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CLASSIFICATION, MILITARY APPLICATIONS, AND OPPORTUNITIES OF UNMANNED AERIAL VEHICLES

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Abstract. Unmanned aerial vehicles (UAVs) are cutting-edge technologies used for military purposes worldwide at tactical, operational, and strategic levels. This study provides an overview of the history and current state of military drones, considering a global and Ecuadorian background. Then, a classification of the UAVs developed and built in Ecuador is conducted based on their endurance, altitude, and wing span to understand the national context and progress. The research also delves into the applications of UAVs in several military operations and missions, aiming to create a framework that aligns UAV capabilities with specific operational needs; this permits the identification of the challenges and opportunities the country faces. Unmanned aerial systems have changed the battlefield, and the government needs to adapt to a national strategy that incorporates this technology; this research analyzes and provides insights to improve military capabilities such as exploring modern UAV military applications, technical updates in communication, navigation, and data acquisition systems; and the integration of emerging technologies like smart materials, artificial intelligence, and electric propulsion systems. This study provides valuable insights into the Ecuadorian UAVs that enhance the country's military operations and offer some applications and uses of this technology for national security.

Keywords: military drones, military capabilities, modern military applications, unmanned aerial vehicle, UAV classification, military operations.

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1. Introduction

An Unmanned Aerial Vehicle (UAV) is a heavier-than-air vehicle able to fly without a human operator onboard. These can be autonomous or operated under remote control (Gortney, 2016). UAVs are also called drones, pilotless aircraft, remotely piloted vehicles (RPV), or remotely piloted aircraft (RPA); all these terms describe that the aerial vehicle is flying without a pilot onboard (Gertler, 2012). UAVs are devices used for numerous applications worldwide due to their adaptability to several cutting-edge technologies that can be carried out (Jara-Olmedo et al., 2018). The UAV can be programmed before it takes off with a defined trajectory, ascend, perform a mission, and land autonomously using an autopilot, or can be controlled remotely by a drone pilot in a ground station using a defined navigation, communication and control system (Patel et al., 2022). To achieve autonomous capabilities, the aerial system must use specific technologies that allow an unmanned flight without a pilot in the cabin. The system can be automatic when programmed by a human operator, human supervised when a ground pilot can interfere with the functional system, or fully autonomous if the air vehicle is self-governing using artificial intelligence (AI) (Sigala & Langhals, 2020).

The design of a UAV is similar to an airplane, based on wings, fuselages, and tail with their respective flight controls. However, weight and size are optimized due to requirements, and systems' redundancy differs from piloted aircraft. These features give UAVs improved versatility, enhanced performance, better maneuverability, and upgraded payload capacity (Sánchez-Zuluaga et al., 2023). As the requirements and regulations change, UAVs can be designed, produced, and tested at a lower cost than aircraft (Hassanalian & Abdelkefi, 2017). Users can also reduce operational costs due to smaller engines converted into reduced fuel consumption. Something to keep in mind when building unmanned aerial vehicles is to ensure that their weight is as low as possible to improve their endurance. The choice of the wing structure and its covering determines the noise generated during the flight of the UAV, which is directly related to the dynamic characteristics (vibration) of the UAV wings (Karpenko & Nugaras, 2022). Additionally, crew and pilots have restrictions to flight during extended times due to safety and security constraints, giving another advantage to drones, which can operate at higher ranges and endurances.

All these features align perfectly with military operation's needs, giving some strategic advantages while avoiding the loss of qualified pilots on the battlefield. These aerial vehicles can carry several payloads, including missiles, projectiles, radars, datalinks, infrared sensors, or electro-optical cameras, to perform a broad spectrum of missions and operations. When unmanned aerial vehicles are used for special purposes, they require the use of special materials for their construction, which allow them to transport the appropriate loads and, at the same time, not affect propulsion. The wings are of special interest to researchers, mainly the shape and the material they are made (Karpenko et al., 2023). For instance, is important to improve the adaptive properties, passive control systems, and vibration damping, with smart materials and structures which can be considered for future designs within unmanned aircraft. Nowadays, drones are widely used in military applications such as combat warfare, security of strategic areas, reconnaissance, real-time surveillance, border control, and tracking of convoys (Gertler, 2012). Due to this technology, commanders can plan and monitor an operation even far away from the battlefield.

UAVs have become a technological device of significant influence in defense and security (Andrade Santamaría & Molina Bustamante, 2016). This industry has shown recent strong growth, with estimates indicating it will reach USD 102.7 billion by 2030 (Research & Markets, 2024). UAVs can be classified according to military applications and purposes due to their complex and sophisticated missions, from surveillance to automatic target recognition (Silva et al., 2012). This article aims to comprehensively analyze the classification of unmanned aerial vehicles produced and operated by the Ecuadorian military and significantly evaluate their various military applications that drones can be used and adapted in a general context of security and defense, to provide an understanding of the capabilities and limitations of different types of drones in diverse military contexts, allowing to identify potential opportunities and challenges.

Several UAV reviews have been done in the Latin American context explaining applications and capabilities of drones; specific applications have been presented as part of the review, showing interesting points of view and advances in sensors and devices. In the drone history of Latin America, Ecuador was one of the pioneers to develop and fly unmanned aircraft in the region. However, this current state of the art presents a gap in UAV categorization and military applications in the country. This paper will explore how UAVs can contribute to the strength and effectiveness of the Ecuadorian Armed Forces.

2. Background

The history of military autonomous aerial vehicles begins in 1584 during the Antwerp naval blockade; tactical aerial vehicles were used against naval fleets using burning ships formed of gunpowder that were launched against enemy boats to disrupt navy attacks. Early designs of Unmanned Aerial Combat Vehicles (UCAV) appeared in 1783; devices configurated as aerostat balloons made of paper and powered by hot air were filled with gunpowder to be used as aerial bombs against cities (Kozera, 2018).

The Ruston Proctor Aerial Target, a design inspired by Nikola Tesla's radio control, was developed in Great Britain in 1916. Since then, the military industry has massively explored UAV technology. For example, in 1930, the US Army implemented aerial torpedoes called "Bugs" to attack enemy positions. In 1942, the US Navy added the first weapons in the radio-controlled USS Ranger (CV4), widely used during the Second World War. Other American experiments were conducted simultaneously; the Aphrodite and Anvil projects tried to control unmanned flights to eliminate the German rocket developments. During the Cold War, previous designs were upgraded and tested inside the arms race, and as a result, some projects, such as the RP-71, launched remote reconnaissance missions (Blom, 2010).

During the Vietnam Era, reconnaissance and intelligence signals (SIGINT) were the main operational uses of UAVs in South Asia. Ryan 147A Fire Fly drones were used to perform programmed missions over the enemy positions with several range, landing, and control limitations. The purpose of those autonomous machines was to provide information on the radars, troops, and enemy positions. After the Vietnam War, Lockheed began the Aquila project, a drone able to provide laser designation of targets, which probably opened the research and development of new strategies and uses for autonomous aircraft. It was not until 1982 that the Israeli Air Force began using battlefield UAVs with the Pioneer UAV for surveillance and reconnaissance of enemy targets and positions, leading to the modern use of autonomous flights (Blom, 2010).

An extended use of UAVs in military applications was performed during the Gulf War in the 1990s. Short-range UAVs such as the Hunter helped the troops with real-time intelligence to the Army during the Desert Storm Shield and Desert Storm. Another implementation was using close-range (CR) UAVs to help tactical maneuvers using Infrared Radar (FLIR) systems. Since then, other conceptual approaches have been introduced, such as maritime vertical take-off and landing (VTOL) and infrared sensors to monitor enemy targets. The Pioneer flew more than 177 hours in the Dessert Storm Operation, proving the value of UAVs in military missions (Blom, 2010).

In 1994, one of the most successful military UAVs in history, the medium-altitude endurance UAV called Predator, was presented as part of a reconnaissance program; it was the first autonomous drone of the US military which was employed in Bosnia, Somalia, and Kosovo as part of the Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) office (Kunertova, 2019). Autonomous flights were massively used in military operations during the invasion of Afghanistan; more than 5,000 UAVS were employed until 2001 during this war. Other systems appeared on the scene, such as Raven for CR operations with notable improvements in its performance to help troops at a tactical level; the MQ-9 Reaper with multimission capabilities able to target, engage, and attack sensitive targets (Zountouridou et al., 2023); and the Operational Global Hawk as a strategic High Altitude Long Endurance (HALE) for missions of Intelligence, Surveillance, and Reconnaissance (ISR) (Venable, 2020).

The extensive use of drones at a large scale can be noticed in the Ukraine war; the conflict shows the full potential power and applications of UAVs in the war field. Fleets of drones are used in different categories, positions, and missions, extending the range of the troops, giving invaluable information to the commanders, and integrating cutting-edge technologies for precise attacks (Kunertova, 2023). Remote strikes and long-endurance reconnaissance are the main capabilities used. During this campaign, drones are used for psychological operations, passing through surveillance, and exploiting their maximum potential by acting as UCAVs. During this war, the Bayraktar drone gained a reputation for conducting reconnaissance and laser target acquisition, striking over 300 kilometers away (Despont et al., 2022).

Over centuries of research and development, UAVs have notably changed the war scenario; these systems are used worldwide to plan and operate military operations at all command levels. The incorporated technology allows us to get real-time information even at intercontinental distances. The combination of navigation, communications, and inertial position systems permits the conduct of combat missions remotely with a high level of accuracy; those are the reasons why the expanded use and application of UAVs in military applications are growing at the highest historical levels.

2.1. Ecuadorian context

As with the majority of the countries around the world, the development of UAVs in Ecuador began due to military needs; after the Paquisha War (1981), the conflict between Ecuador and Peru due to undefined territorial limits, the country started to explore new devices to sustain the operational strategies with the possibility of facing a new war episode against Peruvian troops (Lekanda Laban, 2010). This is why, in the early 1990s, the Ecuadorian Air Force (FAE) began to explore the potential of drones in military operations. In 1994, the FAE created the Department of Aeronautical Engineering as part of the Cotopaxi Air Force Base to address unmanned aerial vehicles' technical and operational challenges.

The Department of Aeronautical Engineering created a project called "Rayo" which focused on designing and producing remote aerial systems. Consequently, the first UAV developed by the FAE had its first flight in 1997 in Latacunga city. The system was called "RPV Cotopaxi" and had a ceiling of 4,500 meters, a speed of 156 km/h, a wingspan of 4.4 meters, and a payload of 60 pounds. This RPV was used for communications relay and remote pilot training. The RPV Cotopaxi is the first unmanned aerial vehicle to take off and guide to land for a ground station in South America (Andrade Santamaría & Molina Bustamante, 2016).

In 1998, the FAE established the Research and Development Center (CIDFAE) in Ambato, a pioneer city in manufacturing development. The CIDFAE is considered one of the most significant technological centers in the Ecuadorian aeronautical industry. It can implement projects for military defense, modify aircraft structures according to logistical needs, and is suitable for designing and developing aerial systems. In 2011, CIDFAE launched the "RPV Cotopaxi" modernization project to develop unmanned aerial vehicles that could take off, perform a mission and land autonomously. The project developed several versions of UAVs, such as Bluebird, Gorrion, Fenix, Gavilan, and Colibri, which will be analyzed during this study.

Ecuador has used UAVs for various military purposes, including operational planning, surveillance, reconnaissance, and disaster management, to support the country's defense and provide security in strategic areas and natural resources. (Jaramillo, 2014). In 2007, through the National Directorate of Aquatic Spaces (DIRNEA), the Ecuadorian Navy launched a surveillance and control project to reduce fuel smuggling in the maritime area. The project established the need for an integrated surveillance system, which included using drones for aero-maritime exploration in areas near the continental coastline. In 2009, the Navy acquired four Searcher and two Heron UAVs from the Israel Aerospace Industries to combat smuggling, piracy, and drug trafficking at sea.

The Military Geographic Institute (IGM) uses a tactical UAV Trimble UX5 for cartography, photogrammetry, and research applications. The UAV was mainly used in the 2016 earthquake when the Armed Forces helped to control disaster management in the province of Manabí. It is also used for orthophoto graphic mapping in Ecuador's extension in Antarctica. The Joint Electronic Monitoring and Reconnaissance Group (GMREC) uses the ALTI Transition UAV for intelligence and counterintelligence operations. This UAV has vertical takeoff and landing (VTOL) capability, carrying electro-optical sensors for day and night observation (Montoya & Briones, 2019).

Ecuador has limited unmanned aerial vehicles because the technology developed has not yet been fully adapted to international capabilities. Nonetheless, the nation has shown essential advances in the creation of UAVs. There is a growing interest worldwide in using this technology for various purposes. The main challenges facing the development of unmanned aerial vehicles in Ecuador include financing new projects in the development of drones, technical updates to personnel and facilities, and introducing regulations and military doctrine that include new technologies and strategies. Despite these challenges, Ecuador has the potential to become a leader in developing and using unmanned aerial vehicles in Latin America. The country has a solid technical base and a demand for cutting-edge technology to support military operations. The following sections of this work describe how UAVs can help the Ecuadorian Armed Forces, proposing a classification, applications, and future challenges and opportunities from a military perspective.

3. Classification of UAVs

UAVs can be classified according to various categories, such as performance, shape, size, propulsion system, and flight mode. Commonly, drones are characterized by their technical features, including weight, wing span, wing loading, maximum altitude, speed, or endurance (Hassanalian & Abdelkefi, 2017). Comparison based on wing span and flight endurance allow to classify drones in the following categories: High Altitude Long Endurance (HALE), Medium Altitude Long Endurance (MALE), Low Altitude Low Endurance (LALE), Low Altitude Short Endurance (LASE), Medium Range Endurance (MRE), Mini and Micro Air Vehicles (MAVs) (Watts et al., 2012).

Endurance is the time capacity that a UAV can fly; it relates to the aerodynamic performance, the engine efficiency, and the weight of the flight machine (PS & Jeyan, 2020). If the lift-to-drag ratio is optimized, the power plant will have more efficiency; therefore, less fuel or battery consumption is needed. Additionally, less fuel consumption makes more energy available to fly for extended periods (Bronz et al., 2013). It is an optimal cycle that compromises designers to reduce weight, improve aerodynamic efficiency, and reduce fuel consumption. For the military, endurance is an estimation that helps understand how long a UAV can fly to perform a mission; the longer it is, the more complicated the applications, given a considerable advantage against human pilots who cannot fly at their maximum capabilities for extended periods.

Wing span is the measure of the distance between both wingtips on an unmanned aircraft; it gives an estimation of the size of the UAV, which is related to several performance features such as wing loading, aspect ratio, fuel capacity, and maximum take-off weight (Diasinos et al., 2013). A direct relation exists between the span and the other features. Span cannot be extended indefinitely due to regulatory restrictions and structural limitations; longer wings could carry more fuel, giving more endurance to the air vehicle; however, it would influence the weight to unsustainable levels. Finding the perfect combination of efficiency in size and performance is the real challenge for designers.

Table 1 shows the classification of UAVs according to their performance; the first column is the category of the list, the second one corresponds to the shortened name of each category, and the following one indicates how long the UAV can stay flying in a full battery or fuel configuration, the next one corresponds to the wing span, and it helps to understand how big is the drone structure; finally the flight altitude of the UAV is listed according to its designed performance.

HALE are considered to operate at high altitudes. They are large, expensive, and require substantial facilities to operate. These drones are generally used for surveillance and target acquisition at the strategic levels (Chaturvedi et al., 2019). MALE are drones that operate at medium altitudes. They are smaller than HALEs with similar functions at lower distances. These drones are suitable for border patrol, disaster management, reconnaissance, and surveillance applications (Gupta et al., 2013). LALE are drones that operate at lower altitudes. It is easy to monitor and communicate with this category of drones. Thanks to specific cameras and sensors, it is used in tactical and operational missions for real-time surveillance and recognition (Jung et al., 2019). LASE are similar to LALE, but with fewer flight times, These drones are lightweight and smaller than the previous, but they fly at the same altitudes and can be used for the same applications but at a smaller distance.

MRE drones in this category are designed to prioritize applicability over endurance, they are small and lightweight, allowing them to be flexible to operate anywhere without sophisticated installations (Gašparović & Gajski, 2016). This characteristic places them at the tactical level within military applications. Mini UAVS are small and lightweight UAVs; these drones are popular for commercial applications such as photography and delivery. However, it can also help military forces in urban operations. Micro UAVs are the smaller and lighter of the list, they are often used for indoor applications with specific uses at the lower tactical level (Kaamin et al., 2017). They have a lot of benefits, such as complex maneuverability, high speed, good adaptability, and low cost (Wang et al., 2020). Nowadays, they are designed for short missions and include new features for obstacle avoidance, image processing, and computer vision techniques that can be used for accurate intelligence missions.

Figure 1 illustrates a classification of military drones operated in Ecuador; it includes various types of UAVs characterized by their endurance and weight. Seven of

Table 1. UAV classification according to performance (source: Bendea et al., 2008)

UAV Category	Acronym	Endurance (Hours)	Wing Span (m)	Altitude (m)
High Altitude Long Endurance	HALE	>48	>15	>15,000
Medium Altitude Long Endurance	MALE	24 to 48	10 to 30	9,000 to 15,000
Low Altitude Long Endurance	LALE	17 to 24	4 to 20	3,000 to 9,000
Low Altitude Short Endurance	LASE	10 to 17	4 to 20	3,000 to 9,000
Medium Range Endurance (Tactical)	MRE	5 to 10	4 to 8	<3000
Mini UAVs	Mini	1 to 5	1 to 4	<300
Micro UAVs	Micro	<1	<0.15	<30

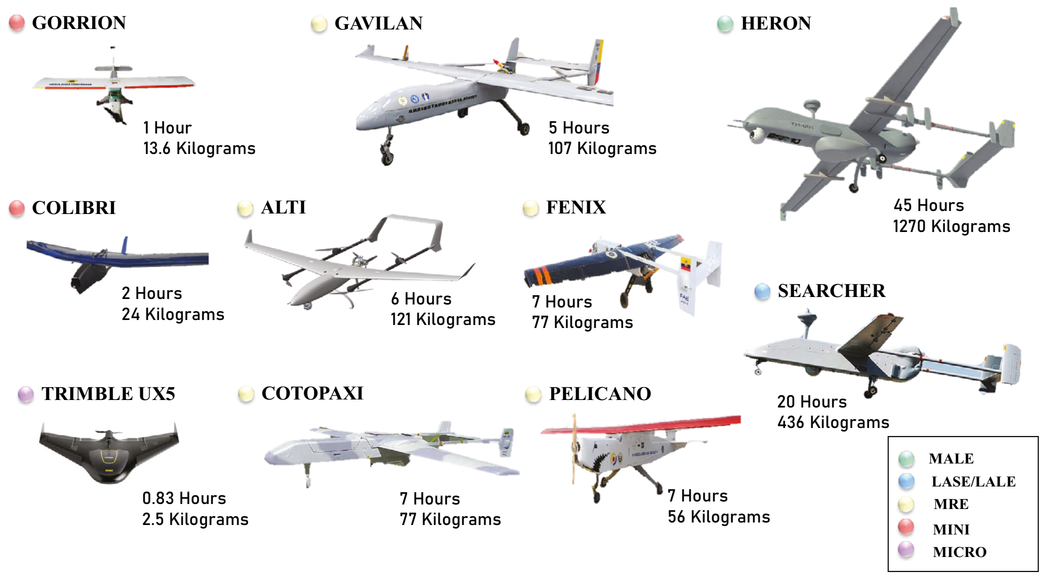

Figure 1. Military UAVs operated in Ecuador

them are designed and produced by the Ecuadorian Air Force (FAE), which has focused mainly on the medium-range sector, while the biggest ones in the LALE and MALE categories are from Israel. Other systems, such as the Alti Transition, come from South Africa; the smallest one on the list (Trimble UX5) is from the United States.

Inside the MALE category, the UAV with the highest altitude and endurance operated by the Ecuadorian Armed Forces is the Israeli drone named Heron, which can fly continuously for up to 45 hours at up to 11,000 meters of altitude. It has 16.6 meters of wing span and a maximum takeoff weight (MTOW) of 1270 kilograms (Sadot, 2016). This drone is designed to carry a valuable payload that allows it to perform intelligence, surveillance, target acquisition, and reconnaissance (ISTAR) missions in an extensive range over 1000 kilometers away from the ground station.

Following the list, the LALE Searcher UAV is cataloged as a multimission drone able to fly for up to 20 hours at heights of up to 7,000 meters. This aerial vehicle can cover a range of 300 kilometers with a MTOW of 436 kilograms. The wing span of this drone is 8.55 meters, and the overall length is 5.85 meters (Rodman, 2010). This UAV is used for missions at operational and tactical levels for surveillance, reconnaissance, and signal intelligence (SIGINT) by using several sensors and payloads.

The pinnacle of the Ecuadorian design and development is the UAV Gavilan, a medium-range endurance drone designed to perform reconnaissance at altitudes of 4,500 meters, with 5 hours of endurance, can cover a range of 80 kilometers. It weighs 107 kilograms and has a wing span of 6.5 meters. A completely autonomous UAV can take off, complete a mission, and land completely autonomous. It marks the history of the region's fully autonomous development of aerial devices. Gavilan UAV is the final version of the previous prototypes tested and designed (Cotopaxi, Fenix, Pelicano). A vertical takeoff landing (VTOL) Alti Transition is also inside the MRE category. This drone has some tactical performance used by the Army to monitor and reconnaissance for intelligence operations. This drone has an endurance of six hours with 3 meters of wing span and a MTOW of 121 kilograms.

The UAV Colibri is a prototype built inside the Mini category. This drone can fly for two hours in a complete electrical battery configuration, has a span of 2.3 meters, and has been tested for surveillance missions at the squadron level. Similarly, the Gorrion UAV belongs to the same category with 2.5 meters of wing span and a lower endurance of one hour; it was designed to perform training for military drone pilots. Finally, the Trimble UX5 falls in the micro category with less than an hour of performance, weighs 2.5 kilograms, and has a span of one meter; it is used for aerial imagery inside defined areas at squadron levels. A diagram of the complete classification of Ecuador's UAVs based on endurance, and wing span is shown in Figure 2.

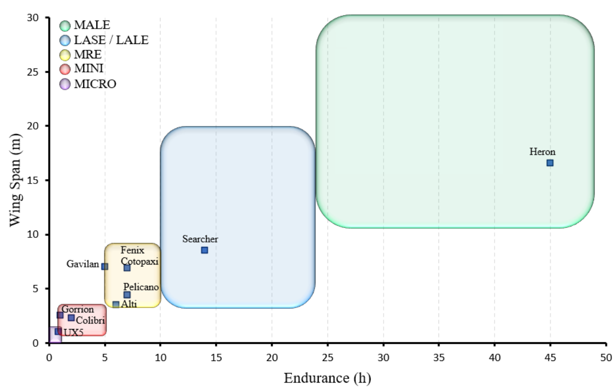

Figure 2. Ecuadorian military UAVs are classified according to endurance, and wing span

4. Military applications

The use of military drones on the battlefield has become essential in the modern frontline. This technology is used at strategic, operational, and tactical levels in all the branches of the Armed Forces. UAVs provide flexibility and adaptability for a wide range of military applications that have changed their original reconnaissance responsibilities. New roles are assigned to this technology by combining sophisticated navigation and communications systems that allow drones to act in a broad spectrum of military applications. This section explores the different applications of autonomous aerial systems and how they modify the war conditions by critically analyzing their strengths, weaknesses, and adaptability to the Ecuadorian reality.

Usually, reconnaissance operations involved a limited number of UAVs employed in previous battles. Today, these unmanned aircraft can also be used for specific military applications such as high-altitude surveillance, signal gathering, targeted strikes, electronic warfare, attack tasks with precision munitions in high-risk areas, and communications relay (Karpowicz, 2021). Moreover, the versatility of drones allows us to employ them not only in combat missions but also in providing logistics assistance, risk management, psychological operations, and advanced photography, helping to support military ground operations (Patel et al., 2022).

Military commanders can select among a variety of advanced sensors and weapons that permit them to perform specific tasks such as chemical, biological, radiological, and nuclear (CBRN) reconnaissance (Gertler, 2012); Reconnaissance Surveillance and Target Acquisition (RSTA) (Gupta et al., 2013); electronic jamming, or an accurate mission of signals intelligence (SIGINT).

The Ecuadorian military has used a diverse fleet of drones for several military applications. Table 2 shows how these drones can be classified according to the NATO UAV classification, which categorizes the aerial devices into three classes according to the operational level, endurance, altitude, weight, and typical military unit. Class I, the lighter and smaller UAVs such as the Colibri, are employed at the tactical level by companies, platoons, squads, or their equivalents in the Armed Forces. The primary use of Class I vehicles is related to close reconnaissance to support ground operations. Moving up in size and complexity, Class II encompasses MRE/LASE/LALE UAVs; these platforms are used at a tactical level, employing advanced sensors for surveillance and target acquisition; inside this category, Gavilan or Searcher platforms can be used for this purpose. The largest Class III UAV, such as the Heron, operates at an operational level, supporting large-scale missions with its medium-altitude, long-endurance capabilities; this platform is crucial because it can provide intelligence and communications relays over extended periods. Notably, HALE drones are currently absent from the strategic level, reflecting a focus on tactical and operational applications in the actual national landscape.

Although drones in Ecuadorian military aviation show a diversification of their aerial capabilities, most of their applications have been focused on reconnaissance and image acquisition missions. However, the development of autonomous aerial platforms has shown the national interest and commitment to utilize cutting-edge technologies for military purposes. As technology evolves, further adaptation and innovation within the Armed Forces UAV fleet are expected to ensure its effectiveness against new threats in the modern war landscape.

Unmanned Aerial Vehicles offer unique capabilities that enhance military operations across multiple domains. Table 3 provides a review of military applications according to the military operations, missions, and UAV capabilities, which will be detailed in the following sub-sections.

4.1. Counter air force operations

UAVs play a crucial role in counter-air force operations, including strike missions (SM), Suppression of Enemy Air Defenses (SEAD), Collaborative Combat Aircraft (CCA), and Counter Unmanned Aerial Systems (C-UAS). Predator is an example of UAVs designed for armed strikes and air-to-air combat. Acquiring targets, destroying the enemy's air force positions, and neutralizing enemies with surgical precision (Ukaegbu et al., 2021).

UAVs are essential to support tactical and operational missions. They provide commanders with real-time combat data, leading to accomplishing the desired results. Army drones have flown more than 375,000 hours and nearly participated in 130,000 maneuvers in support of strike missions in Iraq and Afghanistan (Kappenman, 2008). The Armed Forces utilize drones as an extension of

Table 2. NATO UAV classification for military applications (source: Szabolcs, 2018)

Class	Acronym	Level	Military Unit	Ecuadorian UAV
Class III (>600 kg)	HALE	Strategic	Theatre	None
	MALE	Operational	Joint Task Force (JTF)	Heron
Class II (>150 kg – <600 kg)	LALE	Tactical	Brigade	Searcher
	LASE	Tactical	Battalion, Regiment	Gavilan, Alti, Fenix, Cotopaxi
	MRE	Tactical		
Class I (<150 kg)	Mini	Tactical	Company, Platoon, Squad	Colibri
	Micro	Tactical	Platoon, Squad	Trimble UX5

Table 3. Applications of UAVs classified according to military missions and operations

Military Operations	Missions	UAV capabilities	Applications
Counter Air Force Operations	Strike and Combat (SM) Suppression of Enemy Air Defenses (SEAD) Collaborative Combat Aircraft (CCA) Counter Unmanned Aerial Systems (C-UAS)	Precision strike Kinetic strike Autonomous guidance and navigation Target acquisition Minimize collateral damage	Suppress enemy air defensive positions Destroy enemy airpower on the ground Protect and escort manned aircraft Defeat enemy UAVs
Air Defense Operations	Air Interdiction Combat Air Patrol Target and Decoy	Autonomous guidance and navigation. Adaptability for radar sensors Satellites communications GPS Navigation Systems Expanded endurance and range	Track illegal aircrafts Expand radar location coverage Deception operations
Counter Ground Force Operations	Ground Attack Close Air Support (CAS) Ground Interdiction Armed Reconnaissance	Weapons systems can be adapted Route and landing reconnaissance support Obstacle avoidance systems Autonomous guidance and navigation Ground Moving Target Indicators (GMTI) Battle Damage Assessment (BDA)	Attack targets on land Battlefield support Convoy Protection High-value unit protection (HVU) Urban warfare
Counter Naval Force Operations	Naval Attack Aeromarine Patrol Naval Interdiction	Broad Area Maritime Surveillance (BAMS) Naval Moving Target Indicators (NMTI)	Attack targets at sea Detect illegal activities at sea (smuggling, illegal fishing, drug trafficking) Naval fire support
Combat Support Operations	Intelligence, Surveillance, and Reconnaissance (ISR) Electronic Attack (EA) Communications Relay Transport and Logistics Search and Rescue (SAR)	Sophisticated imagery systems Real-time video transmission Gathering information on enemy positions Electronic warfare (EW) devices Signals Intelligence (SIGINT) Satellite communication and navigation	Real-time intelligence Disrupt enemy communications or radar systems Border patrol Remote cargo delivery Provide connectivity in remote areas Reconnaissance of illegal activities (mining, border crossings, arms and drug trafficking) Psychological Operations
Homeland Defense and Security Operations	Force Protection Search and Rescue (SAR) Humanitarian Assistance and Disaster Relief (HA/DR)	Real-time video transmission Access to remote areas Autonomous flight and navigation Adaptability to sensors and electronic devices	Security of own forces Internal defense and security of state strategic areas. (Oil and gas pipelines, natural sources, wildlife trafficking) Deliver aid and assess damage in disaster zones Disaster Planification Detect radioactive material and biological/toxic waste

the commander's vision to locate and attack targets using precision missiles. Drones with bombs and missiles allow for a direct strike on the battlefield. They can construct a three-dimensional communication network to provide strategic situational awareness for decision-making (Wang et al., 2020).

Aerial vehicles flying autonomously at lower altitudes can evade warning and missile systems providing another advantage in the operational tether (Kunertova, 2023). UAVs with laser-designator payloads are designed to detect and attack platforms as part of a cooperative assignation, giving maximum separation distance for conventional aircraft and enhancing survivability.

4.2. Air defense operations

The capabilities of these aerial systems allow us to use them in air defense operations. Military use UAVs for air interdiction, combat air patrol, and target/decoy missions at all the military levels. Their autonomous guidance and navigation systems, adaptability for radar sensors, satellite communications, GPS navigation systems, and expanded endurance and range make them ideal for these operations and allow them to protect strategic areas from enemy attacks (Hlotov et al., 2019). UAVs can track illegal aircraft and expand radar location coverage, applications where their characteristics can perform long-term missions without manned crews that cannot fly for extended periods.

4.3. Counter ground force operations

UAVs are also instrumental in counter-ground force operations; missions include ground attack, close air support (CAS), ground interdiction, and armed reconnaissance. Their weapon systems can be adapted for different missions, offering adequate armed reconnaissance support. Ground troops require assistance from this technology, which can employ obstacle avoidance systems, autonomous guidance and navigation, and ground-moving target indicators (GMTI). The modern use of unmanned aerial vehicles in ground operations involves urban warfare. Since 2005, more than 1500 unmanned aircraft have flown in Afghanistan over urban combat zones (Wang et al., 2020). Nowadays, drones are requested due to their utility in urban scenarios inside cities to perform several missions, and new technologies are being studied to assist battlefield needs.

4.4. Counter naval force operations

To participate in counter-naval force operations, UAVs have several functions, including engaging enemy naval forces and conducting precise strikes during a naval attack. The ability to carry out these operations is due to its advanced weapons systems adapted to different missions and objectives, neutralizing a wide range of naval threats, from surface ships to submarines, and providing naval fire support. Broad Area Maritime Surveillance (BAMS) is another UAV mission where drones provide real-time surveillance and reconnaissance data of potential threats at sea (Bergmann, 2020); that means unmanned aerial vehicles can be used as Aeromarine patrol to detect prohibited activities in remote areas to assist naval personnel against them.

UAVs can also accomplish naval interdiction missions using Naval Moving Target Indicators (NMTI). These devices allow them to notice, track, and intercept moving aims. This capability is necessary to disrupt enemy supply lines and outbreak targets of enemy forces directly at sea.

4.5. The role of UAVs in combat support operations

The reason why UAVs were developed remains on the scene. Providing combat support operations is one of the primary uses of autonomous aerial vehicles in modern warfare. Drones are versatile and valuable because they can integrate imagery systems, real-time communications, and sophisticated electronic sensors to gather valuable information for military strategies. The following list explores the use of UAVs in these operations, focusing on their missions, capabilities, and applications in this category:

1. Intelligence, Surveillance, and Reconnaissance (ISR). Using UAVs in ISR operations is still the primary mission assigned worldwide. Drones are equipped with modern electro-optical/infrared systems, night vision goggles, metadata/telemetry communications, and video transceivers that can gather information on enemy positions (Wang et al., 2020).
2. Electronic Attack (EA). UAVs can be equipped with electronic warfare (EW) devices and Signals Intelligence (SIGINT) equipment, enabling them to disrupt enemy communications or radar systems in a short period of time. Longer endurance and autonomous flight are perfect for using these devices to intercept communications and detect radiofrequency spectrum use of enemy weapons and systems and also the new Electronic Warfare Intelligent Information System (EWIIS) (Al-Khawaja & Sadkhan, 2021).
3. Communications Relay. Manned aircraft as Ground stations need an extension of their communications capabilities; in these cases, UAVs play a crucial role in acting as communications relays (Kim et al., 2018).
4. Transport and Logistics. No war has been won without logistical support. In this area, unmanned aerial vehicles are used to deliver cargo remotely. This feature evades the risk of human loss and improves logistics procedures (Rana et al., 2016), making it especially helpful for providing soldiers in inaccessible places.
5. Search and Rescue (SAR). UAVs can access difficult or unsafe areas for people (Mayer et al., 2019). Their ability to provide real-time video streaming and detailed images makes them necessary tools for locating people in combat or natural disasters.

4.6. Homeland defense and security operations

Lastly, UAVs are used in homeland defense and security operations for Force Protection (FP), Search and Rescue (SAR), and Humanitarian Assistance and Disaster Relief (HA/DR) missions. For instance, Colombia has designed and produced a UAV ART Quimbaya to constantly monitor strategic infrastructure, illicit mining, and environmental crimes (Castellanos-Sanabria & Rodríguez- Pirateque, 2020). Drones can transmit real-time video, access isolated areas, autonomously fly and navigate, and use various sensors and electronic devices. These capabilities allow UAVs to guarantee the security of their forces, defense, and security of strategic areas, carry aid and assess damage in adversity zones, and support disaster planning.

UAVs have transformed military operations, improving performance and capabilities that provide mission effectiveness at operational and tactical levels. Their accuracy and autonomous flight make them a platform for an extensive range of missions and requests.

5. Challenges and opportunities for military UAVs in Ecuador

The development and exploration of unmanned military aerial vehicles in Ecuador began many years ago, but despite that, the technology has not reached its full potential. Today, the challenges and opportunities in this field have grown exponentially. To unlock UAVs potential, a multi-pronged approach is necessary. Firstly, a national strategy is crucial, encompassing investments in local development, doctrine updates, regulatory frameworks, and technological integration with airspace, which are essential, particularly in military operations. Secondly, infrastructure and logistics also require significant attention because maintaining and operating UAVs requires specialized equipment across diverse disciplines that need specific solutions. Thirdly, human resources development is compulsory, demanding to train pilots, operators, and maintenance personnel of unmanned aerial vehicles.

One of the challenges is that UAVs are susceptible to being lost, hijacked, or destroyed, making it necessary to consider many network problems, such as internal communications, surveillance, security, and data management (Patel et al., 2022). Encryption techniques such as hash function and public key cryptography to protect shared data can be used to confirm the accuracy of the information that has been processed, increasing security and mitigating system failures (Alladi et al., 2020).

At the same time, new opportunities appear, mainly because the demand obeys the national needs. Some applications, such as border security and surveillance for tracking illegal activities, are required to effectively monitor the entire national territory, confronting organized crime and terrorism associated with illegal mining, smuggling, and drug trafficking. Another benefit is the real-time aerial surveillance from these autonomous vehicles that can provide valuable information for military operations and response to natural disasters, which Ecuador continually faces. In conventional or unconventional warfare, UAVs offer more precise targeting capabilities within military operations, potentially minimizing collateral damages. This advantage extends to counter-air force, air defense, counter-ground force, counter-naval force, combat support, homeland defense, and security operations, where remote monitoring makes UAVs a cost-effective alternative.

5.1. Employ military UAVs for different operations, missions, and applications

Although unmanned aerial technology holds promise for enhancing Ecuador's intelligence gathering, reconnaissance, and real-time video capabilities, its implementation can also be attractive for a wide spectrum of military applications due to UAVs' specific capabilities. Using different types of drones equipped with an extensive range of sensors, they are suitable for interacting with troops to conduct complex missions at the tactical, operational, and strategic levels. Risks and threats to national security have evolved; now is the time to evolve the way to combat them. In January 2024, Ecuador began a military intervention due to the presence of an internal armed conflict against twenty-two terrorist organizations that operate at a transnational level (Acosta & Mantilla, 2024); these criminal groups finance crime with multiple illicit activities associated with drug trafficking, smuggling of fuel and natural species, illegal minery, trafficking of people and organs, among others. To combat them, national regulation can be integrated with drones, especially to improve control of critical areas such as borders, natural and strategic sources, oil and gas pipelines, and determine areas under the control of criminal organized groups. Table 3 details some applications that UAVs can perform to enhance national security; they are classified according to their respective military operation.

UAVs have revolutionized Counter Air Force Operations, providing unique capabilities that enhance the effectiveness of the missions. Their adaptability, precision, and autonomous flight make drones a powerful tool in modern warfare. Equipped with precision-kinetic strike capabilities, UAVs can autonomously navigate, acquire, and defeat targets, minimizing collateral damage. These capabilities enable UAVs to suppress enemy air defensive positions, destroy enemy airpower on the ground, protect and escort manned aircraft, and defeat enemy UAVs (Abiodun & Taofeek, 2020).

Drones can also monitor areas outside radar range detection, a suitable characteristic for tracking and locating illegal aircraft. As a passive air defense strategy, UAVs are also used as decoys to conduct deception operations. On the Counter Ground Operations field, UAVs can attack targets on land, provide battlefield support, asses battle damage (BDA), and protect convoys and high-value units. These characteristics help to achieve the country's security strategy. As terrorism operates in urban areas, the battlefield has shifted from the borders to the urban environment. UAVs can be adapted to this new reality by choosing sensors, weapons, and artificial intelligence to provide situational awareness and real-time data in those situations to determine the activities of enemy forces, the neutral population, and friendly forces in the operational theater and urban traffic monitoring (Xu et al., 2020).

Inside Counter Naval Operations, unmanned aerial vehicles can be adapted to detect illegal activities at sea, such as smuggling, illegal fishing, and drug trafficking. Equipped with advanced surveillance systems, UAVs can monitor vast maritime areas, detect suspicious activities, and provide valuable intelligence information. These capabilities not only enhance maritime security but also help preserve natural resources.

UAVs can carry out sophisticated imagery systems, electronic warfare devices, and advanced communications equipment to provide real-time information from inaccessible areas. These capabilities suit well with Combat Support and Homeland Security Operations, where modern technology allows the acquisition of detailed three-dimensional images over large and remote areas. These functionalities can be used for applications such as border patrol, reconnaissance of illegal activities, search and rescue, surveillance of strategic positions, or gathering intelligence in real time. These capabilities allow UAVs to ensure the security of their forces, defend the state's strategic areas, deliver aid and assess damage in disaster zones, and aid in disaster planning.

Current drones have limited endurance and restricted altitude operation. Ecuador has only operated and developed drones for operational and tactical applications; the country can estimate the use of a strategic UAV for a more significant impact at the national level. High altitudes, long-endurance UAVs (HALE), and sophisticated navigation and communications systems are needed to operate over the country's diverse regions for extended periods to enhance military strategies in the long and medium term.

Drones represent a considerable potential that Ecuador can use to improve its security at all the Armed Forces branches. Class I, II, or III of UAVs could be used to combat the country's risk and threats, starting at the highest strategic stage, as well as to directly assist troops on the battlefield, a combination of applications, performance, endurance, sensors, altitudes, and missions is critical to understand how to take advantage of the capabilities that UAVs provide over the enemy.

5.2. Exploring new sensors for autonomous navigation, data acquisition and communications

Ecuador's involvement in the forefront of autonomous UAVs necessitates the exploration of advanced sensor technologies. These sensors can improve autonomous navigation, data acquisition, and communication across various applications. Advanced drones integrate cameras, GPS, accelerometers, energy, thermal, distance, and altitude sensors. Additionally, they carry out network devices such as satellite communications (SATCOM) and wireless hotspots (Sánchez-Zuluaga et al., 2023). These integrations improve self-defense survivability by enabling them to navigate precisely according to how they were programmed and to gather real-time information as desired with high accuracy.

Further advancements in sensors also include radar warning systems such as the Synthetic Aperture Radar (SAR), radar jammer, and tracking devices used in military and civilian applications (Tian et al., 2020) that allow drones to execute SIGINT missions and make them avoid enemy positions autonomously. For enhanced intelligence, Solid-State LiDAR sensors offer superior 3D mapping and obstacle detection, a desired capability for precision strikes and battle assessment. Other sensors, called multi-modal, provide robust navigation in different environments, including the Global Navigation Satellite System (GNSS) and SATCOM positioning.

Interoperability remains crucial for complex operations where not only the UAV platform is needed. It requires the development of Unmanned Aerial Systems (UAS), with drone systems that are more interconnected with different ground components; they are also compatible with various command and control systems. This can be achieved by integrating four system elements: 1) An adequate situation notification interface, which allows transmitting the objective, position, payload, operator, and mission assignment method to another unmanned airplane and ground units. 2) A payload interface that will allow the transmission of surveillance information. 3) A weapons interface as an independent means of transfer by which all operators can coordinate offensive capabilities and, finally, 4) The UAV control interface that allows navigation and knowing the location from the ground concerning the rest of the aircraft (Gertler, 2012).

To sustain interoperability, it is also necessary to establish a methodology to test, certify, and guarantee that the UAV's navigation and communications system converges with all the other equipment of the system. In this case, the applicability of military airworthiness standards for unmanned aerial vehicles is needed. An aeronautical professional must certify and test them based on the airworthiness necessities of a previously established military regulation, such as NATO (North Atlantic Treaty Organization) standards (Jara-Olmedo et al., 2018). For instance, UAV communications need high availability for extreme weather conditions, networked and non-networked controllers, compatibility with manned aircraft, extended communications, alternative configurations, and damage tolerance.

5.3. Use emerging technologies to empower Ecuadorian drones

The rapid evolution of technology necessitates Ecuador to develop or utilize emerging solutions to enhance its UAVs' capabilities and performance. Key focus areas include technology, data, and programmatic challenges (Sigala & Langhals, 2020).

Cybersecurity, artificial intelligence (AI), machine learning (ML), and simultaneous localization and mapping (SLAM) represent crucial areas for exploration. Implementing robust cybersecurity systems allows data protection and military operational integrity due to the sensibility of data processing. AI and ML algorithms can evaluate information in real-time, allowing them to autonomously avoid obstacles, route planning, and decision-making, customizing flights based on specific missions and environments. SLAM allows UAVs to obtain real-time maps without depending on external infrastructure, facilitating autonomous navigation.

Another advance that must be considered is electric and hybrid propulsion; this technology increases endurance, reduces the use of fossil fuels, avoids noise pollution, and reduces operating costs by increasing energy efficiency. Using technologies such as solar panels, wind turbines, or structural batteries integrated into unmanned aerial vehicles allows flight times to be lengthened and reduces dependence on traditional loading methods.

Material advancements, such as composite materials and metamaterials, can significantly reduce drone weight, and using these materials provides better performance for unmanned vehicles. Lightweight UAVs need small engines and can fly with better efficiency ratios; the cost of production, maintenance, and sustainability are some advantages that can be used to enhance the development of drones in the country.

Lightweight, long-lasting batteries, alternative energy technology, practical data bandwidth tools, stealth capability, and collaborative technologies capabilities further enhance drone performance, allowing UAVs to operate alone or in collaboration with manned aircraft. By actively exploring and integrating these emerging technologies, Ecuador can ensure its drone fleet remains at the forefront, contributing to enhanced security, efficiency, and effectiveness in various military applications.

6. Conclusions

This study concludes by highlighting the contributions this research offers to the Ecuadorian military's classification and applications of UAVs. A comprehensive classification of the current UAV fleet used for the Armed Forces in Ecuador, classified according to wing span, endurance, and altitude (MALE, LALE, MRE, Mini, Micro) was presented. The research also reveals the immense potential of expanding drone usage across a wider spectrum of military operations, analyzed from a capability-application perspective. This bridges the gap between existing technology and the understanding of operational use in the nation's defense strategy and allows to identify the challenges and opportunities.

Unmanned Aerial Vehicles have revolutionized military operations with their capabilities and performance. The autonomous characteristics and ability to carry out several electronic devices and weapons allow them to fly within an extended endurance at diverse altitudes, aligning with several military needs. Ecuador has developed and operated drones that can conduct reconnaissance and surveillance missions, while other countries have expanded their use to sophisticated and complex missions.

This research presents a novelty UAV classification that relates several capabilities, applications, missions and military operations of UAVs. While most applications involve combat support operations, there is considerable potential to expand the use of military drones in Ecuador. These systems can be used in diverse missions and applications inside Counter-Air Force, Air Defense, Counter Ground Force, Counter Naval, Combat Support, and Homeland Defense and Security Operations. UAV capabilities include precision strikes, autonomous guidance, and navigation, adaptability with sensors and weaponry systems, advanced communications, and sophisticated real-time imagery systems. These competencies suit the country's needs well, where modern military applications can provide increased accuracy and efficiency against new risks and threats to the nation. The same perspective can generally be adapted for other countries according their needs and capabilities.

This gap opens countless opportunities to explore the UAV technology of the country mentioned above, including expanding military applications in the broad spectra of missions and operations where drones can be used. For instance, the integration of drones in urban warfare operations against terrorist organizations, border security to control migration and smuggling, or even conducting precision strikes according to the strategical national plans. To achieve this purpose, Ecuador needs to face several challenges related to new technologies and modern devices. Looking towards the future, this study lays the ground work for further exploration in areas that could integrate and develop new sensors to enhance navigation, data acquisition, and communications for UAVs in the country. Additionally, several emerging technologies, such as artificial intelligence, electric propulsion, and advanced materials, can also pave the way to make it possible.

This study analyzes the landscape of military UAVs in Ecuador, encompassing their classifications, potential applications across diverse missions, and the future opportunities and challenges they present. The practical applications of this research are vast, it provides valuable insights to the Ecuadorian military that could serve to make critical decisions regarding acquisition strategies, research and development priorities, doctrinal updates, and operational strategies. All of them are related to enhancing the military capabilities of the country. In conclusion, this research offers a significant contribution by outlining a roadmap for the operational integration of UAV technology into the Ecuadorian military, ensuring its preparedness for the demands of modern warfare.

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Author contributions

Criollo Linker conceptualized the study, collected information for analysis, and wrote the initial draft of the manuscript. Mena Carlos conducted the literature review and created the data visualizations. Shen Xing interpreted and analyzed the information, validated the results, and supervised the review.

Disclosure statement

The authors declare that no competing financial, professional, or personal interests or benefit they have arising from the direct applications of this research.

References

Abiodun, T. F., & Taofeek, C. R. (2020). Unending war on Boko Haram terror in Northeast Nigeria and the need for deployment of military robots or autonomous weapons systems to complement military operations. *International Journal of Advanced Academic Research*, *6*(6), 1–17. https://doi.org/10.46654/ij.24889849.s662

Acosta, A., & Mantilla, J. (2024, January 8). *Executive Decree No. 110. President of the Republic of Ecuador declared a state of* *emergency throughout the national territory.* Dentons. https://www.dentons.com/en/insights/articles/2024/january/12/decretos-ejecutivos-no-110-de-08-de-enero-de-2024-y-no-111-de-09-de-enero-de-2024

Al-Khawaja, A., & Sadkhan, S. B. (2021). Intelligence and electronic warfare: Challenges and future trends. In *2021 7th International Conference on Contemporary Information Technology and Mathematics* (*ICCITM*) (pp. 118–123). IEEE. https://doi.org/10.1109/ICCITM53167.2021.9677877

Alladi, T., Chamola, V., Sahu, N., & Guizani, M. (2020). Applications of blockchain in unmanned aerial vehicles: A review. *Vehicular Communications*, *23*, Article 100249. https://doi.org/10.1016/j.vehcom.2020.100249

Andrade Santamaría, A. A., & Molina Bustamante, C. S. (2016). *Estudio del Estado del Arte de las Tecnologías de Percepción Remota en el Ecuador*. Universidad de las Américas.

Bendea, H., Boccardo, P., Dequal, S., Giulio Tonolo, F., Marenchino, D., & Piras, M. (2008). Low cost UAV for post-disaster assessment. *The International Archives of the Photogrammetry*, *Remote Sensing and Spatial Information Sciences*, *37*(B8), 1373–1379.

Bergmann, K. (2020). RAAF starts to examine trusted autonomy for uninhabited aerial systems. *Asia-Pacific Defence Reporter* (*2002*), *46*(10), 26–30. https://search.informit.org/doi/abs/10.3316/informit.633837801916641

Blom, J. D. (2010). *Unmanned aerial systems: A historical perspective* (Vol. 45). Combat Studies Institute Press Fort Leavenworth, KS.

Bronz, M., Hattenberger, G., & Moschetta, J. M. (2013). Development of a long endurance mini-UAV: Eternity. *International Journal of Micro Air Vehicles*, *5*(4), 261–272. https://doi.org/10.1260/1756-8293.5.4.261

Castellanos-Sanabria, Y. A., & Rodríguez-Pirateque, G. W. (2020). UAV systems for multipurpose heterogeneous networks: A review of design, development and performance. *Aeronautics and Aerospace Open Access Journal*, *4*(3), 121–140. https://doi.org/10.15406/aaoaj.2020.04.00114

Chaturvedi, S. K., Sekhar, R., Banerjee, S., & Kamal, H. (2019). Comparative review study of military and civilian unmanned aerial vehicles (UAVs). *INCAS Bulletin*, *11*(3), 183–198. https://doi.org/10.13111/2066-8201.2019.11.3.16

Despont, C. P., Kunertova, D., & Masuhr, N. (2022). Militärische Drohnennutzung: Erfahrungen, Technologie und Schweizer Optionen. In *Bulletin 2022 zur schweizerischen Sicherheitspolitik* (pp. 31–62). Enter for Security Studies (CSS), ETH Zürich. https://doi.org/10.56181/AZGO1008

Diasinos, S., Barber, T. J., & Doig, G. (2013). Influence of wing span on the aerodynamics of wings in ground effect. *Proceedings of the Institution of Mechanical Engineers*, *Part G: Journal of Aerospace Engineering*, *227*(3), 569–573. https://doi.org/10.1177/0954410011434884

Gašparović, M., & Gajski, D. (2016). Unmanned aerial photogrammetric systems in the service of engineering geodesy. In *International Symposium on Engineering Geodesy* (pp. 20–22). Varaždin, Croatia.

Gertler, J. (2012). *US unmanned aerial systems*. Congressional Research Service Washington, DC.

Gortney, W. E. (2016). Department of defense dictionary of military and associated terms. *Joint Chiefs of Staff Washington United States*.

Gupta, S. G., Ghonge, D. M., & Jawandhiya, P. M. (2013). Review of unmanned aircraft system (UAS). *International Journal of Advanced Research in Computer Engineering & Technology* (*IJARCET*), *2*(4). https://doi.org/10.2139/ssrn.3451039

Hassanalian, M., & Abdelkefi, A. (2017). Classifications, applications, and design challenges of drones: A review. *Progress in Aerospace Sciences*, *91*, 99–131. https://doi.org/10.1016/j.paerosci.2017.04.003

Hlotov, V., Hunina, A., Kniaziev, S., Kolesnichenko, V., & Prokhorchuk, O. (2019). Analysis of application of the UAVs for military tasks. *Suchasni Dosyagnennya Geodezichnoï Nauki Ta Virobnitstva*, *1*(37), 69–77. https://doi.org/10.33841/1819-1339-2019-1-37-69-77

Jaramillo, E. (2014). Aplicaciones de los UAS en Apoyo al Desarrollo en el Ecuador. *Aeroespacial*, *Investigación y Desarrollo*, *4*, 25–28.

Jara-Olmedo, A., Medina-Pazmiño, W., Galarza, E. E., Silva, F. M., Galarza, E. D., & Naranjo, C. A. (2018). Data link system flight tests for unmanned aerial vehicles. In A. Rocha & T. Guarda (Eds), *Developments and Advances in Defense and Security: Proceedings of the Multidisciplinary International Conference of Research Applied to Defense and Security* (Vol. 94, pp. 151–161). Springer. https://doi.org/10.1007/978-3-319-78605-6_12

Jung, S., Jo, Y., & Kim, Y.-J. (2019). Aerial surveillance with low-altitude long-endurance tethered multirotor UAVs using photovoltaic power management system. *Energies*, *12*(7), Article 1323. https://doi.org/10.3390/en12071323

Kaamin, M., Razali, S. N. M., Ahmad, N. F. A., Bukari, S. M., Ngadiman, N., Kadir, A. A., & Hamid, N. B. (2017). The application of micro UAV in construction project. *AIP Conference Proceedings*, *1891*(1), Article 020070. https://doi.org/10.1063/1.5005403

Kappenman, J. (2008). Army unmanned aircraft systems: Decisive in battle. *Joint Force Quarterly*, *49*, 20–23.

Karpenko, M., & Nugaras, J. (2022). Vibration damping characteristics of the cork-based composite material in line to frequency analysis. *Journal of Theoretical and Applied Mechanics*, *60*(4), 593–602. https://doi.org/10.15632/jtam-pl/152970

Karpenko, M., Stosiak, M., Deptuła, A., Urbanowicz, K., Nugaras, J., Królczyk, G., & Żak, K. (2023). Performance evaluation of extruded polystyrene foam for aerospace engineering applications using frequency analyses. *The International Journal of Advanced Manufacturing Technology*, *126*(11), 5515–5526. https://doi.org/10.1007/s00170-023-11503-0

Karpowicz, J. (2021). Warfare use of unmanned aerial vehicles. *Safety* & *Defense*, *2*, 51–64. https://doi.org/10.37105/sd.135

Kim, S. J., Lim, G. J., & Cho, J. (2018). Drone relay stations for supporting wireless communication in military operations. In J. Chen (Eds), *Advances in Human Factors in Robots and Unmanned Systems. AHFE 2017. Advances in Intelligent Systems and Computing* (Vol. 595). Springer. https://doi.org/10.1007/978-3-319-60384-1_12

Kozera, C. A. (2018). Military use of unmanned aerial vehicles – a historical study. *Safety* & *Defense*, *4*, 17–21. https://doi.org/10.37105/sd.4

Kunertova, D. (2019). *Military drones in Europe: The European defense market and the spread of military UAV technology*. SDU. https://www.sdu.dk/en/cws

Kunertova, D. (2023). The war in Ukraine shows the game-changing effect of drones depends on the game. *Bulletin of the Atomic Scientists*, *79*(2), 95–102. https://doi.org/10.1080/00963402.2023.2178180

Lekanda Laban, P. (2010). El conflicto territorial entre Ecuador y Perú por el río del Cenepa (1995): Entre una mediación fallida y otra exitosa. *Pléyade*, *4*, 186–211. https://revistapleyade.cl/index.php/OJS/article/view/281

Mayer, S., Lischke, L., & Woźniak, P. W. (2019). Drones for search and rescue. In *1st International Workshop on Human-Drone Interaction*. Glasgow, Scotland, UK.

Montoya, P. B., & Briones, R. V. (2019). Empleo de los UAV, en operaciones de seguridad y vigilancia en las áreas estratégicas en el ecuador. *Revista de Ciencias de Seguridad y Defensa*, *4*(4), 15–15.

Patel, T., Salot, N., & Parikh, V. (2022). A systematic literature review on Security of Unmanned Aerial Vehicle Systems. *arXiv Preprint arXiv:2212.05028*. https://doi.org/10.48550/arXiv.2212.05028

PS, R., & Jeyan, M. L. (2020). Mini unmanned aerial systems (UAV) – A review of the parameters for classification of a Mini UAV. *International Journal of Aviation*, *Aeronautics*, *and Aerospace*, *7*(3), Article 5. https://doi.org/10.15394/ijaaa.2020.1503

Rana, K., Praharaj, S., & Nanda, T. (2016). Unmanned aerial vehicles (UAVs): An emerging technology for logistics. *International Journal of Business and Management Invention*, *5*(5), 86–92.

Research and markets. (2024). *UAV drones – global strategic business report* (Anual 4806222). http://tinyurl.com/Research-Markets-UAVs-2024

Rodman, D. (2010). Unmanned aerial vehicles in the service of the Israel Air Force: "They will soar on wings like eagles". *Middle East Review of International Affairs Journal*, *14*(3), 77–84.

Sadot, U. (2016). *A perspective on Israel*. Center for a New American.

Samad, T., Bay, J. S., & Godbole, D. (2007). Network-centric systems for military operations in urban terrain: The role of UAVs. *Proceedings of the IEEE*, *95*(1), 92–107. https://doi.org/10.1109/JPROC.2006.887327

Sánchez-Zuluaga, G. J., Isaza-Giraldo, L., Zapata-Madrigal, G. D., García-Sierra, R., & Candelo-Becerra, J. E. (2023). Unmanned aircraft systems: A Latin American review and analysis from the Colombian context. *Applied Sciences*, *13*(3), Article 1801. https://doi.org/10.3390/app13031801

Sigala, A., & Langhals, B. (2020). Applications of unmanned aerial systems (UAS): A Delphi study projecting future UAS missions and relevant challenges. *Drones*, *4*(1), Article 8. https://doi.org/10.3390/drones4010008

Silva, D. M., de Oliveira, L. F. F., Macedo, M. G., & Bastos Filho, C. J. (2012). On the analysis of a swarm intelligence based coordination model for multiple unmanned aerial vehicles. In *2012 Brazilian Robotics Symposium and Latin American Robotics Symposium* (pp. 208–213). IEEE. https://doi.org/10.1109/SBR-LARS.2012.41

Szabolcsi, R. (2018). UAV operator training – beyond minimum standards. *Scientific Research and Education in The Air Force-Afases*. https://doi.org/10.19062/2247-3173.2016.18.1.25

Tian, T., Zhou, F., Li, Y., Sun, B., Fan, W., Gong, C., & Yang, S. (2020). Performance evaluation of deception against synthetic aperture radar based on multifeature fusion. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *14*, 103–115. https://doi.org/10.1109/JSTARS.2020.3028858

Ukaegbu, U., Tartibu, L., & Okwu, M. (2021). Unmanned aerial vehicles for the future: Classification, challenges, and opportunities. In *2021 International Conference on Artificial Intelligence*, *Big Data*, *Computing and Data Communication Systems* (*icABCD*) (pp. 1–7). IEEE. https://doi.org/10.1109/icABCD51485.2021.9519367

Venable, J. (2020). *US air force*. https://www.heritage.org/military

Wang, H., Cheng, H., & Hao, H. (2020). The use of unmanned aerial vehicle in military operations. In S. Long & B. S. Dhillon, *Man-Machine-Environment System Engineering*. *MMESE 2020. Lecture Notes in Electrical Engineering* (Vol. 645, pp. 939–945). Springer. https://doi.org/10.1007/978-981-15-6978-4_108

Watts, A. C., Ambrosia, V. G., & Hinkley, E. A. (2012). Unmanned aircraft systems in remote sensing and scientific research: Classification and considerations of use. *Remote Sensing*, *4*(6), 1671–1692. https://doi.org/10.3390/rs4061671

Xu, C., Liao, X., Tan, J., Ye, H., & Lu, H. (2020). Recent research progress of unmanned aerial vehicle regulation policies and technologies in urban low altitude. *IEEE Access*, *8*, 74175–74194. https://doi.org/10.1109/ACCESS.2020.2987622

Zountouridou, E., Kiokes, G., Dimeas, A., Prousalidis, J., & Hatziargyriou, N. (2023). A guide to unmanned aerial vehicles performance analysis – the MQ-9 unmanned air vehicle case study. *The Journal of Engineering*, *2023*(6), Article e12270. https://doi.org/10.1049/tje2.12270