# MODERN AIR DEFENSE METHODS AND COUNTERMEASURES FOR USE IN OPERATIONAL-TACTICAL MISSILES

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## INTRODUCTION

Currently, in modern military conflicts, one of the most significant types of weaponry is operational-tactical missile systems. To protect against operational-tactical missile systems, modern missile defense methods are being developed and constantly improved. These methods encompass a wide range of technologies and strategies, from classic anti-aircraft missile systems to innovative control algorithms and artificial intelligence. The methods examined can aid in the development of countermeasures against air defense systems to enhance the effectiveness and accuracy of operational-tactical missile flights in combat conditions.

## OBJECTIVE AND TASKS

The goal of this work is to examine existing methods of protecting military equipment and ways to counter high-precision weapons. The information obtained from this research will help identify the most effective and priority technologies that can be employed as countermeasures against missile defense systems for operational-tactical missiles.

## MATERIALS AND METHODS

Undoubtedly, the most reliable method of protecting military equipment from high-precision weapons is to thwart the attack through a counter-force impact on the attacking munition, or if possible, on the carrier of this munition – known as "hard kill" in the terminology of Western specialists. The range of systems implementing this protection method is extremely broad, encompassing everything from complex systems that include combat units from several different branches of the military to specialized onboard devices designed to protect a single combat vehicle. The choice of protection system structure is determined by the value of the protected object and the types of high-precision weapons that may be used against it.

Let's consider an attack scenario on a strategically important object. It may involve the use of cruise missiles or aircraft equipped with air-to-ground missiles and glide bombs. The defense of the object may involve the deployment of military units consisting of radar systems, air defense forces, and aviation.

It should be noted that a characteristic feature complicating the defense process is the effective scattering area of attacking munitions, which, thanks to advancements in STEALTH technology, can be reduced to less than 0.1 square meters. Control of the airspace around the strategic object is conducted by radar surveillance. An example of such radar system is the AN/TPS-43E station by Northrop Grumman (see Figure 1). The detection range of an airborne object with an effective scattering area of 1 square meter is 450 km.

**Figure 1 – AN/TPS-43E Radar**

The station has been in service with the US Army for about 30 years. Currently, it has been replaced by the AN/TPS-75 radar system, also developed by the same company, which utilizes phased array antennas (see Figure 2).

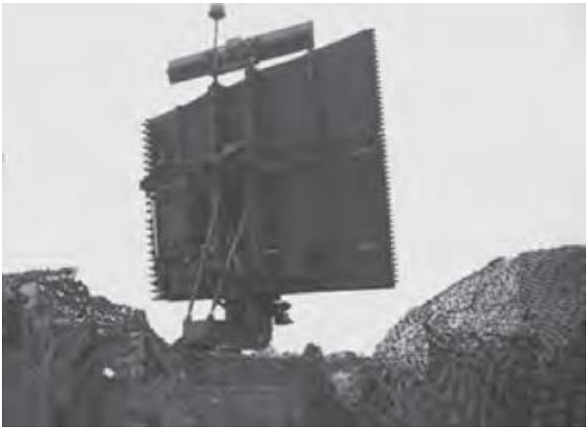

**Figure 2 – AN/TPS-75 Radar**

As means of defense, standard radar and air defense systems can be used, tasked with intercepting approaching enemy munitions.

Once the decision to intercept the attack is made, the command to engage the target (aircraft or missile) is issued to the fighter aircraft covering the defended object, employing air-to-air missiles for this purpose. The task can be accomplished using long and medium-range missiles with active seeker head, such as the AIM-54C Phoenix with a range of over 180 km (see Figure 3).

**Figure 3 – The AIM-54C Phoenix missile mounted on the pylon of an F-14 fighter jet**

An alternative defense option is the use of air defense systems. Depending on the nature of the defended object, medium or short-range surface-to-air missile systems may be employed. In this case, the list of defended objects, in addition to those mentioned above, may include military stationary objects (groups and headquarters of radar and air defense systems), and the list of intercepted munitions may include all means of individual guidance (missiles, glide bombs, aviation containers, large-caliber projectiles). As an example of a system capable of fulfilling the defense task, the Tor-M1 surface-to-air missile system can be considered (see Figure 4).

**Figure 4 – The Tor-M1 surface-to-air missile system**

The reconnaissance and targeting station is a three-coordinate Doppler radar with digital signal processing, mounted on a tower in a gyro-stabilized suspension and capable of operating while the vehicle is in motion. The radar system can detect up to 48 targets and track 10 of them simultaneously. The surveillance range is 25 km, and the target altitude ranges from 50 m to 6 km. The information processing algorithm involves prioritizing and ranking targets based on their level of danger and priority. The processed results are displayed on the commander's display and the missile guidance station.

In addition to surface-to-air missile systems for air defense, close-in weapon systems (CIWS) can also be successfully employed to combat incoming threats. For example, there is information about the successful use of the Phalanx close-in weapon system by the US Army in Iraq to protect military camps during artillery and mortar attacks. The Phalanx CIWS installation consists of a six-barrel 20mm gun capable of firing at a rate of 3000 rounds per minute, two radar systems, and a mount with high-speed drives (see Figure 5). The installation provided protection for a radius of 1470 m around the camp, effectively countering single mines.

**Figure 5 – Mark 15 Phalanx CIWS System**

Active protection systems include onboard technical systems designed to exert force on incoming munitions aimed at a combat vehicle, with the aim of preventing them from hitting the vehicle or at least mitigating the consequences of such impacts.

This goal is achieved by destroying or prematurely detonating the warhead of the incoming munition and by altering the kinematic parameters of the penetrator. A simplified yet effective form of active protection systems can be close-in defense complexes, where the mere detection of an incoming threat triggers the defense system, and the entire protection cycle lasts less than 1 millisecond.

An example of such development is the Ukrainian "Zaslon" active protection system by "Microtek" company. The system features a modular design (see Figure 6), with each module containing two extendable rods.

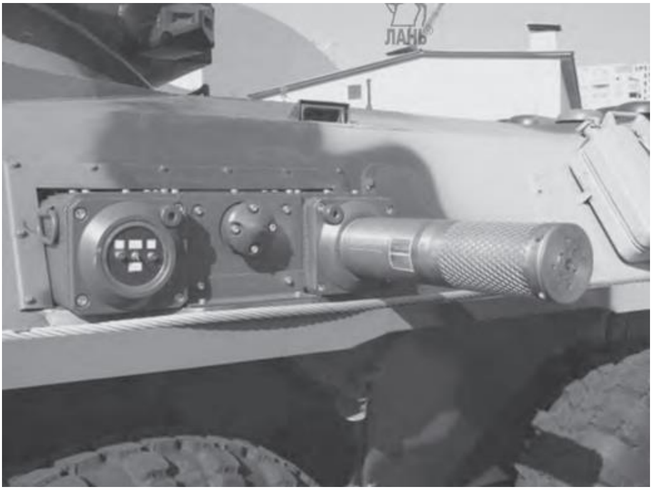

**Figure 6 – “Zaslon” active protection system**

The sensor detects the passage of the munition and issues a command to detonate the fragmentation warhead installed on the stand in front of it. The circular fragmentation pattern (see Figure 7) is coordinated with the sector of emission with an adjustment for the projectile's removal time when the system is activated. Fragments hit the lateral projection of the passing munition, destroying it and initiating the premature detonation of its warhead.

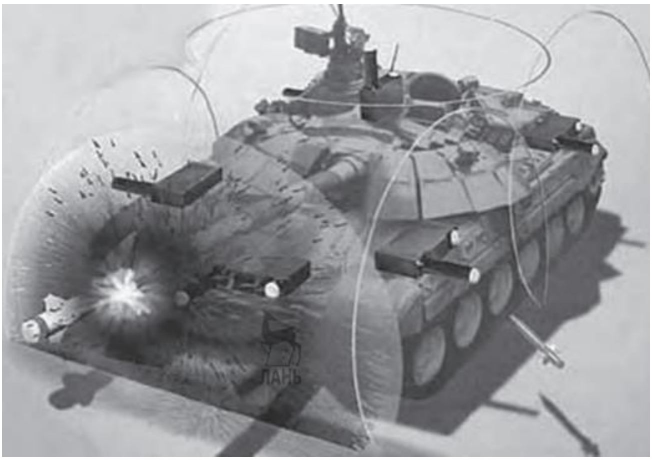

**Figure 7 – The operational scheme of the "Zaslon" active protection system**

It is known that powerful electromagnetic actions pose a danger to electronic equipment. The more complex the equipment, the higher the likelihood of functional disruptions. The amplitudes of current impulses induced by external radiation in the closed circuits of the equipment can reach hundreds of amperes. This leads to breakdown and destruction of semiconductor elements, burning out of circuits, and even detonation of explosive munitions. Sensory devices of munitions and reconnaissance means are most susceptible to the action of electromagnetic pulses (see Figure 8). By their functional purpose, they are highly sensitive and fundamentally impossible to protect. Even in well-shielded products, every conductor leading into the block is similar to an antenna and can become a source of equipment damage.

**Figure 8 – The Vigilant Eagle jamming station**

For successful radar operations, it is crucial to recognize the adversary's use of false air targets (see Figure 9). Such radar countermeasures are intended to reduce the probability of hitting combat aircraft by diverting the attention of air surveillance and missile guidance systems, allowing the simulation of mass air raids on diversionary routes. While designers of attacking missiles employing stealth technology aim to minimize emitted and scattered radiation, the reverse task is addressed in the design of radar countermeasures like the Miniature Air-Launched Decoy (MALD). In this case, the goal is to develop an inexpensive (and therefore small and lightweight) device capable of emitting and scattering radiation, mimicking the characteristics of "large" combat vehicles.

**Figure 9 – The installation of the ADM-160B false radar target**

## RESULTS

The methods discussed have allowed for the identification of the most priority directions in the development of countermeasures against missile defense systems.

## CONCLUSIONS

Minimizing ESA: Tactical missiles can be designed using STEALTH technology to reduce their effective scattering area, making them harder to detect by radars.

Maneuvering Navigation: Tactical missiles can be programmed to execute complex maneuvers during flight to evade detection and destruction by enemy radars and air defense systems.

Electronic Jamming: Rockets can be equipped with electronic jamming systems that interfere with the operation of enemy radar systems, complicating their ability to detect and engage targets.

Group Attack: Instead of individual attacks, tactical missiles can be used in large groups to overwhelm enemy defense systems and create additional difficulties in their detection and interception.

Electromagnetic Protection: Missiles can be equipped with special protective systems that reduce the sensitivity of their electronic equipment to electromagnetic pulses, using shielding, filtering, or isolation.

Backup Systems: To prevent missile failure due to damage to primary components from electromagnetic influences, backup power and guidance systems can be used to ensure reliable missile operation even under electromagnetic pulse.

Experimental Research: It is important to conduct research and experiments on the impact of electromagnetic pulses on missiles to understand their vulnerability and develop effective protection measures.

Structural Analysis: Conducting a structural analysis of the missile considering its potential vulnerability to electromagnetic pulses will help identify weaknesses and develop strategies for improving protection.

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