THE USE AND ADAPTATION OF ANTI-AIRCRAFT ARTILLERY AGAINST DRONES

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DOI: 10.19062/1842-9238.2024.22.2.3

Abstract: *In the context of the rapid development of drone technology and their increasingly frequent use in modern conflicts, the adaptation and use of anti-aircraft artillery against drones has become a priority for armed forces around the world. This article explores the possibilities of modifying and adapting anti-aircraft artillery systems, initial designed to combat large aircraft, so that they become effective against drones of different sizes, speeds and flight altitudes. Thus, the adaptation of classic anti-aircraft artillery systems is analyzed by improving the detection systems, by using projectiles with proximity warheads as well as the integration of advanced sensors and I.A. algorithms to detect, intercept and combat the drones. The article highlights the technical and tactical challenges associated with adapting these systems, including the limitations of conventional air defense systems against drones*

Keywords: *drones, anti-aircraft artillery, proximity warhead, artificial intelligence …*

1. INTRODUCTION

In recent years, the use of UAVs has increased significantly, both for commercial and military purposes. They are often small, maneuverable and capable of flying at low altitudes, posing a unique challenge to traditional air defense systems. These characteristics make them difficult to detect and intercept. Also, the low cost of drones compared to the price of anti-aircraft missiles raises questions about the economic efficiency of air defense systems. This has created new challenges for air defense forces, which must develop and adapt strategies to counter the threats they represents.

Anti-aircraft artillery systems, originally designed to intercept aircraft and missiles, are now being evaluated and adapted to meet the following new challenges:

- Small dimensions and low radar cross section: Drones are much smaller than fighter planes and helicopters, and the effective reflection surface is reduced, which makes them difficult to detect for the radars of the air defense units.
- Flying at low altitudes: Many drones operate at extremely low altitudes, below the level detected by conventional air defense radar systems, allowing them to avoid detection until it is too late to be intercepted [1].
- Drone swarms: One of the modern tactics is the use of drone swarms, a form of attack where multiple drones are used simultaneously to overwhelm air defense systems.
- High operating costs: Using an expensive missile to destroy a small, low-cost drone is not financially sustainable in the long term [2, 3].

2. THE ADAPTATION OF CLASSIC ANTI-AIRCRAFT ARTILLERY AGAINST DRONES

The role of anti-aircraft artillery against drones is a crucial component of modern air defense. By adapting traditional systems and integrating new technologies, the growing threats posed by drones can be effectively countered. As drone technology continues to advance, so will the methods and tools to neutralize this versatile and persistent threat, ensuring that air defense systems remain robust and adaptive in the face of new challenges. To deal with the threats posed by drones, classic air defense systems have been modernized or adapted, improvements have been made that allow them to be used successfully:

1. Improvement of detection systems: Traditional air defense radars are designed to detect aircraft with a large radar cross section flying at medium and high altitudes. Small drones are difficult to see on traditional radars. Thus, radar systems have been updated to be able to detect smaller and faster objects. Among the adaptations brought to the detection systems are:

- Specialized radars with machine learning algorithms to distinguish drones from other airborne objects, able to detect small drones and differentiate between them and other airborne objects such as birds [4].

- Optical and infrared detection systems that work well against drones that have low radar signatures.

- Passive detection systems such as acoustic microphones or vibration sensors to identify approaching drones without relying on radar [5].

2. Proximity warhead-equipped fragmentation projectiles: Unlike conventional munitions, which require a direct impact to destroy the target, these projectiles are designed to detonate when they are at an optimal distance from the target, without the need for physical contact . Fragmentation projectiles, equipped with proximity warheads, represent an effective solution adapted to the new requirements of modern anti-aircraft combat, especially in the context of combating drones. This technology significantly increases the chance of success against small and fast targets such as drones, as controlled explosions generate a shower of shrapnel that can more easily hit and neutralize moving objects.

Fragmentation projectiles equipped with proximity warheads are equipped with sensors that detect proximity to the intended target. These sensors can be of various types, such as radar or optical, and are able to determine the optimal moment for detonation so that the fragments are scattered in a cone of explosion in the direction of the target. This directed explosion increases the chances that fragments from the detonation will hit and damage critical components of the drone, such as the propulsion systems, electronics, or physical structure.

One of the major advantages of this technology is that it does not require extreme precision in projectile trajectory. Given that small drones are difficult to track and intercept with conventional ammunition, which requires direct contact, the proximity warhead allows drones to be neutralized even if the trajectory of the projectile is not perfectly aligned with the target. This makes projectiles much more effective in scenarios where drones are maneuvering quickly and at low altitudes.

One of the most important uses of this technology is to combat drone swarms. A drone swarm is a relatively new tactic in military conflicts, where dozens or even hundreds of small drones are launched simultaneously to overwhelm defense systems. The combination of the large number of targets and their small size makes intercepting individual drones a difficult task for traditional air defenses.

Proximity warhead projectiles, however, are ideal for this type of threat. Instead of trying to hit each drone individually, a single fragmentation projectile can detonate in the middle of the swarm, scattering fragments that can hit multiple drones at once. The extended range of the fragments thus provides greater destruction capacity over a wide area, increasing the chances of neutralizing a significant number of drones with a small number of projectiles. This feature is essential to counter overwhelm tactics and ensure more efficient use of defense resources [6].

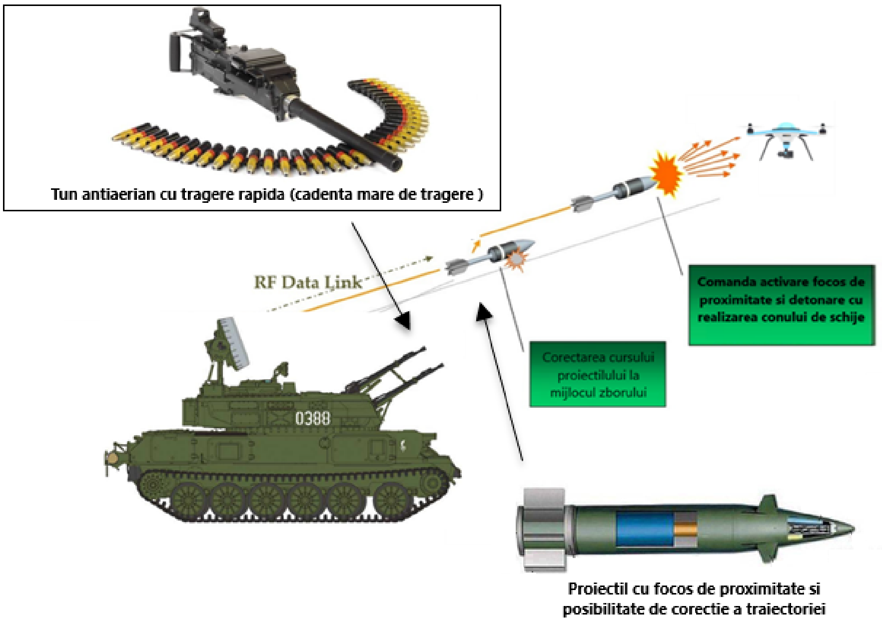

FIG. 1. Graphical representation of an anti-aircraft artillery system with multiple detection possibilities that uses guided projectiles equipped with proximity warheads to combat drones [7]

3. Automated Sighting Systems: Many modern anti-aircraft artillery systems are equipped with automatic targeting technologies. They can quickly calculate a drone's trajectory and adjust the firing angle to effectively intercept it. Such systems eliminate human errors and significantly increase reaction speed [8]. Automated sighting systems for anti-aircraft artillery, combine various advanced technologies to ensure effective detection, tracking and neutralization of drones. These systems rely on the integration of advanced radars, electro-optical sensors and artificial intelligence algorithms (AI) to speed up the identification and reaction processes. AI can learn from past data to improve the effectiveness of targeting systems, adapting to new drone use tactics. AI is also used to predict drone behaviour based on previous movement patterns, thus adapting the aiming strategy. Advanced AI systems can quickly analyse data from sensors, optimizing reaction time and significantly reducing the likelihood of false alarms [9].

Automation allows these systems to act independently without human intervention during the attack. This reduces response time and enables quick reactions in critical situations. The ability to detect and neutralize targets in seconds is critical in the context of swarm attacks, where reaction speed is vital.

These automation technologies lead to the following anti-drone capabilities:

- Quickly classify flying objects and distinguish between drones, birds or other aircraft.

- Automatically calculate the trajectory and speed of the drone, anticipating its movements.

- Optimizing the target engagement process, recommending quick actions based on drone type and potential danger.

4. Integration with other defense systems: To effectively combat drones, anti-aircraft artillery is often integrated with other systems, such as anti-aircraft machine guns or short-range surface-to-air missiles or directed energy lasers. Within this integrated system, artillery can be used to eliminate drones that escape initial interception by other defensive systems.

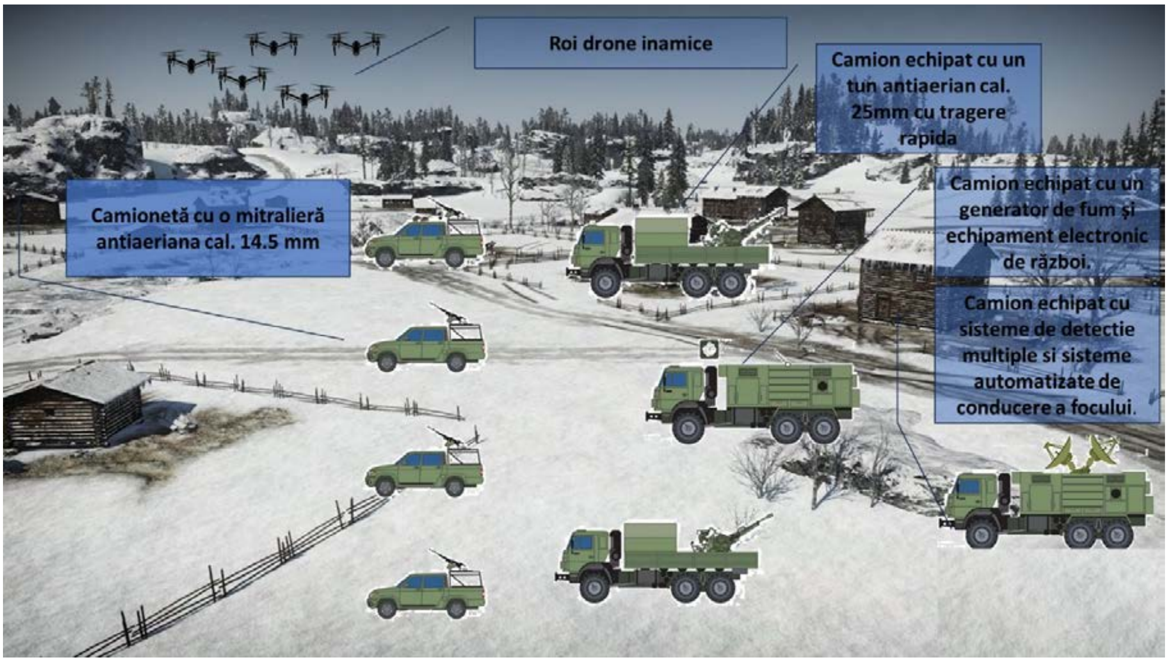

FIG. 2. Graphical representation of a multi-layer anti-aircraft artillery system with possibilities to combat drones [10]

3. THE LIMITS OF CLASSIC ANTI-AIR ARTILLERY SYSTEMS AGAINST DRONES

Despite all the progress made, the use of classic anti-aircraft defense systems against drones also has certain limits:

- High Ammo Consumption: Since drones are small and fast, it is necessary to fire a large number of projectiles to ensure a hit. This makes the use of anti-aircraft artillery relatively expensive.

- Complex coordination: Integration of anti-aircraft artillery systems with other defensive systems requires complex coordination and a very short reaction time.

- Limited capabilities against swarms of drones: An attack with a swarm of drones can overwhelm classic anti-aircraft systems, not being able to deal with the large number of targets in a short time. Most traditional anti-aircraft systems are not designed to target multiple targets simultaneously on such a large scale, making them vulnerable to a saturation attack.

- Disadvantages in urban and forest environments: In urban areas or with varied terrain, such as forests, drones can maneuver much more easily, and fixed radars have difficulty detecting them. Complex environments offer many obstacles and natural camouflage, allowing drones to infiltrate and pose a serious threat.

- Mobility restrictions of anti-aircraft defense systems: Classic defense systems are often stationary or have reduced mobility. Drones, on the other hand, are highly maneuverable and can move quickly out of range of these systems. A possible solution is the integration of classic systems with modern solutions. Classic air defense systems are increasingly integrated with new anti-drone defense technologies such as jamming systems, directed energy lasers and defensive drones. This multi-layered approach provides a more comprehensive defense tailored to both classic and modern threats.

- Jamming and electronic warfare systems: These are used to disrupt communication between drones and their operators, causing them to crash or land in a controlled manner.

- Laser systems: High power lasers can destroy drones by focusing energy on their critical components such as engines or cameras.

- Defensive Drones: Drones can also be used as an active countermeasure against other drones, either through controlled collisions or by placing nets to capture them [11].

CONCLUSIONS

Adapting classic anti-aircraft artillery to counter drone threats has become an essential component of modern air defense. As the use of drones increases in military operations, traditional systems must evolve to meet the technical and economic challenges these devices pose. The integration of advanced technologies, such as high-frequency radars, optical and infrared systems, proximity warhead missiles and automatic targeting systems, significantly improves the ability of anti-aircraft artillery to intercept drones, even in complex scenarios such as drone swarms.

One of the key aspects of modernizing anti-aircraft artillery is economic efficiency. The low cost of drones compared to anti-aircraft missiles calls for a more affordable strategy, which can be achieved by using proximity warhead missiles capable of destroying multiple drones at once. In addition, the implementation of artificial intelligence technologies and machine learning algorithms facilitates the detection and tracking of targets, minimizing errors and increasing the speed of reaction.

Although advances in anti-aircraft artillery have significantly improved defense capabilities against drones, there are still important limits. Intercepting large numbers of drones, especially in drone swarm scenarios, remains a challenge, and high ammunition consumption makes artillery-only air defenses difficult to sustain over the long term.

Also, coordination of artillery with other defensive systems, such as electronic jamming and high-powered lasers, is essential for a complete and effective defense.

In conclusion, to maintain a robust and adaptable defense in the face of technological evolution of drones, a multi-layered approach is required, combining modernized anti-aircraft artillery with new defensive technologies. This approach enables the military to effectively respond to both conventional and emerging air threats, ensuring an effective and sustainable air defense.

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