to coordinate with land, air, and sea components to better overcome modern difficulties. The Chief Admiral of Staff of the Portuguese Navy Gouveia e Melo has been observing and analyzing the current conflicts and their respective difficulties and technological advances, keeping the Portuguese Navy up to date and developing it towards a robotic and technologically advanced future warfare, composed of carbon sailors, which are humans, and silicon sailors, which are drones.

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8.15. Appendix O- Article Submitted to the RUSI Journal

The article shown below is an article submitted to the RUSI Journal that addresses a gap identified in the current state of the art of Drone Warfare, which is the necessary, detailed, and demanding study of the application of UAS and C-UAS in the operational organizations of the armed forces. The study enables the reader to understand the various ways of applying the systems in operational organizations, both in parallel and vertically, and with transfers of responsibility.

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**Optimizing Operational Organization for Drone Warfare: A
Comparative Analysis of Global Practices**

Francisco José Teixeira da Costa and Miguel Ângelo de Brito Araújo

Military Sciences, Navy School, Lisbon, Portugal;

Teixeira da Costa is an aspiring Marine Officer of the Portuguese Marine Corps, currently in the final year of the officer's course in the Navy. He is writing a master's dissertation entitled "Drone Warfare: Operational Context, Countermeasures, and Tactical Insights for the Portuguese Marine Corps." His research focuses on the operational organization, countermeasures, and tactical applications of drone warfare, aiming to enhance the preparedness and capabilities of the Portuguese Marine Corps in future conflicts.

Brito Araújo is a Lieutenant in the Portuguese Marine Corps, serving as the second commander of the Combat Support Unit and the Chief of the Communications Service in the Marine Corps. His extensive experience in military operations and communications provides valuable insights into the strategic and operational aspects of drone warfare. His collaboration in this research brings a practical perspective to the study, ensuring its relevance and applicability to real-world military scenarios.

Optimizing Operational Organization for Drone Warfare: A Comparative Analysis of Global Practices

The article explores the emerging field of drone warfare, examining the operational organizations employed by various armed forces around the world. It begins by defining drones, also known as unmanned aerial vehicles (UAVs), and their increasing importance in modern combat, as evidenced by their use in recent conflicts. It studies operational organizations of several countries, including Ukraine, Russia, Serbia, the United States, Portugal, and Israel, in order to find an optimal Operational Organization.

It was analyzed that the Ukrainian forces have developed a specialized structure, with tactical and operational levels, utilizing both commercial and military-grade drones. Russia, on the other hand, has faced challenges in adapting to this new form of warfare, lacking a cohesive command and control structure. The article also explores the approaches of other nations, such as Serbia's integration of UAV operators and countermeasures specialists into infantry sections, and the US Army's requirement for quadcopter drones at the platoon level. Portugal's Marine Corps has a similar organization, with drone operators and a dedicated ISR unit for extended-range reconnaissance. Israel presents a completely different operational organization with inclusion of liaison officers and a parallel framework.

The study concludes that the recommended operational organization involves the integration of NATO Class I drones into infantry units up to the platoon level, coordinated by ISR units at the company or battalion level. The composition of these units may vary, but they typically include a commander, a drone operator, and a navigator or countermeasures specialist.

Keywords: Drone Warfare, Operational Organization, UAV, UAS.

Introduction

Drone Warfare is the military discipline that studies and analyzes the use of drones in armed conflicts (Gusterson, 2016). These drones, colloquially known as "unmanned short-sized flying machines capable of performing various functions such as photography

and video", (My Dear Drone, 2023). are more formally defined in military terms as UAVs (unmanned aerial vehicles). According to the (International Civil Aviation Organization, 2011), a UAV is "an aircraft which is intended to operate with no pilot."

Initially, UAVs were large, high-altitude, and long-range machines. However, with technological advancements, they have evolved into smaller, more agile, and accessible devices that have changed the nature of combat, as seen in the Second Nagorno-Karabakh War, (Antal, 2022), and currently in the conflicts in Ukraine and Gaza, (Borsari & Jr., 2023). Various armed forces around the world have studied and analyzed the testing grounds of Nagorno-Karabakh and Ukraine, recognizing the numerous advantages of using drones in combat. These advantages include the cost-effectiveness of drones, often compared to the exorbitant costs of F-35s and other heavy artillery, offering a comparable solution at a much lower cost, (Ross, 2023). Additionally, drones possess diverse capabilities and high modifiability, allowing them to be used for reconnaissance, targeting, acquisition, combat, surveillance, and fire correction, (Hecht, 2022).

Consequently, many countries have recognized the need to adapt, equip, and modernize their armed forces to this new and ever-evolving form of warfare known as drone warfare. This involves creating new training methods, operational organizations, and resources to address the technologically advanced challenges that lie ahead.

Operational Organization

Operational organization is one of the most important considerations of TTPs (Tactics, Techniques, and Procedures) in the deployment of any system or method. The operational organization aims to model the tactical organization of forces of different sizes and functions so that they can fulfill their tasks more effectively. Operational organization refers to "the cognitive approach by commanders and staffs-supported by

their skill, knowledge, experience, creativity, and judgement-to develop strategies, campaigns, and operations to organize and employ military forces by integrating ends, ways and means.”, Operational organization is one of the most important considerations of TTPs (Tactics, Techniques, and Procedures) in the deployment of any system or method. The operational organization aims to model the tactical organization of forces of different sizes and functions so that they can fulfill their tasks more effectively. Operational organization refers to “the cognitive approach by commanders and staffs-supported by their skill, knowledge, experience, creativity, and judgement-to develop strategies, campaigns, and operations to organize and employ military forces by integrating ends, ways and means.”, (Joint Chiefs of Staff, 2011).

The study of operational organization in the deployment of UAS (Unmanned Aerial Systems) and C-UAS (Counter-Uncrewed Aerial Systems) in armed forces such as those of Russia, Ukraine, Serbia, USA, Israel and Portugal, is necessary to assess the best way to employ these means in combat

Ukraine

Ukrainian forces have been at the forefront of adapting to a new form of combat that emerged with the Russian invasion of their territory. Faced with the need to innovate and respond to Russian offensives in a cost-effective and efficient manner, they turned to the strategic use of drones. The deployment of drones by Ukrainian forces has allowed them to counter conventional Russian warfare with remarkable effectiveness, utilizing these devices to strike targets well beyond enemy lines, (Halem, 2023). This approach has led to the development of a specialized operational organization dedicated to drone warfare.

To maximize the effectiveness of their drones, Ukrainian forces have structured their drone operations into two distinct levels: tactical and operational. Initially they created assault and mechanized battallions that would employ drone dedicated companies of 120 personnel, (Reuters, 2024). These companies would then be divided into platoons and, consequently, sections and tactical teams, each having dozens of dji commercial drones or DIY (Do It Yourself) drones that would be used for combat or reconnaissance. In the operational level, the company commander of these drone dedicated companies would be equipped with CLASS II or III NATO drones such as the Bayraktar TB2 or Urkjet UJ-22 that would be utilized for decision making, SA, reconnaissance, kill confirming and shot correction, (Reuters, 2024), as it can be seen in the figure 1.

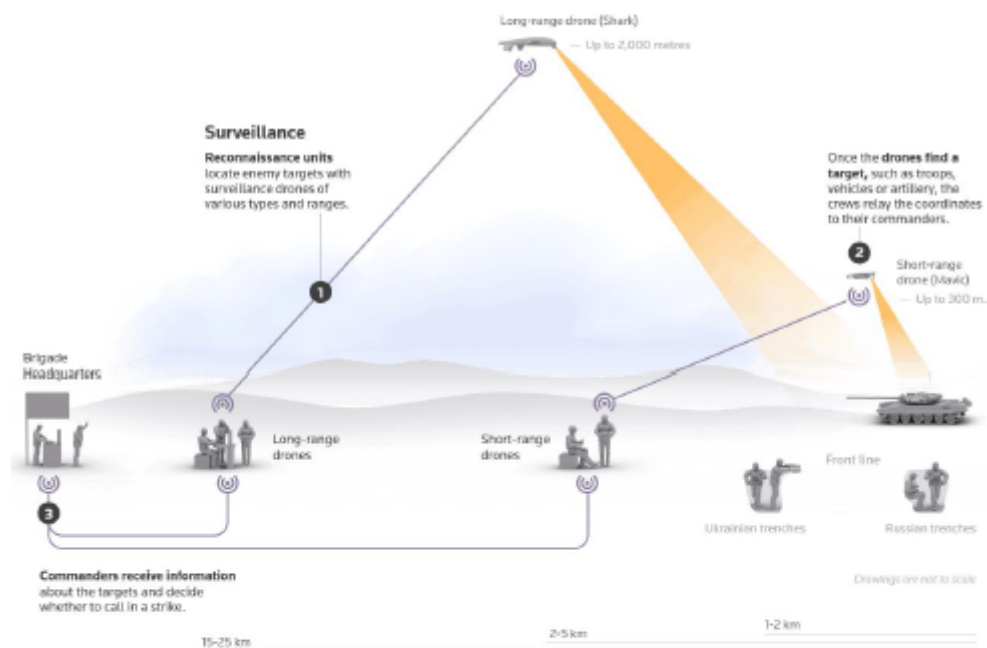


Figure 1- Ukrainian Forces Command and Control, taken from (Reuters, 2024).

This organizational structure is logical as it provides company commanders and team leaders with enhanced Situational Awareness (SA), enabling quicker and more accurate decision-making, (Roblin, 2023). It grants teams the flexibility to use drones for

various purposes and promptly relay information to the company commander, who can then employ heavier drones controlled from ground stations for a comprehensive understanding of the battlefield. The company leader receives information from tactical leaders and decides on the neutralizing way of the enemy drone so the tactical leaders can act. This flexible and fast communication is due to good C2 (Command and control) systems, making drone warfare more effective.

In conclusion, as can be seen in Figure 2, ukrainian forces have defined that the best way to employ drones in the field would be through dedicated infantry companies, specialized in drone warfare. These companies would work in battallions with ISTAR (Intelligence, Surveillance, Reconnaissance, Targeting, Acquisition and reconnaissance) functions. In the operational level there would be employed Class II or III NATO drones for longer ranges and higher altitudes and in the tactical level numerous Class I drones due to their light weight, durability and cheaper cost.

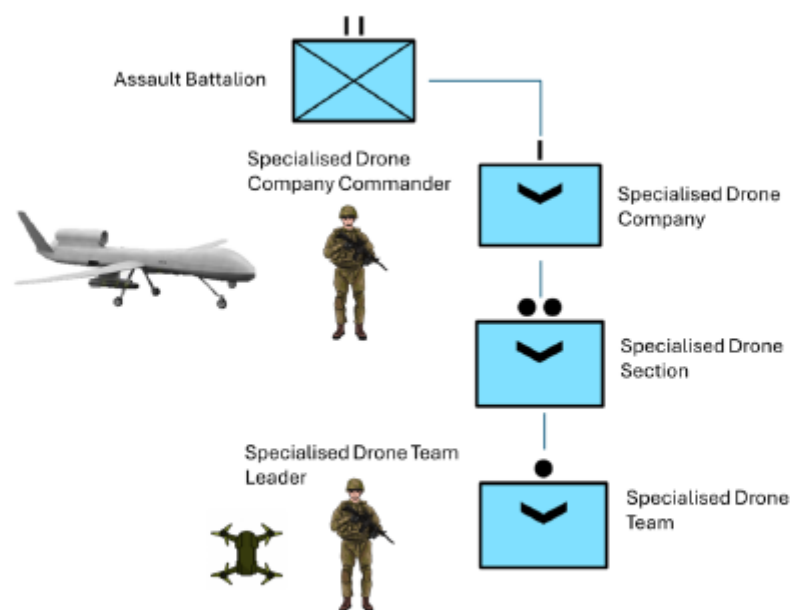


Figure 2- Ukrainian Operational Organization for Drone Warfare

Russia

Russian forces had to keep pace with technological advancements and the emerging drone warfare that was becoming prominent in the conflict. Parallel to Ukrainian forces, they also had to adapt and match their adversaries in countermeasures and drone utilization. Initially, Russian forces employed NATO Class II drones or higher, such as the well-known Shahed-136, Orlan-10, and Zala (Kunertova, 2023). However, it was only after engaging with Ukrainian forces that they began to invest in DIY FPV (First Person View) drones, applying them in a manner similar to the Ukrainians, (Edmond & Bendett, 2023).

Before the war, Russian forces organized their UAS (Unmanned Aerial Systems) into companies, subdividing them into platoons and teams of equal size to facilitate C2 (Command and Control), with an arsenal of 2,000 UAVs, representing a global power in drone warfare, (Edmond & Bendett, 2023). However, it was only with the onset of the war that they realized the necessity of incorporating NATO Class I drones into their arsenal for use at the team or section level.

The estimated operational organization of Russian forces is comparable to that of the Ukrainians, with at least three commercial drones at the team level, belonging to UAV reconnaissance squadrons integrated into air and mechanized brigades, (Luzin, 2023). However, Russian forces face communication and flexibility challenges due to bureaucratic hurdles in training, utilization, and acquisition of these systems, creating disadvantages compared to Ukrainian forces. The lack of a defined and applied command and control structure between the operational and tactical levels, as seen in Russia diminishes efficiency. This forces teams to act autonomously, giving operational decision-making authority to the tactical level, specifically to the team leader, lowering combat power.

Serbia

The Serbian armed forces quickly identified the need to implement UAS and C-UAS in their operational organization and to formulate TTPs to address emergent Drone Warfare. They recognized the tactical threat that these systems pose in armed conflicts, especially those that can be operated by a single individual and understood that a squad of shooters is capable of operating NATO Class I UAVs and their countermeasures, (Žnidaršič & Radovanović, 2020), however, it is easy to train a shooter to perform the functions of a UAV operator and countermeasures operator. Two options were verified: adding a UAV operator to a nominal section of 9 people, totaling 10, or having a shooter from that section take on the additional roles of UAV operator and countermeasures operator.

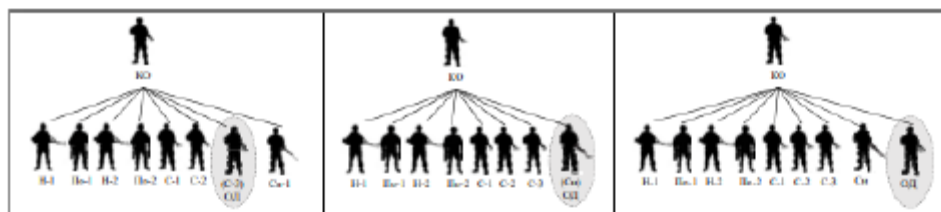


Figure 3- Types of Serbian Operational Organization for Drone Warfare, taken from (Žnidaršič & Radovanović, 2020)

In Figure 3, different modalities for the deployment of the UAV operator and countermeasures operator are observed. The first model, on the left, shows a member belonging to the section, an ordinary rifleman that would accumulate functions as UAV operator. The second model also depicts a member belonging to the section but is a designated rifleman, benefiting from the detachment from the battlefield and the equipment they typically carry. Lastly, there is an additional member outside the section, a UAV and countermeasures specialist, totaling a 10 men section.

Among the options presented above, the first and third are the most appreciated. In the first option, a rifleman belonging to the section, without any leadership function

but solely as an assistant, could serve the section leader in a team of three elements. This would allow the section leader to have situational awareness and control over the UAV's objectives. However, this would require another team to lose a member in their action, and the section leader would have an additional responsibility.

The third option seems to be the most efficient, despite adding one more man to the section, which would necessitate changes in the section's tactical action, including its efficiency, formations, and functioning. However, it would not cause organizational dysfunctions and could, in parallel with the section leader, provide coverage, ISR, and combat power to the section.

Serbian Armed Forces show, again, that the use of UAV systems should remain in a low echelon, in this case, section level. It shows that the most effective one would be the addition of specialist on Drone Warfare to an already 9-man nominal section formation, becoming a 10-man section with various capabilities that could be divided in two teams of four and section leader assisted by a Drone Warfare operator for combat, reconnaissance and awareness capabilities, as in Figure 4.

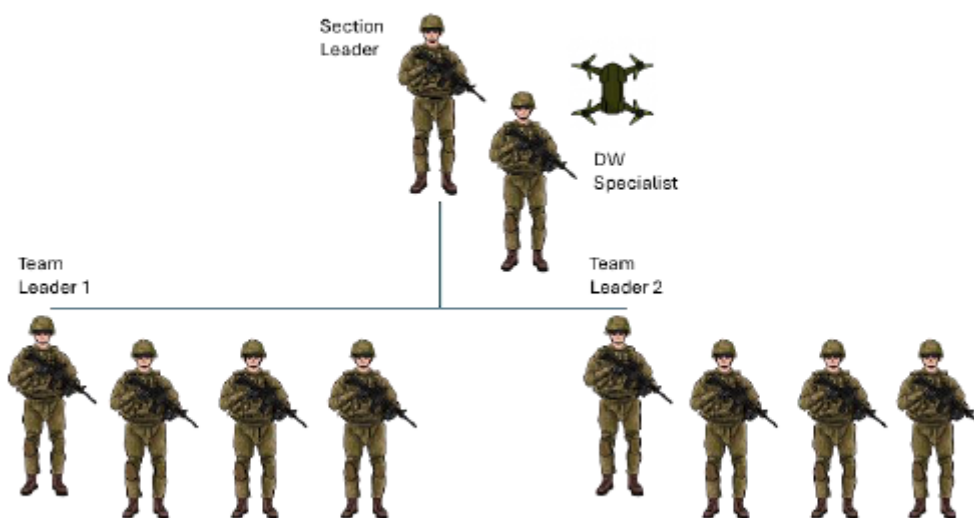


Figure 4- Recommended Serbian Drone Warfare Operational Organization

United States of America

The United States Armed Forces were the first to use UAS and C-UAS systems and understand their potential, especially in counterterrorism actions. What was initially used for ISR operations at the operational level, such as the MQ-9A Reaper, has evolved towards surgical actions using increasingly smaller UAVs like the RQ-11 Raven. The US military quickly realized the potential of these assets in combat in places like Syria and Mosul, where terrorists were using commercial UAVs worth \$600 to gain an advantage, (Gusterson, 2016). Therefore, the US Army recognized the need to develop its Drone Warfare capabilities, which remain relevant today.

Currently, there is a need for each force to have at least two quadcopters per platoon, which is a 32 men nominal NATO definition, in addition to the existing RQ-11 Raven, (Broman, 2018). This is because it is argued that the quadcopter UAV has considerable advantages over most UAVs available in the market today. Being a quadrotor allows it to have greater agility, hover in stationary flight, and enter tight and heavily protected areas such as urban or wilderness areas, all at a low price of \$300. The robustness of a quadcopter is higher, and its audiovisual capabilities can also be modified to support a long-range camera. The efficiency of these UAVs has been constantly reported to be advantageous, mainly in urban warfare in Gaza, (Hussaini, 2024).

In February 2018, the Navy and Marine Corps Small Tactical Unmanned Aircraft Systems Office ordered 800 InstantEye quadcopters, four years before the conflict in Ukraine, to integrate them into the operational organization of sniper teams, (Broman, 2018). For their use, units with two or three men per platoon are required, trained specifically as UAV operators and countermeasures operators, as done in Ukraine and one of the variants in Serbia. Each platoon should be equipped with two quadcopter UAS, however, each UAV should be the responsibility of the platoon commander to make better use of mission command, (Broman, 2018), as can be seen in Figure 5.

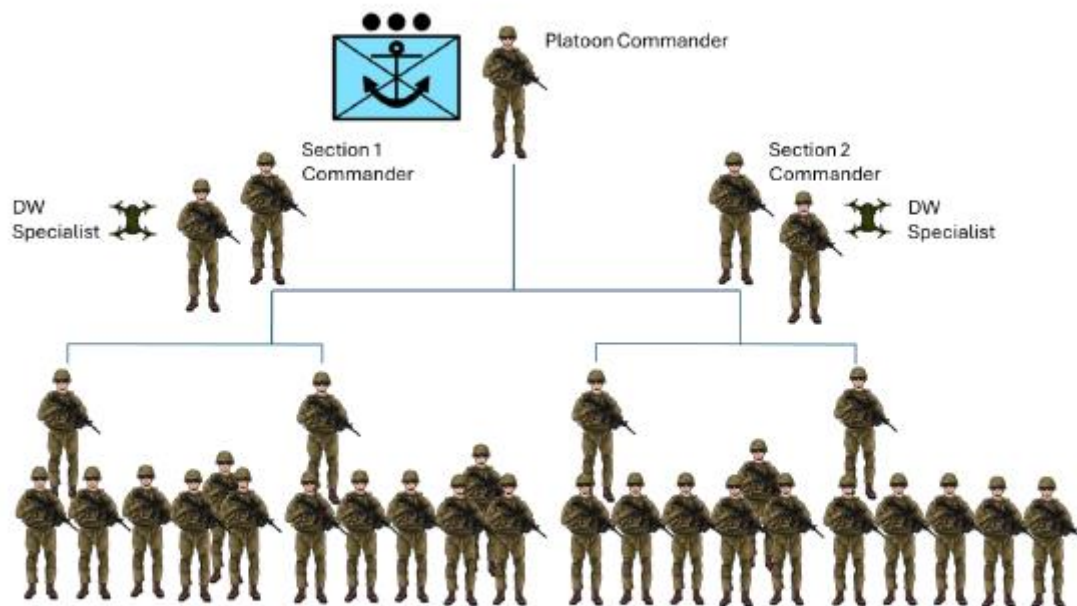


Figure 5- United States of America Recommended Operational Organization for Drone Warfare

Portugal

The Portuguese Marine Corps adopts an operational organization like that of the United States, employing drone operators and countermeasures within NATO-standard platoons of 32 men. This naval infantry platoon includes a combat support team of four men, two of whom are drone warfare specialists and designated drone operators, (Alves, 2023). Each operator is equipped with an FPV quadcopter drone to assist the section commander with situational awareness (SA) within a nominal team of 19 men, as depicted in Figure 6.

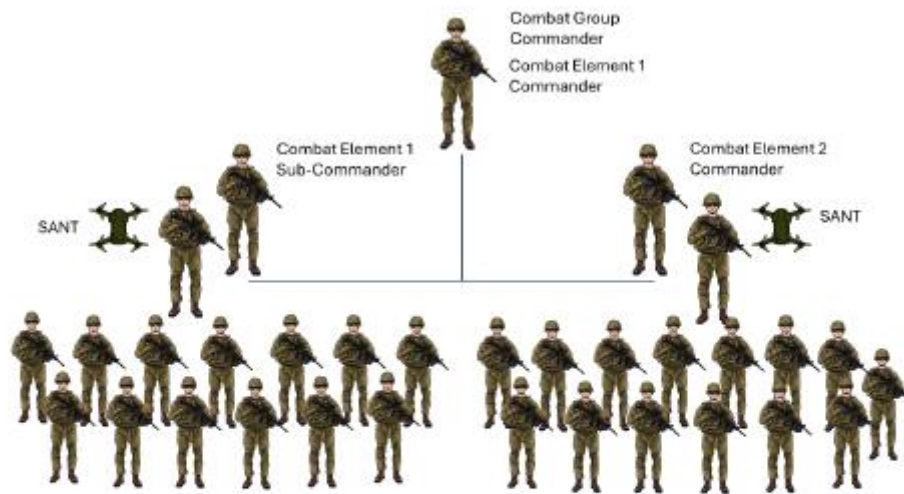


Figure 6- Portuguese Drone Warfare Operational Organization

Additionally, the Portuguese Marine Corps envisions the application of a separate unit for the use of NATO Class II drones for extended-range reconnaissance, battlefield surveillance, and situational awareness at the company level. This unit, known as ISR (Intelligence, Surveillance, and Reconnaissance), consists of a team of four members operating from a ground station. The team includes a navigator, gimbal operator, countermeasures specialist, and UAV operator, (Alves, 2023), as shown in Figure 7.

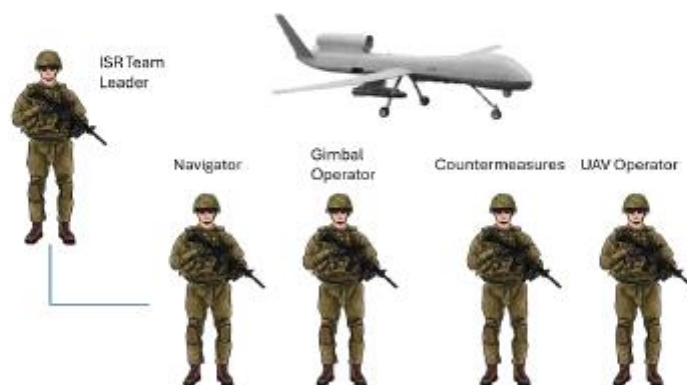


Figure 7-Portuguese ISR Unit for Drone Warfare

The creation of the ISR unit aims to emulate the command-and-control systems developed in Ukraine, bridging the gap between operational and tactical levels. This reduces decision-making time and increases overall effectiveness.

Israel

Like the Russian forces, Israel applies Drone Warfare units in mechanized brigades with the use of liaison officers who assist in the communication between chiefs and commanders and the drone units, (Frantzman, 2024), thus maximizing the effectiveness of these units.

The Israeli Defense Forces (IDF) have a unique operational organization for their drone units. The drones used by the ground forces are smaller and easier to operate, with the main functions of reconnaissance, such as NATO Class I drones, (Reuters, 2022). However, the drones of the air force are larger and more complex, reaching Class II and III, being more strategic with a longer range, (Bob, 2023). Drones such as Heron 900, Heron TP, and Hermes 450 are some examples of Israeli drones that perform these capabilities, as well as engage enemy drones, (Borg, 2021). The teams operating these drones consist of an operator and a commander, both highly ranked, each with a 6-month specialization course.

In conclusion, the IDF presents an operational organization quite different from the one currently used in the other armed forces. It has similarities in the use of NATO Class I drones for lower echelons and Class II and III for higher echelons, but the teams are composed of only two elements and operate in parallel with air force brigades and in integrated coordination with mechanized brigades through liaison officers. As can be observed in Figure 8.

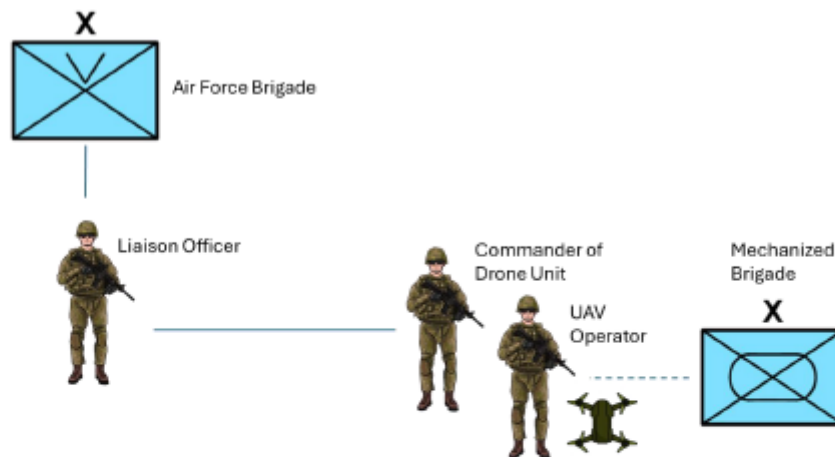


Figure 8- IDF Drone Warfare Operational Organization

Conclusion

With an extensive study on the operational organizations applied in countries such as Russia, Ukraine, Serbia, the United States of America, Portugal, and Israel, it is concluded that nations worldwide have recognized the emergence of preparing their forces for Drone Warfare. They have been designing and experimenting with various operational organizations, employing diverse means and functions.

In all armed forces, NATO Class I drones have been employed and selected for lower echelons such as teams and sections. This is due to their light weight, agility, accessibility, and cost-effectiveness, which provide numerous advantages for both reconnaissance and combat. However, the limitations of these systems, such as range, operational altitude, capacity, and endurance, have necessitated the creation of separate units, as seen in Portugal, Israel, and Russia, or separate platoons within the same company, as observed in other countries. These units are dedicated to Class II or III drones for more intensive combat or reconnaissance functions.

Differences also began to emerge in how these units would be formed, whether by two or four elements, with three or dozens of means at their disposal, which would vary according to the mission.

Nevertheless, it can be concluded that the recommended operational organization would involve the employment of NATO Class I drones integrated into infantry units up to the platoon level. These would be coordinated by ISR (Intelligence, Surveillance, and Reconnaissance) units belonging to company or battalion echelons to maximize communications, situational awareness, and decision-making. The composition of these units may depend on the mission, but it will always be necessary to have at least a commander, a drone operator, and a navigator or countermeasures specialist.

9. Annexes

9.1. Annex A- SWATTER Experimentation in Semi-Controlled Environment

The following report is a test report of the SWATTER system, tested in the dissertation, which was conducted in 2023 at the Portuguese Navy Marine Corps. Taken from (SWATTER, 2023).

Teste nº1

Drone: DJI Mavic 2 Enterprise DUAL/FLIR

Cenário 1

Neste cenário de teste foi testada a eficácia do equipamento SPG lite da Swatter nas frequências 2.4GHz e 5.8GHz, nomeadamente o bloqueio de sinal do link controlo remoto ↔ *drone*, considerando o *drone* a uma altitude de 50 metros.

Inicialmente o *drone* levantou voo com uma distância de aproximadamente 322 metros da SPG lite (Fig.1) e uma distância de aproximadamente 170 metros do controlo remoto (Fig.2).



Fig. 1: distância de descolagem, drone ↔ jammer



Fig. 2: distância de decolagem, controlo remoto ↔ drone

De seguida o *drone* foi comandado para se dirigir em direção à SPG lite, atingindo uma distância de aproximadamente 290 metros controlo remoto ↔ *drone* (Fig. 3) e uma distância de aproximadamente 190 metros *drone* ↔ *jammer* (Fig. 4) até iniciar o *jamming* das comunicações.



Fig. 3: distância de início de jamming, controlo remoto ↔ drone



- S** SPG lite: 38.6536, -9.1396
- D** Drone: 38.6514, -9.1374
- H** Home Point: 38.6524, -9.1384

Fig. 4: distância de início de jamming, drone ↔ jammer

Após iniciar a emissão dos sinais de *jamming* o controle remoto deixou de ter controle sobre o *drone* e o mesmo iniciou o procedimento de *return to home* efetuando a aterragem no *home point*.

Cenário 2

Neste cenário de teste foi testada a eficácia do equipamento SPG lite da Swatter nas frequências 2.4GHz, 5.8GHz e 1.5GHz, nomeadamente o bloqueio de sinal do link controle remoto – *drone* e de sinais GNSS (*Global Navigation Satellite System*) com o *drone* a uma altitude de 50 metros.

Efetuada o mesmo procedimento de descolagem no mesmo local do cenário 1, o *drone* foi comandado para se dirigir em direção à SPG lite, atingindo uma distância de aproximadamente 290 metros controle remoto ↔ *drone* (Fig. 5) e uma distância de aproximadamente 190 metros *drone* ↔ jammer (Fig. 6) até iniciar o *jamming* das comunicações.



- C** Controle: 38.6536, -9.1396
- D** Drone: 38.6514, -9.1374
- H** Home Point: 38.6524, -9.1384

Fig. 5: distância de início de jamming, controle remoto ↔ drone



Fig. 6: distância de início de jamming drone ↔ jammer

Após iniciar a emissão dos sinais de *jamming* o controlo remoto deixou de ter controlo sobre o *drone* e o mesmo não iniciou o procedimento de *return to home* nem procedimento de aterragem forçada apenas manteve-se a pairar até parar de emitir sinais de *jamming* de controlo remoto e GNSS.



Fig. 8: distância de decolagem, controle remoto ↔ drone

De seguida o *drone* foi comandado para se dirigir em direção à SPG lite, atingindo uma distância de aproximadamente 290 metros controle remoto ↔ *drone* (Fig. 9) e com uma distância de aproximadamente 190 metros *drone* ↔ *jammer* (Fig. 10) até iniciar o *jamming* das comunicações.



Fig. 9: distância de início de jamming, controle remoto ↔ drone

Teste nº2

Drone: DJI mini 2

Cenário 1

Neste cenário de teste foi testada a eficácia do equipamento SPG lite da Swatter nas frequências 2.4GHz e 5.8GHz. Nomeadamente o bloqueio de sinal do link controle remoto ↔ *drone* com o *drone* a uma altitude de 120 metros.

Inicialmente o *drone* levantou voo com uma distância de aproximadamente 322 metros do equipamento de *jamming* (Fig.7) e uma distância de aproximadamente 170 metros do controle remoto (Fig.8).



- S SPG lite: 38.6501, -9.1360
- D Drone: 38.6524, -9.1384
- H Home Point: 38.6524, -9.1384

Fig. 7: distância de decolagem drone ↔ jammer



- S SPG lite: 38.6536, -9.1396
- D Drone: 38.6514, -9.1374
- H Home Point: 38.6524, -9.1384

Fig. 10: distância de início de jamming drone ↔ jammer

Após iniciar a emissão dos sinais de *jamming* o controle remoto deixou de ter controle sobre o *drone* e o mesmo iniciou o procedimento de *return to home*. Ao chegar na posição do *home point* o controle remoto conseguiu obter controle parcial do *drone* (devido à maior proximidade do controle remoto ao *drone* e assim ter a possibilidade de cancelar a aterragem no *home point*) permitindo aproximar o *drone* do controle remoto, mas ao tentar aproximar do *jammer* perde completamente o controle (Fig. 11).



Fig. 11: distância de home point ↔ jammer

Cenário 2

Neste cenário de teste foi testada a eficácia do equipamento SPG lite da Swatter nas frequências 2.4GHz, 5.8GHz, nomeadamente o bloqueio de sinal do link controle remoto – *drone* com o *drone* a uma altitude de 120 metros.

Efetuada o mesmo procedimento de descolagem no mesmo local do cenário 1 o *drone* foi comandado para se dirigir em direção à SPG lite, atingindo uma distância de aproximadamente 290 metros controle remoto ↔ *drone* (Fig. 12) e com uma distância de aproximadamente 190 metros *drone* ↔ *jammer* (Fig. 13) até iniciar o *jamming* das comunicações.



Fig. 12: distância de início de jamming, controle remoto ↔ drone



- S** SPG lite: 38.6536, -9.1396
- D** Drone: 38.6514, -9.1374
- H** Home Point: 38.6524, -9.1384

Fig. 13: distância de início de jamming drone ↔ jammer

Após iniciar a emissão dos sinais de *jamming* o controle remoto deixou de ter controle sobre o *drone* e o mesmo iniciou o procedimento de *return to home*. Ao chegar na posição do *home point* o controle remoto conseguiu obter controle parcial do *drone* (devido à maior proximidade do controle remoto ao *drone* e assim ter a possibilidade de cancelar a aterragem no *home point*) permitindo aproximar o *drone* do controle remoto, mas ao tentar aproximar do *jammer* perde completamente o controle. No cenário 2 registou-se o mesmo comportamento do cenário 1 (Fig. 11).

Cenário 3

Neste cenário de teste foi testada a eficácia do equipamento SPG lite da Swatter nas frequências 2.4GHz, 5.8GHz e 1.5GHz, nomeadamente o bloqueio de sinal do link controle remoto – *drone* e de sinais GNSS com o *drone* a uma altitude de 120 metros.

Efetuando o mesmo procedimento de descolagem no mesmo local do cenário 2 o *drone* foi comandado para se dirigir em direção à SPG lite, atingindo uma distância de aproximadamente 290 metros controle remoto ↔ *drone* (Fig. 14) e com uma distância de aproximadamente 190 metros *drone* ↔ *jammer* (Fig. 15) até iniciar o *jamming* das comunicações.



- C** Controle: 38.6536, -9.1396
- D** Drone: 38.6514, -9.1374
- H** Home Point: 38.6524, -9.1384

Fig. 14: distância de início de jamming, controle remoto ↔ drone



Fig. 15: distância de início de jamming, controle remoto ↔ drone

Após iniciar a emissão dos sinais de *jamming* o controle remoto deixou de ter controle sobre o *drone* e o mesmo não iniciou o procedimento de *return to home*. Devido às condições atmosféricas o *drone* começou a desviar-se com o vento (Fig. 16) e por questões de segurança não foi possível verificar se o mesmo iniciou o procedimento de aterragem forçada no local.



Fig. 16: desvio do drone com o vento

Teste nº3

Drone: AUTEL EVO NANO PLUS

Cenário 1

Neste cenário de teste foi testada a eficácia do equipamento SPG lite da Swatter nas frequências 2.4GHz e 5.8GHz, nomeadamente o bloqueio de sinal do link controle remoto ↔ *drone* com o *drone* a uma altitude de 120 metros.

Inicialmente o *drone* levantou voo com uma distância de aproximadamente 322 metros do equipamento de *jamming* (Fig. 17) e uma distância de aproximadamente 170 metros do controle remoto (Fig. 18).



- S** SPG lite: 38.6501, -9.1360
- D** Drone: 38.6524, -9.1384
- H** Home Point: 38.6524, -9.1384

Fig. 17: distância de decolagem drone ↔ jammer



- C** Controlo: 38.6536, -9.1396
- D** Drone: 38.6524, -9.1384
- H** Home Point: 38.6524, -9.1384

Fig. 18: distância de decolagem, controlo remoto ↔ drone

De seguida o *drone* foi comandado para se dirigir em direção à SPG lite, atingindo uma distância de aproximadamente 290 metros controlo remoto ↔ *drone* (Fig. 19) e com uma distância de aproximadamente 190 metros *drone* ↔ *jammer* (Fig. 20) até iniciar o *jamming* das comunicações.



Fig. 19: distância de início de jamming, controle remoto ↔ drone



Fig. 20: distância de início de jamming drone ↔ jammer

Após iniciar a emissão dos sinais de *jamming* o controle remoto deixou de ter controle sobre o *drone* por 1 segundo. O *drone* procedeu com o *frequency hopping* e mudou a frequência de controle para os 5.2GHz continuando a ser controlado sem obstrução.

Cenário 2

Neste cenário de teste foi testada a eficácia do equipamento SPG lite da Swatter nas frequências 2.4GHz, 5.8GHz e 1.5GHz. Nomeadamente o bloqueio de sinal do link controle remoto – *drone* e de sinais GNSS com o *drone* a uma altitude de 120 metros.

Efetuando o mesmo procedimento de descolagem no mesmo local do cenário 1 o *drone* foi comandado para se dirigir em direção à SPG lite, atingindo uma distância de aproximadamente 290 metros controle remoto ↔ *drone* (Fig. 21) e com uma distância de aproximadamente 190 metros *drone* ↔ *jammer* (Fig. 22) até iniciar o *jamming* das comunicações.



- C** Controlo: 38.6536, -9.1396
- D** Drone: 38.6514, -9.1374
- H** Home Point: 38.6524, -9.1384

Fig. 21: distância de início de jamming, controlo remoto ↔ drone



- S** SPG lite: 38.6536, -9.1396
- D** Drone: 38.6514, -9.1374
- H** Home Point: 38.6524, -9.1384

Fig. 22: distância de início de jamming, controlo remoto ↔ drone

Após iniciar a emissão dos sinais de *jamming* o controlo remoto deixou de ter controlo sobre o *drone* por 1 segundo. O *drone* procedeu com o *frequency hopping* e mudou a frequência de controlo para os 5.2GHz continuando a ser controlado sem obstrução. Mas devido ao *jamming* dos sinais GNSS e às condições atmosféricas o *drone* começou a desviar-se com o vento (Fig. 23).



Di Desvio Inicial: 38.6514, -9.1374

Df Desvio Final: 38.6514, -9.1357

Fig. 23: desvio do drone com o vento

Teste nº4

Drone: MAVIC PRO

Cenário 1

Neste cenário de teste foi testada a eficácia do equipamento SPG lite da Swatter nas frequências 2.4GHz e 5.8GHz, nomeadamente o bloqueio de sinal do link controle remoto ↔ *drone* com o *drone* a uma altitude de 120 metros.

Inicialmente o *drone* levantou voo com uma distância de aproximadamente 322 metros da SPG lite (Fig. 24) e uma distância de aproximadamente 170 metros do controle remoto (Fig. 25).



S SPG lite: 38.6501, -9.1360

D Drone: 38.6524, -9.1384

H Home Point: 38.6524, -9.1384

Fig. 24: distância de decolagem drone ↔ jammer



Fig. 25: distância de decolagem, controlo remoto ↔ drone

De seguida o *drone* foi comandado para se dirigir em direção à SPG lite, atingindo uma distância de aproximadamente 290 metros controlo remoto ↔ *drone* (Fig. 26) e com uma distância de aproximadamente 190 metros *drone* ↔ *jammer* (Fig. 27) até iniciar o *jamming* das comunicações.



Fig. 26: distância de início de jamming, controlo remoto ↔ drone



Fig. 27: distância de início de jamming drone ↔ jammer

Após iniciar a emissão dos sinais de *jamming* o controlo remoto deixou de ter controlo sobre o *drone* e o mesmo iniciou o procedimento de *return to home* efetuando a aterragem no *home point*.

Cenário 2

Neste cenário de teste foi testada a eficácia do equipamento SPG lite da Swatter nas frequências 2.4GHz, 5.8GHz e 1.5GHz. Nomeadamente o bloqueio de sinal do link controlo remoto – *drone* e de sinais GNSS com o *drone* a uma altitude de 120 metros.

Efetuada o mesmo procedimento de descolagem no mesmo local do cenário 2 o *drone* foi comandado para se dirigir em direção à SPG lite, atingindo uma distância de aproximadamente 290 metros controlo remoto ↔ *drone* (Fig. 28) e com uma distância de aproximadamente 190 metros *drone* ↔ *jammer* (Fig. 29) até iniciar o *jamming* das comunicações.



Fig. 28: distância de início de jamming, controlo remoto ↔ drone



- S SPG lite: 38.6536, -9.1396
- D Drone: 38.6514, -9.1374
- H Home Point: 38.6524, -9.1384

Fig. 29: distância de início de jamming, controlo remoto ↔ drone

Após iniciar a emissão dos sinais de *jamming* o controlo remoto deixou de ter controlo sobre o *drone* e o mesmo não iniciou o procedimento de *return to home*. Devido às condições atmosféricas o *drone* começou a desviar-se com o vento (Fig. 30) mas foi possível verificar que o mesmo iniciou o procedimento de aterragem forçada no local.



- Di Desvio Inicial: 38.6514, -9.1374
- Df Desvio Final: 38.6516, -9.1356

Fig. 30: desvio do drone com o vento

Teste nº5

Drone: DJI Mavic 2 Enterprise DUAL/FLIR

Cenário 1

Neste cenário de teste foi testada a eficácia do equipamento SPG lite da Swatter nas frequências 2.4GHz e 5.8GHz, nomeadamente o bloqueio de sinal do link controlo remoto ↔ *drone* com o *drone* a uma altitude de 120 metros.

Inicialmente o *drone* levantou voo com uma distância de aproximadamente 322 metros da SPG lite e uma distância de aproximadamente 170 metros do controlo remoto como nos procedimentos anteriores.

De seguida o controlo remoto e o *drone* afastaram-se dos locais anteriormente adotados, aumentando a distância à SPG lite, atingindo uma distância de aproximadamente 200 metros controlo remoto ↔ *drone* (Fig. 31) e com uma distância de aproximadamente 600 metros *drone* ↔ *jammer* (Fig. 32).

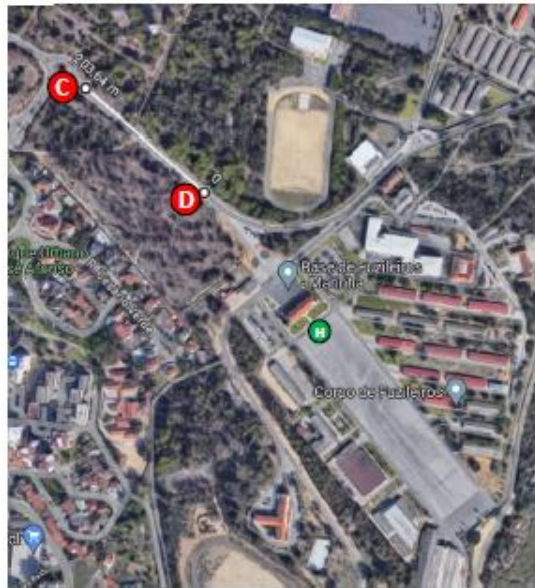


Fig. 31: distância de descolagem, controle remoto ↔ drone

- C** Controle: 38.6553, -9.1420
- D** Drone: 38.6538, -9.1399
- H** Home Point: 38.6524, -9.1384



Fig. 32: distância de descolagem, drone ↔ jammer

- S** SPG lite: 38.6496, -9.1361
- D** Drone: 38.6538, -9.1399
- H** Home Point: 38.6524, -9.1384

Após iniciar a emissão dos sinais de *jamming* o controle remoto deixou de ter controle sobre o *drone* e o mesmo iniciou o procedimento de *return to home*. prontamente foi desligado o *jammer* para testar distâncias maiores e o procedimento de *return to home* foi cancelado.

Cenário 2

Neste cenário de teste foi testada a eficácia do equipamento SPG lite da Swatter nas frequências 2.4GHz, 5.8GHz. Nomeadamente o bloqueio de sinal do link controlo remoto – drone com o drone a uma altitude de 120 metros.

Reaproveitando a localização do cenário 1 o controle remoto e o *drone* afastaram-se dos locais anteriormente adotados, aumentando a distância da SPG lite, atingindo uma distância de aproximadamente 200 metros controle remoto $\leftrightarrow$ *drone* (Fig. 33) e com uma distância de aproximadamente 800 metros *drone* $\leftrightarrow$ *jammer* (Fig. 34).



Fig. 33: distância de início de jamming, controlo remoto ↔ drone

- C** Controllo: 38.6565, -9.1444



Fig. 34: distância de início de jamming drone $\leftrightarrow$ jammer

- SPG lite: 38.6496, -9.1361
- Drone: 38.6554, -9.1422
- Home Point: 38.6524, -9.1384

Após iniciar a emissão dos sinais de *jamming* o controle remoto deixou de ter controle sobre o *drone* e o mesmo iniciou o procedimento de *return to home*. Prontamente foi desligado o *jammer* para testar distâncias maiores e o procedimento de *return to home* foi cancelado.

Cenário 3

Neste cenário de teste foi testada a eficácia do equipamento SPG lite da Swatter nas frequências 2.4GHz, 5.8GHz. Nomeadamente o bloqueio de sinal do link controle remoto – drone com o drone a uma altitude de 120 metros.

Reaproveitando a localização do cenário 1 o controle remoto e o *drone* afastaram-se dos locais anteriormente adotados, aumentando a distância da SPG lite, atingindo uma distância de aproximadamente 230 metros controle remoto ↔ *drone* (Fig. 35) e com uma distância de aproximadamente 1050 metros *drone* ↔ *jammer* (Fig. 36).

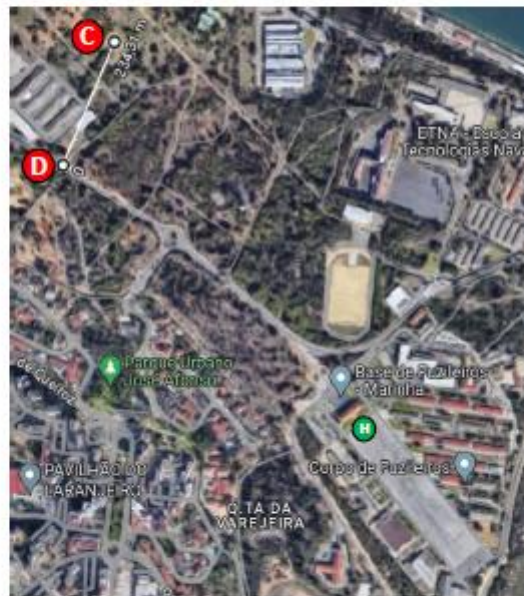


Fig.35: distância de início de jamming, controle remoto ↔ drone

- C** Controle: 38.6585, -9.1434
- D** Drone: 38.6565, -9.1444
- H** Home Point: 38.6524, -9.1384

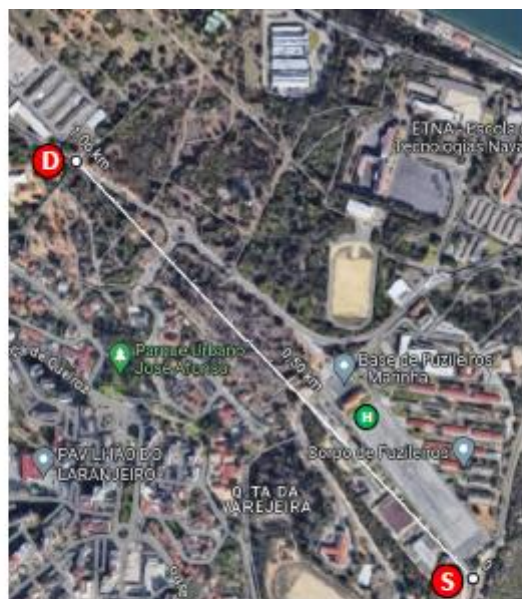


Fig. 36: distância de início de jamming drone $\leftrightarrow$ jammer

- S** SPG lite: 38.6496, -9.1361
- D** Drone: 38.6565, -9.1444
- H** Home Point: 38.6524, -9.1384

Cenário 4

Neste cenário de teste foi testada a eficácia do equipamento SPG lite da Swatter nas frequências 2.4GHz, 5.8GHz. Nomeadamente o bloqueio de sinal do link controlo remoto – *drone* com o *drone* a uma altitude de 120 metros.

Reaproveitando a localização do cenário 1 o controlo remoto e o *drone* afastaram-se dos locais anteriormente adotados, aumentando a distância à SPG lite, atingindo uma distância de aproximadamente 245 metros controlo remoto $\leftrightarrow$ *drone* (Fig. 37) e com uma distância de aproximadamente 1170 metros *drone* $\leftrightarrow$ *jammer* (Fig. 38).



Fig. 37: distância de início de jamming, controlo remoto ↔ drone

- C** Controlo: 38.6596, -9.1457
- D** Drone: 38.6584, -9.1434
- H** Home Point: 38.6524, -9.1384



Fig. 38: distância de início de jamming drone ↔ jammer

- S** SPG lite: 38.6496, -9.1361
- D** Drone: 38.6584, -9.1434
- H** Home Point: 38.6524, -9.1384



Fig. 40: distância de início de jamming drone ↔ jammer

- S** SPG lite: 38.6496, -9.1361
- D** Drone: 38.6584, -9.1486
- H** Home Point: 38.6524, -9.1384

Após iniciar a emissão dos sinais de *jamming* o controlo remoto deixou de ter controlo sobre o *drone* e o mesmo iniciou o procedimento de *return to home*. prontamente foi desligado o *jammer* para testar distâncias maiores e o procedimento de *return to home* foi cancelado.

9.2. Annex B- Training Requirements for UAS

The checklist represented below is a list of training level requirements that a UAV operator must meet, formulated by NATO. This list can be used by the Marine Corps when creating their training list for their UAV operators. The list consists of four levels with increasing levels of requirement. Taken from (North Atlantic Treaty Organization, 2019).

TRAINING CATEGORY	BUQ LEVEL			
MISSION PREPARATION	BUQ I	BUQ II	BUQ III	BUQ IV
Aviation Weather	X	X	X	X
Crew Resource Management and Communications	X	X	X	X
Human Factors and Performance	X	X	X	X
Error and Threat Management	X	X	X	X
Inflight Emergency Equipment / Procedures	X	X	X	X
Aircraft Performance Data and Limitations	X	X	X	X
Publications	X	X	X	X
Departure and Arrival Planning	X	X	X	X
Computerized Flight Planning Systems	X	X	X	X
Mission Route Selection and Analysis	X	X	X	X
Aeronautical Charts-Sectional, Tactical, Global		X	X	X
Global Flight Operations Knowledge				X
COMMUNICATIONS	BUQ I	BUQ II	BUQ III	BUQ IV
Plan and Manage Communications	X	X	X	X
Functions of Airborne Communication Systems	X	X	X	X
Data Links	X	X	X	X
Satellite Communications				X
AIRCRAFT OPERATIONS	BUQ I	BUQ II	BUQ III	BUQ IV
Identify and Avoid Weather Hazards	X	X	X	X
General Flight Rules	X	X	X	X
Fuel Planning	X	X	X	X
Operate Integrated Navigation Systems	X	X	X	X
Aviation Principles	X	X	X	X
Time and Course Control	X	X	X	X
Basic Manual Navigation	X	X	X	X
Aircraft Systems and Directives	X	X	X	X

Emergency Procedures	X	X	X	X
Manual Flight Control Skills	X	X	X	X
Air Tasking Order / Airspace Control Order		X	X	X
Radio Aid Navigation		X	X	X
Radar Navigation/Fixing		X	X	X
Basic Instrument Flight			X	X
Instrument Flight Procedures				X
Global Navigation Procedures				X
(1) BEFORE FLIGHT CATEGORY	BUQ I	BUQ II	BUQ III	BUQ IV
Plan VFR Mission	X	X	X	X
Obtain Weather Data for Mission Planning	X	X	X	X
Obtain Operational Data for Mission Planning	X	X	X	X
Perform Mission Briefing	X	X	X	X
Prepare Maps for Use During Flight	X	X	X	X
Plan Route to Destination and Alternates	X	X	X	X
Select Enroute Altitudes per Flight Information Publications	X	X	X	X
File Appropriate Flight Plan	X	X	X	X
Review Maintenance Logs	X	X	X	X
Perform Exterior Inspection Check	X	X	X	X
Perform Appropriate Communications Checks	X	X	X	X
Perform Starting Engine(S) Checks	X	X	X	X
Perform Navigation/Global Positioning System/Position Check	X	X	X	X
Obtain Appropriate Clearances Before Flight	X	X	X	X
Perform Preflight Check	X	X	X	X
Perform Interior Inspection Check	X	X	X	X
Perform UAS Control Station Instrument Checks	X	X	X	X
Perform Before Launch/Takeoff Checks	X	X	X	X
Obtain Appropriate Flight Clearances	X	X	X	X
Compute Takeoff and Landing Data		X	X	X

Perform Before Taxi Check		X	X	X
Obtain Clearance to Taxi		X	X	X
Taxi To Runway		X	X	X
Obtain Clearance for Takeoff		X	X	X
Taxi Into Takeoff Position		X	X	X
Perform Line-Up Check		X	X	X
Check Operation of Navigation Systems		X	X	X
Operate Air Traffic Surveillance Equipment (IFF/SIF/TCAS/Sense and Avoid System)			X	X
Accomplish IFR Mission Planning				X
(2) CONTACT CATEGORY	BUQ I	BUQ II	BUQ III	BUQ IV
Perform Takeoff/Launch, Initial Climb and Associated Checks	X	X	X	X
Crosswind Takeoff/Launch	X	X	X	X
Accelerate to Climb Airspeed	X	X	X	X
Perform Tech Order Climb	X	X	X	X
Perform Basic Departure Procedures	X	X	X	X
Perform Level Off	X	X	X	X
Establish and Maintain Altitude	X	X	X	X
Perform Applicable In-Flight Checks	X	X	X	X
Set, Establish and Maintain Proper Altitude/Attitude Throughout Flight	X	X	X	X
Perform Level Off/Routine Checks	X	X	X	X
Establish Basic Area Orientation	X	X	X	X
Use Local Area Map For Orientation	X	X	X	X
Perform Clearing	X	X	X	X
Change Airspeed, Straight-And-Level As Required	X	X	X	X
Clear Airspace in Direction of Turn	X	X	X	X
Perform Slow Flight	X	X	X	X
Perform Basic Aero Manoeuvres	X	X	X	X
Perform Manoeuvres Within Assigned Airspace	X	X	X	X
Perform Turns, Climbs, Descents as Required	X	X	X	X
Recognize Unusual Attitudes and Perform Recoveries	X	X	X	X
Recognize Stalls/Approach to Stalls and Perform Recovery	X	X	X	X

Recognize Approach to Departure from Controlled Flight and Perform Recovery	X	X	X	X
Perform Before Descent Check	X	X	X	X
Perform Descent	X	X	X	X
Perform Approach To Field Check	X	X	X	X
Request and Receive Landing/Recovery Clearance	X	X	X	X
Analyze Wind Conditions	X	X	X	X
Respond to Traffic Conflicts as Appropriate	X	X	X	X
Perform Normal Traffic Patterns	X	X	X	X
Configure Aircraft to Land/Recover and Perform Appropriate Checks	X	X	X	X
Initiate Automatic Approach and Landing/Recovery	X	X	X	X
Fly Final Approach	X	X	X	X
Perform Approach to Landing/Recovery	X	X	X	X
Crosswind Landing/Recovery	X	X	X	X
Perform Go-Around on Final Approach/Flare	X	X	X	X
Perform Go-Around/Missed Approach Check	X	X	X	X
Perform Landing and Rollout, or Recovery	X	X	X	X
Demonstrate Airmanship, Judgment and Decision-Making	X	X	X	X
Perform and Demo UAS Control Station Safety Procedures	X	X	X	X
Perform Normal Overhead Pattern			X	X
Perform Closed Pattern			X	X
(3) INSTRUMENT CATEGORY	BUQ I	BUQ II	BUQ III	BUQ IV
Identify Weather Phenomena Which Affect Flight			X	X
React to Hazardous/Adverse Weather Conditions During Flight			X	X
Operate Aircraft Instruments and Navigation Equipment			X	X
Maintain Aircraft Control Under Instrument Conditions			X	X
Perform Aircraft Manoeuvres Under Instrument Conditions			X	X

Recognize Improper Nose Low Condition			X	X
Recognize and Recover from Unusual Attitudes Under Instrument Conditions			X	X
Recognize and Address Instrument Malfunctions			X	X
Obtain In-Flight IFR Clearance				X
Perform Auto/Instrument Takeoff, Climb And Departure				X
Perform Instrument Cross Check				X
Comply with ATC Procedures				X
Turn to and Maintain Directed Headings				X
Establish and Maintain Directed Altitudes				X
Maintain Proper Airspeed and Airspace				X
Perform Course Intercept				X
Determine Angle Of Intercept				X
Determine Intercept Heading				X
Determine Lead Point				X
Determine Rate Of Intercept				X
Complete Intercept				X
Perform IFR Navigation				X
Perform Fix-to-Fix Navigation				X
Maintain Selected Course Correcting for Wind				X
Intercept Arc				X
Establish Arc				X
Maintain Arc				X
Perform Radial Intercept from Arc				X
Receive and Understand Holding Instructions				X
Establish Proper Holding Configuration				X
Perform Proper Holding Pattern Entry				X
Maintain Position Within Holding Pattern Airspace				X
Perform Wind Analysis to Assist in Maintaining Position Within Holding Pattern Airspace				X
Depart Holding Pattern				X

Perform En Route Descent				X
Determine Descent Gradient				X
Perform Descent				X
Perform Instrument Meteorological Conditions Penetration				X
Comply With Standard Instrument Approach Plate Procedures				X
Perform Instrument Approach				X
Perform Procedure Turns				X
Remain Within Procedure Turn Airspace				X
Perform Radar Pattern				X
Perform Non-Precision Radar Approach				X
Perform Precision Radar Approach				X
Perform Gyro-Out Instrument Pattern				X
Perform Half Standard-Rate Turns on Final				X
Perform Gyro-Out Precision Radar Approach				X
Establish Landing Configuration				X
Maintain Glide Slope Control				X
Maintain Course Control				X
Calculate Visual Descent Point				X
Transition From Instruments to Visual				X
Transition from Minimum Descent Altitude to Runway				X
Transition from Glide Path to Runway				X
Perform Circling Approach				X
Comply with Missed Approach Procedures				X
Comply with ATC Missed Approach Clearance				X
Complete Missed Approach Check				X
(4) NAVIGATION CATEGORY	BUQ I	BUQ II	BUQ III	BUQ IV
Perform Map Reading	X	X	X	X
Identify Appropriate Visual Landmarks	X	X	X	X
Correlate Position with Map	X	X	X	X
Perform Visual Navigation	X	X	X	X

Perform In-Flight Navigation Planning	X	X	X	X
Calculate Actual Fuel/Power Consumption	X	X	X	X
Perform Time and Fuel/Power Management	X	X	X	X
Calculate / Compensate for In-Flight Winds	X	X	X	X
Make Position Reports	X	X	X	X
Perform Lost Comm / Lost Link Procedures	X	X	X	X
Compare Actual and Planned Rates of Fuel/Power Consumption	X	X	X	X
Compare Actual and Planned Ground Speeds	X	X	X	X
Perform Dead Reckoning Navigation		X	X	X
Calculate New Estimated Time of Arrival		X	X	X
Request In-Flight Clearances		X	X	X
Use Automated Terminal / Weather Information Services, Report Inflight Weather Conditions		X	X	X
Interpret Radio Weather Condition Report		X	X	X
Alter Navigation Based on Weather Report		X	X	X
Perform Strange Field Departure			X	X
Perform Strange Field Visual and Instrument Approaches			X	X
Perform Low-Level Navigation			X	X
(5) EMERGENCY CATEGORY	BUQ I	BUQ II	BUQ III	BUQ IV
Recognize Emergency Conditions	X	X	X	X
Maintain Aircraft Control During Emergency Conditions	X	X	X	X
Analyze Situation, Including Systems for Possible Emergency	X	X	X	X
Recognize and Perform All Applicable Emergency Procedures	X	X	X	X
Initiate Communications/Declare Emergency (If Required)	X	X	X	X
Recognize and Properly Respond to Unplanned Lost Link Events	X	X	X	X

Land as Soon as Conditions Permit	X	X	X	X
(6) AFTER FLIGHT CATEGORY	BUQ I	BUQ II	BUQ III	BUQ IV
Perform After Landing Check	X	X	X	X
Perform Engine Shutdown Check	X	X	X	X
Perform All Safety Procedures for Securing Aircraft	X	X	X	X
Perform Post-Landing Procedures	X	X	X	X
Complete Maintenance Logs	X	X	X	X
Complete Flight Time Logs	X	X	X	X
Taxi Clear of Runway		X	X	X
Taxi to Parking		X	X	X
Close Flight Plan with ATC		X	X	X
(7) INSTRUCTOR / TEST SYSTEM CATEGORY	BUQ I	BUQ II	BUQ III	BUQ IV
Demonstrate Understanding of Learning Theory	I	I	I	I
Demonstrate Effective Instructional Presentation Techniques	I	I	I	I
Demonstrate an Understanding of Courseware Theory Design	I	I	I	I
Demonstrate Subject Matter Expertise	I	I	I	I
Demonstrate Understanding of Test Plan	I	I	I	I
Demonstrate Proper Use of Training Aids	I	I	I	I
Perform System Test Procedures	I	I	I	I
Analyze Test Data	I	I	I	I

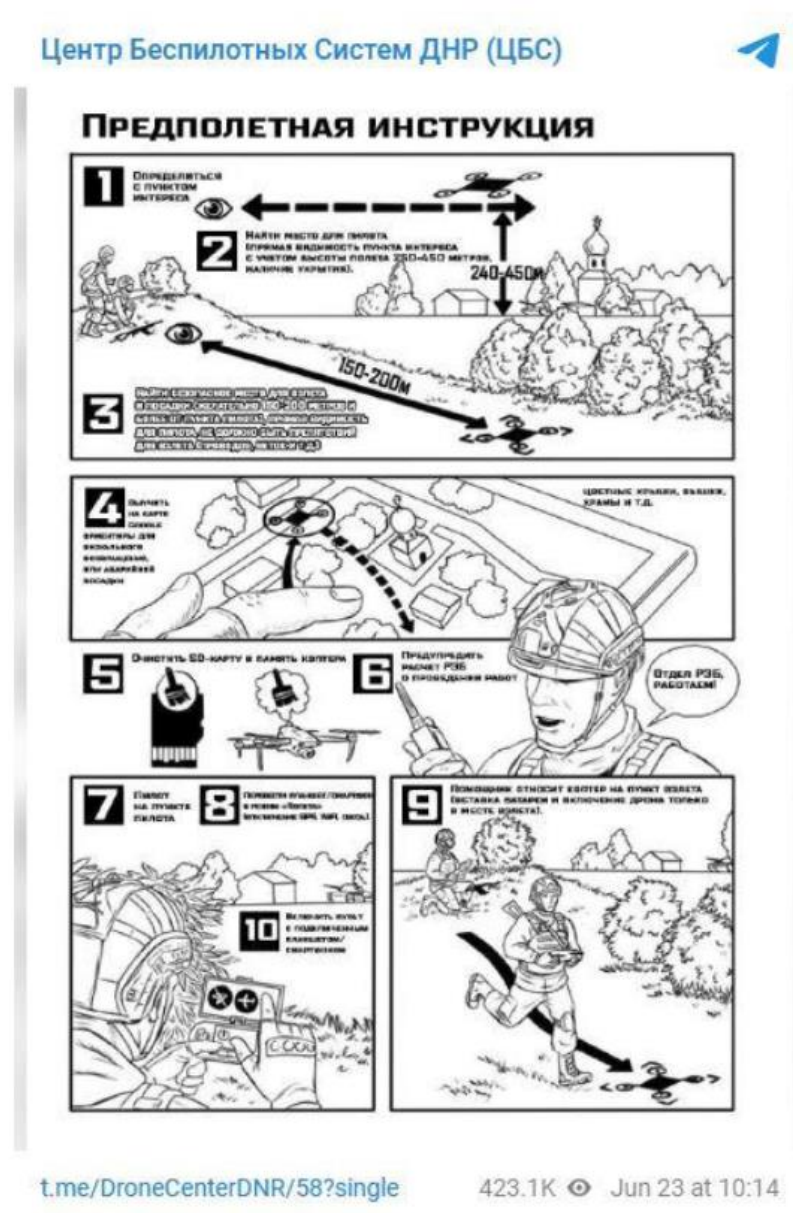
9.3. Annex C- Training Requirements for C-UAS

The list represented below is a list that demonstrates the requirements that a countermeasures operator must meet to perform functions. The list is taken from NATO and can be used to formulate training checklists to train C-UAS operators in the Marine Corps. Taken from (North Atlantic Treaty Organization, 2023).

UNIT AND SUBUNIT TRAINING CONSIDERATIONS	
TRAINING OBJECTIVE	REMARKS
Passive defence techniques	(1) Perform cover drills; (2) Use camouflage and concealment (from the air); (3) Vary routine; (4) Harden positions; and (5) Use air threat avoidance techniques (dummies, decoys and dispersion).
Active defence techniques	(1) Conduct air target identification procedures; (2) Establish ROE and HAC; (3) All-arms air defence policy and engagement; (4) Open fire policy; (5) Fire control orders; (6) Set up and achieve post-engagement policies (re-engagement, redeployment, etc.).
Aircraft recognition	(1) Define the characteristics of threat UAS, as well as those of friendly force UAS; (2) UAS capabilities such as operating altitudes, speeds and range / endurance; and (3) Adapt wing, engine, fuselage, tail (WEFT) theory for UAS.
Air Sentry duties and procedures	(1) Scanning techniques; (2) Target identification; (3) Aircraft recognition; (4) Reporting procedures; (5) Establish and practise early warning network; and (6) Understand and disseminate HAC, fire control orders and AAAD policy.
Air IPOE	(1) Establish a library of UAS capabilities

Below is a list of TTPs identified by expert Samuel Bendett in the study of UAV application in the Russian-Ukrainian conflict. The following images were used as a basis and inspiration for the Drone Warfare manual identified in Appendix J- Drone Warfare Manual. Taken from (Edmond & Bendett, 2023).

Checklist Geral.



Инструкция предполетная



1. Определитесь с пунктом интереса для разведки

150 - 200 м

2. Найдите место для пилота

- прямая видимость пункта интереса с учетом высоты полета 250-450 метров
- наличие укрытия

3. Найдите безопасное место для взлета/посадки

Желательно 150-200 метров от пункта до пилота, отсутствие помех в виде веток и проводов. Пункт взлета и посадки - 7 на 7 метров чистых от преград и высокой растительности

4. Изучить на карте ориентиры для визуального возвращения коптера или аварийной посадки в случае потери связи

Среди ориентиров могут быть цветные крыши, башни, церкви и другое. Лучше использовать Яндекс, Гугл-карты или Maps.me

5. Очистите карту памяти и/или память коптера

6. Предупредите отдел РЗБ или другое подразделение про ведение разведывательных работ с коптера

10. Помощник относит коптер на пункт взлета. Установка батареек и включение дрона только в пункте взлета (для безопасности пилота)

7. Оператор коптера занимает позицию

8. Перед взлетом включить на планшете или телефоне режим полета (выключить GPS, Wi-Fi, Мобильную связь)

9. Включить пульт коптера с подключенным планшетом/телефоном

11. Разложить винты коптера

12. Вставить батарею

13. Включить коптер, поставить на ровную площадку

14. Пилот взлетает, помощнику немедленно покинуть взлетную площадку

T.M.E./S.M.O.T.R.I.Z

Checklist durante voo.

Инструкция полётная

1. Вывести аппарат на высоту 250 метров

2. Прислушиваться к шуму винтов, учитывать громкость коптера во время движения, особенно в режиме «спорт»

3. Продолжать набор высоты до 350 метров

4. Внимательно следить за уровнем сигнала, корректировать позицию, чтобы сигнал не снижался

5. Следить за скоростью полёта, учитывая нормальную скорость полёта в штиль, легко определить встречный и попутный ветер

6. Следить за емкостью батареи, иметь достаточный запас для возврата коптера. Часто на обратный путь нужно идти при заряде батареи в 60 процентов от общего объема батареи

60%

T.ME/SMOTRI_Z

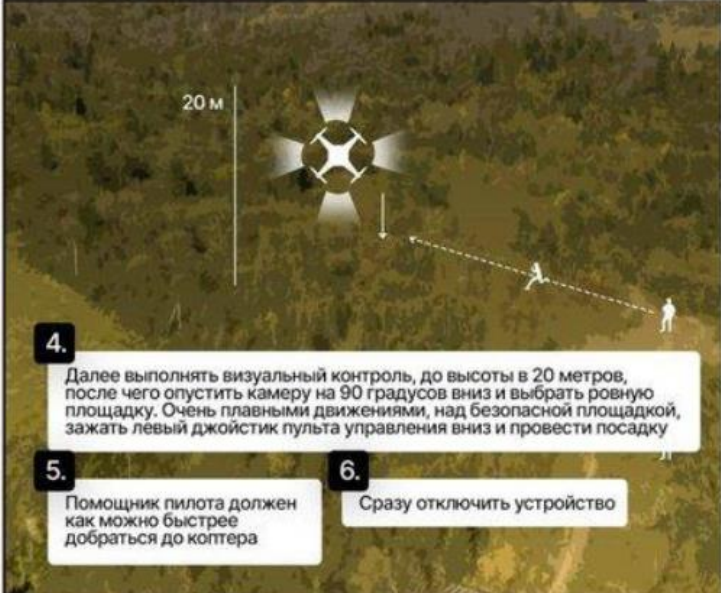
Инструкция завершения полёта



1. Нажать кнопку «возвращение домой»

2. На расстоянии в 1 километр взять управление вручную

3. На подлёте, когда уже не важна маскировка звука, можно начинать приближение и спуск одновременно, до высоты в 250 метров, затем при приближении к 500 метрам, опустить коптер на высоту 120 метров



4. Далее выполнять визуальный контроль, до высоты в 20 метров, после чего опустить камеру на 90 градусов вниз и выбрать ровную площадку. Очень плавными движениями, над безопасной площадкой, нажать левый джойстик пульта управления вниз и провести посадку

5. Помощник пилота должен как можно быстрее добраться до коптера

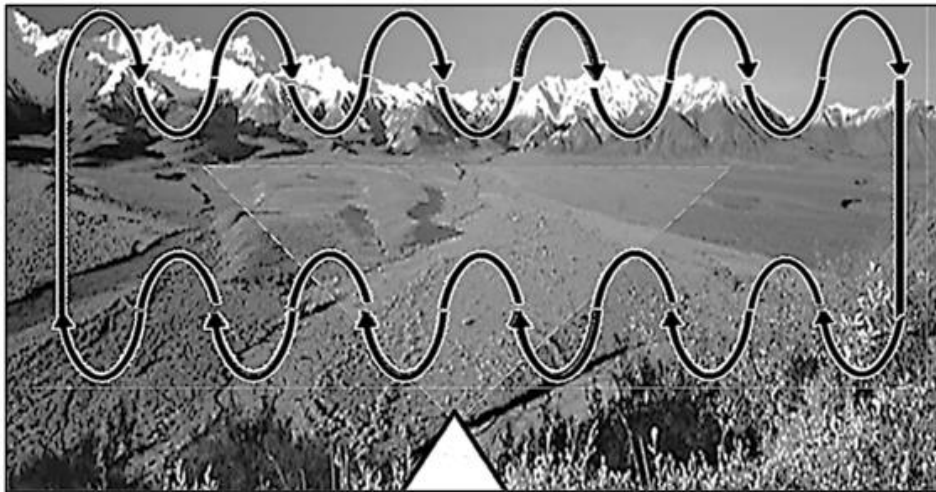
6. Сразу отключить устройство

T.M.E./SMOTRI.Z

9.5. Annex E- Vertical and Horizontal UAV Scan Detection Method

The measures for detecting enemy UAVs shown below were taken from North American doctrine and used as a basis and inspiration for the Drone Warfare manual in Appendix J- Drone Warfare Manual. Taken from (Headquarters, Department of the Army, 2023).

Vertical UAV Scan Detection Method



Horizontal UAV Scan Detection Method



9.6. Annex F- Reconnaissance Mission Checklist

The checklist shown below, taken from North American doctrine, provides a list of verifiable items in force reconnaissance. The list was used as a basis and inspiration for the Drone Warfare Manual present in Appendix J- Drone Warfare Manual. Taken from (North Atlantic Treaty Organization, 2020)

Reconnaissance Mission Checklist	
Start Point	Coordinates
Designated Route	Map Route Coordinates SandBox
Time of Mission	GDH Date
IPB	Critical Points Intelligence Constraints and Restrictions
Weather	Good Weather: Above 2500m Operational Altitude 5km Visibility
	Poor Weather: 90m to 2500m of Operational Altitude 1.5km Visibility
	Adverse Weather: Below 90m of Operational Altitude Bad or No Visibility
Unit	UAS Model and Category miro

9.7. Annex G- Checklist for UAS Missions Planning

The checklist below is a very comprehensive list for planning UAS missions, taken from NATO doctrine. It was used in the formulation of the Drone Warfare Manual for the tactical leader to adopt on missions. The Drone Warfare Manual can be found in Appendix J- Drone Warfare Manual. Taken from (North Atlantic Treaty Organization, 2020)

Duty Assignments:	
	Critical skill specialties identified and on-hand
	Additional personnel necessary for planned mission time
Enemy Situation:	
	Units / order of battle / uniforms-dress
	Enemy unit locations plotted on map
	Strengths / weaknesses
	Most probable COA
	Most dangerous COA
	ADA threats (for each weapon system)
	System Location plotted on map
	Maximum/minimum range (threat rings plotted on map)
	Minimum engagement altitude
	Strengths
	Weaknesses
	Planned reaction
	Night vision capability
	EW threat
	Meaconing, interference, jamming, and intrusion [MIJI] of UAS uplink/downlink
	CBRN threats
Friendly Situation:	
	Overall mission/intent
	Unit mission/intent
	Maps or imagery of operating area
	Friendly unit location plotted on map
	Friendly manoeuvre graphics posted on map
	UAS readiness status
	Supported unit task/purpose
	Adjacent unit task/purpose
	Abort criteria

	Other UAS units task/purpose
	Other UAS units operations posted on map
	Friendly aviation scheme of manoeuvre
	Review site security
	Additional equipment necessary for planned mission time
	Evaluate all specified tasks from:
	OPORD
	WARNOs
	FRAGOs
	Verify ACO, ATO, SPINS requirements
	ROZ locations/dimensions/frequency/call signs
	Artillery position area locations plotted
	Active routes/airspace control points plotted
	Verify method of airspace control
	Positive control measures
	Procedural control measures
	Verify H-hour
	Spare UA procedures
	Emergency procedures
	Divert plan
	Downed UA recovery plan
	Weather decision time
Mission Planning:	
	Sensor selection/options
	EO and IR imagery payload for day/night operations
	Other sensors
	Weapons load (if capable)
	Map reconnaissance of mission area
	Identify terrain that will interfere with LOS data link
	NAIs
	Grids defining NAIs
	Heading and distance to NAI from launch point
	Heading and distance between NAIs

	Identify/mark natural and manmade hazards to flight
	Local hazards
	Sectionals
	Alternate route (ingress and egress)
	Threats plotted along route
	Weather
	Clouds
	Precipitation
	Wind
	Visibility
	Temperature / thermal crossover
	Illumination
	Launch/takeoff and recovery/landing area identified
	Flight route outside threat engagement rings
	Route time
	Loiter time
	Verify grids
	Check all altitudes, azimuths, and distances
	Navigational systems check/accuracy
	Times submitted to higher headquarters
	Waypoint card printed
	Air control points plotted on map
	Primary/alternate routes plotted on map
	Contingency actions
	Fuel planning:
	Availability and on-hand stock age of fuel (AVGAS/MOGAS/JP-8)
	Availability and on-hand stock age of batteries
	Availability and on-hand stock age of ammunition
	Estimated fuel burn rate
	Estimated battery usage rate
	Minimum fuel at departure
	Bingo fuel
	Communication plan:

	Flight operations
	TOCs, command nets
	Air battle net
	Fire support coordinator net
	Administrative and Logistics Operations Centre net
	ATC (airfields, approach, and others)
	ROZ
	LOS characteristics of terrain (UA limits of operation based on LOS data link)
	Contingency actions
	Frequency compromise
	COMSEC compromise
	Emergency procedures for loss of signal
	EW considerations to include friendly communication interference
	Communication frequency bandwidth of UAS operation
	Frequency management
	OPSEC requirements
	Packet/card/map preparation
	Enemy graphics
	Friendly graphics
	ROZ graphics
	Flight routes
	Crew card
	Time flow
	Mission sequence
	Waypoint card
	Rehearsal setup