USE AND ADAPTATION OF CLASSIC ANTI-AIRCRAFT MISSILE SYSTEMS AGAINST DRONES

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Abstract: *The significant increase in the use of drones for military and civilian purposes has required the development of advanced solutions to counter them. Anti-aircraft missiles have become an essential defense tool due to their ability to detect, track and neutralize small and highly maneuverable aerial vehicles. However, their use presents limitations, such as high costs compared to the price of drones, low effectiveness against swarms and difficulties in detecting small or fast drones. In this context, the adaptation of classic anti-aircraft missile systems includes the modernization of short-range missiles, integration with advanced radars and sensors, the use of multi-layer systems and the development of more economical solutions. These measures contribute to optimizing the cost-effectiveness ratio and increasing the defense capacity against asymmetric aerial threats posed by drones.*

Keywords: *UAV, anti-aircraft missiles, drone swarms, hypervelocity missiles …*

1. INTRODUCTION

The rapid growth of drone use, both for military and civilian purposes, has created an urgent need for advanced solutions capable of effectively countering these versatile devices, which are becoming increasingly accessible and sophisticated. In the military, drones are used for reconnaissance, surveillance, intelligence gathering and even precision attacks on strategic targets, reducing the risk to operators and allowing long-range strikes. On the other hand, in the civilian environment, they are used for monitoring critical infrastructure, delivering goods, mapping, but also in illicit activities, such as smuggling or industrial espionage. This rapid expansion of drone use turns them into a complex and difficult-to-manage threat, as they can be launched in large numbers, can be extremely small in size and can operate at variable altitudes, which makes them difficult to detect and neutralize.

In this context, anti-aircraft missiles have emerged as one of the most effective defense options, due to their superior ability to detect, track and neutralize small and highly maneuverable aerial vehicles. These defense systems play an essential role in ensuring the security of critical infrastructure, such as power plants, airports or communication networks, which can be vulnerable to drone attacks. They also contribute to the protection of strategic areas and armed forces, providing a high level of security against increasingly diverse and sophisticated threats. The integration of modern technologies, such as advanced radars and high-precision guidance systems, has considerably increased the efficiency of anti-aircraft missiles, making them capable of responding in real time to critical situations.

2. LIMITS OF THE USE OF ANTI-AIRCRAFT MISSILES AGAINST DRONES

With the increasing use of drones in modern conflicts, anti-aircraft missiles have become a crucial solution for protecting strategic infrastructure, military forces and the civilian population. However, despite their effectiveness, the use of anti-aircraft missiles against drones presents a number of technical, operational and economic limitations that need to be analyzed to improve defense strategies.

1. The high cost of missiles compared to drones

The high cost of missiles compared to drones poses a major challenge in managing military resources, especially in scenarios where drones are used in swarm attacks or as multiple targets. Modern missiles, such as those in the Patriot, S-400 or THAAD systems, which can cost hundreds of thousands or even millions of dollars per unit, are designed to take down complex threats, such as fighter jets or ballistic missiles, and include advanced guidance, propulsion and detection technologies, which justify their high price. On the other hand, drones used in recent conflicts are often simple, mass-produced models with a minimal cost per unit (a few hundred or thousand dollars). This cost-effectiveness asymmetry creates a situation in which adversaries can exploit the drone economy, causing defensive forces to spend disproportionate resources to counter relatively cheap threats. This disproportion makes the use of missiles economically unsustainable in the case of massive attacks.

In the context of modern tactics, a reassessment of the balance between efficiency, costs and strategies is necessary, such as the development of more economical defense systems against drones [1, 2].

2. Low effectiveness against drone swarms

Drone swarms represent a significant innovation in the military field, with the potential to fundamentally change the way air operations are conducted. Consisting of dozens or hundreds of coordinated vehicles, they pose a serious challenge to traditional air defense systems, which are designed to counter individual threats, not mass attacks launched simultaneously. These drones are equipped with advanced sensors and miniaturized warheads, which allows them, at least theoretically, to strike high-value strategic targets, such as radars and surface-to-air missile (SAM) launchers. This capability makes them ideal candidates for suppression of enemy air defenses (SEAD) missions, where they could quickly and effectively neutralize adversary defenses.

A key factor in the operation of these drone swarms is the Global Positioning System (GPS), which provides autonomous navigation and precise position reporting for Mini/Micro-Aerial Vehicles (MAVs). These technologies allow for precise coordination between drones, increasing their operational efficiency and reducing the need for direct human intervention [3].

Figure 1 graphically presents some possibilities for using drone swarms in SEAD (Suppression of Enemy Air Defences) missions.

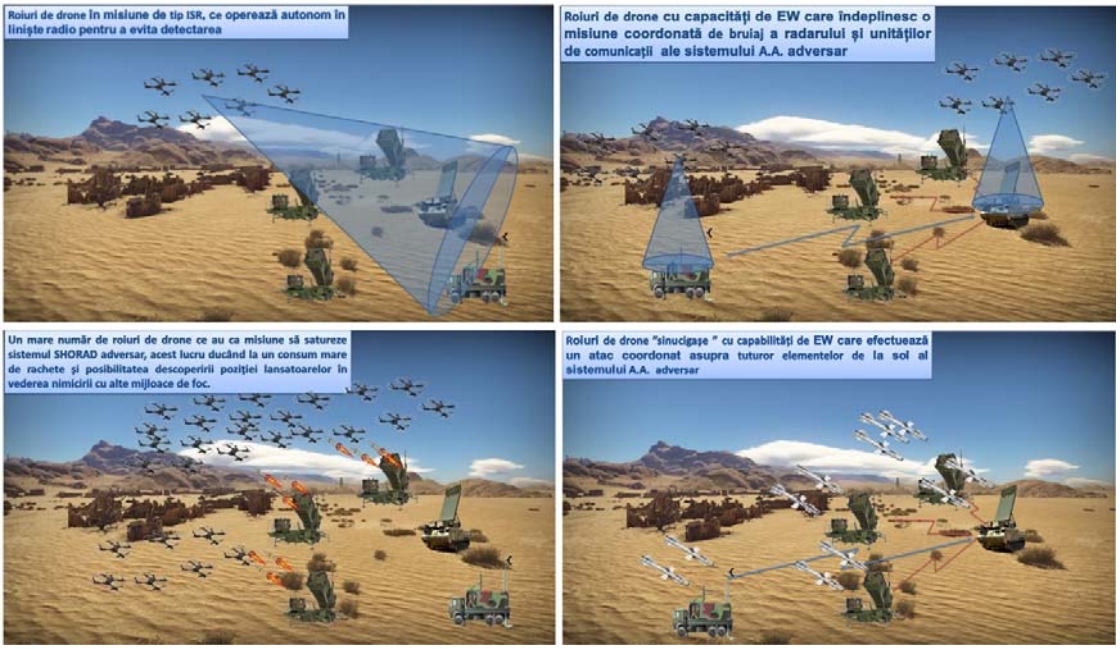

FIG. 1 Possibilities of using drone swarms in SEAD missions

Although some systems can intercept multiple targets simultaneously, the density of swarm attacks can overwhelm defenses. This is compounded by the fact that some drones in the swarm can act as decoys, distracting defenses from more dangerous targets.

3. Difficulties in detecting small, fast drones

Small drones, operating at low altitudes and with low radar signatures, are difficult to detect with conventional radar systems. Small, fast drones pose a major challenge to air defense systems due to the following characteristics that allow them to evade detection and interception:

- Low altitude and small size: Small drones frequently operate at very low altitudes, which allows them to slip through natural or urban obstacles, thus reducing the effectiveness of traditional radar systems. Their small size also contributes to minimal radar reflection, making them difficult to identify in a timely manner.

- Advanced Stealth Technologies: Modern drones are often equipped with stealth technologies that reduce their thermal and acoustic signature. These measures counteract traditional sensors, such as radar or infrared systems, which rely on detecting the heat emitted or the sound produced by engines.

- Confusion with other small objects in the air: Conventional radars can confuse small drones with other objects, such as birds, making it difficult to clearly identify real threats. This confusion can lead to operational errors and inefficient use of defensive resources.

- The constant evolution of drones: As technology advances, drones are becoming increasingly sophisticated, integrating new methods of avoiding detection, such as radar-absorbing materials or flying in formations that disrupt radar operation. [4].

4. Constraints related to range and reaction speed

Anti-aircraft missiles are primarily designed to intercept targets at medium to long altitudes and distances. Drones, on the other hand, can operate very close to the ground, in tight spaces, or near urban areas, which limits the effectiveness of missiles. Also, fast and maneuverable drones can sometimes exceed the reaction time of air defense systems.

At the same time, this characteristic significantly complicates the process of tracking and interception, since many defense systems are optimized for targets with more predictable trajectories [5].

5. Vulnerability to electronic and cyber attacks

Sophisticated drones can use electronic countermeasures to jam radar systems or missile guidance. Furthermore, cyberattacks on air defense systems can compromise their effectiveness, allowing drones to evade interception.

6. Logistics and recharging issues

In the event of sustained attacks with a large number of UAVs, anti-aircraft missile stocks can be quickly depleted, creating a significant vulnerability in air defense. Reloading missile launchers is not an instantaneous process, requiring time, logistical resources, and effective coordination to transport and distribute new ammunition to combat units.

In addition, the infrastructure required to store and transport anti-aircraft missiles can become a strategic target for adversaries, increasing logistical difficulties. If supply routes are compromised or if there are limitations in the production and delivery of these weapons, defense capabilities can be severely affected.

This logistical vulnerability can be exploited by adversaries by launching successive and prolonged attacks, designed to force the rapid consumption of anti-aircraft ammunition. In addition, enemy tactics may include the use of cheaper and more numerous UAVs to exhaust defense resources, followed by attacks with more advanced drones or other means of striking, taking advantage of any gaps created [6, 7].

3. USE AND ADAPTATION OF CLASSIC ANTI-AIRCRAFT MISSILE SYSTEMS AGAINST DRONES

Although designed to counter large and complex aerial threats, classic anti-aircraft missile systems have undergone modifications and improvements to deal with the threat posed by drones. Here are some ways in which these systems have been adapted:

1. Use of specialized ammunition (particularly hypervelocity missiles): Hypervelocity weapons, such as projectiles or missiles, are similar to conventional weapons, but they fly at a higher speed, leading to increased effectiveness in two ways:

1) A less sophisticated fire control system is required, as the time between launch and impact is less than half the flight time of a conventional missile, eliminating the need for numerous in-flight corrections (the probability that the target will change its elevation, azimuth, and range is reduced). The shorter flight time reduces the probability that the target will successfully evade the projectile by maneuvering. Hypervelocity projectiles also offer significantly greater maximum engagement ranges.

2) Hypervelocity projectiles cause more damage than conventional projectiles of equal size due to their higher penetrating kinetic energy resulting from higher velocities. The kinetic energy of this type of ammunition is approximately four times that of conventional missiles [8].

2. Integration with specialized radars

Traditional radar systems have been upgraded or integrated with high-frequency radars capable of detecting small, fast-moving objects at low altitudes. These radars have specialized algorithms to differentiate between drones and other airborne objects, such as birds.

3. Integration of optical and infrared systems

Drones can have low radar signatures, making them difficult to detect solely by radar.

For this reason, many conventional missile systems have been integrated with optical and infrared systems to detect drones visually or by their heat signatures. These systems work well even in low visibility conditions, such as at night or in adverse weather conditions.

4. Multi-layered defense systems

Conventional missile systems are increasingly integrated into a multi-layered defense that combines missiles with other technologies to provide effective protection against drones. This approach involves the use of multiple types of weapons and sensors, such as automated anti-aircraft guns, jamming systems, and even lasers.

FIG. 2 Graphic representation of a multilayer anti-aircraft missile system with capabilities to combat multiple aerial targets including small drones [9]

5. Modernizing short-range missiles for more cost-effective interception

One of the main challenges in using missile systems against drones is the cost disparity between the anti-aircraft missiles and the intended targets. Currently, many air defense systems use sophisticated missiles, equipped with advanced guidance technologies, high-precision sensors, and complex detection and tracking systems. These missiles, originally intended to intercept fighter jets, ballistic missiles, or other major aerial threats, have high costs, reaching hundreds of thousands or even millions of dollars per launch. In contrast, small drones, increasingly used in modern conflicts, are often much cheaper to manufacture and operate. Some modified commercial drones or small military attack drones can cost several hundred or thousands of dollars, making them an "asymmetric" threat from a financial point of view.

This significant discrepancy between interception costs and target value poses serious problems for traditional air defenses. The repeated use of expensive missiles to shoot down relatively inexpensive drones is not economically sustainable, especially in situations where drones are used in "swarm" tactics to overwhelm air defenses. This attack strategy can lead to rapid depletion of expensive missile stocks and significantly increase operational costs.

To address this problem, militaries are focusing on developing more affordable and cost-effective solutions.

One example is smaller missiles specifically designed to intercept drones. These missiles are simpler, lighter, and use less expensive technology, but are still capable of neutralizing small drones. By reducing the size and complexity of these missiles, their cost of production and operation is greatly reduced, making them a more economically viable solution, saving expensive missiles for major threats such as aircraft or operationally tactical missiles. [11, 12].

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CONCLUSIONS

Anti-aircraft missiles have proven effective in protecting critical infrastructure and armed forces against drones, significantly contributing to the security of strategic areas. The integration of advanced technologies, such as modern radars and high-precision guidance systems, has considerably increased the ability of these systems to respond to the complex and diversified threats posed by drones.

The use of anti-aircraft missiles against drones presents challenges such as high costs in relation to the value of the targets, the difficulty of countering drone swarms, and logistical problems related to reloading. Also, modern drones with reduced radar signatures and stealth capabilities challenge the detection and interception capacity of these systems.

To deal with new threats, classic anti-aircraft missile systems have been modernized. Smaller and more affordable missiles, high-performance radars, and optical and infrared systems have been implemented. Also, multi-layered defense, which combines missiles with other technologies, such as electronic jamming and laser weapons, offers a more robust solution against drones.

General conclusion: Continuous development and adaptation of anti-aircraft missile systems are essential in the face of the increasing use of drones. A strategic approach that combines economic efficiency, technological modernization and defense diversification can help maintain a balance between security and costs in this dynamic field.

REFERENCES

[1] https://researchcentre.army.gov.au/library/land-power-forum/how-are-drones-changing-modern-warfare;

[2] O. Molloy, *Drones in Modern Warfare: Lessons Learnt from the War in Ukraine*, Australian Army Occasional Paper No. 29, Australian Army Research Centre, 2024.C;

[3] M. S. Pardesi, *UAVs/UCAVs – Missions, challenges, and strategic implications for small and medium power*s, Institute of Defence and Strategic Studies, Singapore, MAY 2004, pp.14-15;

[4] U. Seidaliyeva, et all, Advances and Challenges in Drone Detection and Classification Techniques: A State-of-the-Art Review. Sensors 2024;
[5] E. G. Jeler, *The use and adaptation of anti-aircraft artillery against drones*, Review of the Air Force Academy No.2 (50)/2024;
[6] J. Rinaldi, J. Vartanian, Rethinking Denial: *The People's Liberation Army's Laser Systems and the Future Challenges for Hellscape*, Strategic studies Institute US Army War Collegee, Jan. 14, 2025;
[7] T. Hamilton, D. A. Ochmanek, *Operating Low-Cost, Reusable Unmanned Aerial Vehicles in Contested Environments: Preliminary Evaluation of Operational Concepts* (RAND Corporation, May 2020);
[8] J. J. Beel, T*hesis - Anti-UAV defense requirements for ground forces and hypervelocity rocket lethality models*, Naval Postgraduate School Monterey, California March 1992;
[9] https://www.drishtiias.com/daily-news-analysis/iron-dome-air-defence-system-israel;
[10]https://sensortec-eu.com/datasheets/Anti-Drone%20Detection/Smart%20Anti%20Drone %20System. pdf;
[11] https://sensortec-eu.com/datasheets/Anti-Drone%20Detection/Smart%20Anti%20Drone%20System.pdf;
[12] https://www.prnewswire.com/news-releases/savage---smart-anti-drone-weapon-300941541.html.