doi: 10.5937/str2301026R

Analysis Of The Development Of Five Generation Of Anti-Armor Missile Systems

Marko Radovanović [1)]
Aleksandar Petrovski [2)]
Saša Smileski [2)]
Željko Jokić [1)]

The modern way of conducting combat operations has led to an expansion in the development of various combat systems. Experiences from modern military operations indicate that regardless of the place of combat operations, maneuvering ground or urban space, the systems for counter-attack ATGMs represent a very important weapon that contributes to the success of combat operations and is significantly represented in the arsenal of many armies. The paper presents the development of five generations of anti-armor missile systems, as important weapons whose main task is to destroy and neutralize tanks, combat armored vehicles, MRAP vehicles and non-combat vehicles, fortifications and bunkers at different firing ranges. Different tactical-technical features of the mentioned systems, development of several different types and generations of anti-aircraft missiles and the conditions in which they are used have led to the complexity of the problem of anti-aircraft missile systems research. An analysis of the development of anti-armor missile systems was carried out and a conclusion was drawn on the degree of efficiency of the mentioned systems in combat operations, with a proposal for the implementation of anti-armor missile systems of the third, fourth and fifth generation in infantry units. The paper also shows the requirements for the next generation of anti-armor systems.

Key words: **anti-armor missile system, anti-tank guided missile, guidance system, combat operation, tank, armored vehicle.**

Introduction

THE accelerated development of tanks and various types of armored vehicles began after the Second World War as a result of the interconnectedness of science and technology. Means for anti-tank warfare have been developed in parallel with the development of modern armored vehicles (tanks [1], armored fighting vehicles, Mine-Resistant Ambush Protected vehicles (MRAPs), wheeled armored vehicles, etc.) that have varying degrees of ballistic and anti-mine protection.

All of the above led to the development of anti-armor missile systems, which were an effective means of countering armored vehicles and tanks. Regardless of whether combat operations are conducted on maneuvering terrain (ground combat), hilly and mountainous terrain, or in urban areas, one of the main weapons - the anti-armor missile systems represent a very significant weapon that contributes to the success of the execution of all combat operations. The way of conducting modern combat operations, which aims to maximize the effect on the target, sets the conditions for the possibility of successfully conducting anti-aircraft operations in all conditions and at all (short, medium, and long) distances. During direct shooting, the risk of the anti-armor missile system is more easily detected and exposure to the enemy's action is increased. Experiences from modern combat actions require equipping infantry soldiers with such type of weapon that is able to neutralize heavily armored vehicles and tanks that have active-reactive armor from a significantly greater (and safer) distance than the first missile, and also that the anti-armor system has the possibility of shooting from closed rooms and at short distances, in order to operate in urban areas.

Modern anti-armor missile systems must be able to neutralize a range of targets while achieving a high level of launch flexibility – including launching from various firing positions, from wheeled or tracked infantry fighting vehicles, trucks, armored personnel carriers, tanks, helicopters and drones (UAV - unmanned aerial vehicle and UGV - unmanned ground vehicle) [2], and preferably have the possibility of integration with command and information systems C4ISR [3] (command, control, communications, computers, intelligence, surveillance and reconnaissance), C5ISR (C4ISR + cyber-defense) and C6ISR (C5ISR + combat systems) system. The authors graphically presented an overview of the development of anti-armor systems in Fig, 1.

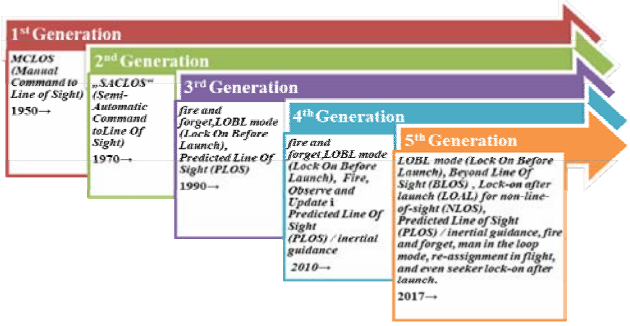


Figure 1. Development of anti-armor missile systems

1) Military Academy, University of Defence in Belgrade, Veljka Lukića Kurjaka 33, 11000 Belgrade,, SERBIA
2) University "Goce Delchev", Shtip, Military Academy "General Mihailo Apostolski", Skopje, Vasko Karangelevski, REPUBLIC OF NORTH MACEDONIA
Correspondence to: Marko Radovanović, e-mail: markoradovanovicgdb@yahoo.com

Anti-armor missile systems (AAMS) perform firing tasks to the greatest extent by direct shooting, while a certain number of modern AAMS have the ability to perform indirect firing tasks (non-line-of-sight (NLOS), Predicted Line of Sight (PLOS) and Beyond Line Of Sight) (BLOS)) and by semi-indirect shooting with OTA type missiles (Overfly Tank Attack) with the option of Top attack. Most often, this type of weapon in a portable version is a part of infantry and artillery anti-tank units [4] and special units. An anti-tank guided missile (ATGM) was designed for the successful destruction of tanks and other armored and unarmored vehicles in all conditions and at different distances.

Literature analysis

In the paper, different sources of literature that were available to the authors were used, where the authors who dealt with the problem of analysis of anti-tank missile systems and anti-tank guided missiles were singled out Radovanović et al. (2019) [5]. In their work they analyzed anti-armor systems of II and III generation and selected the most favorable alternatives using the AHP method. Jokić et al. (2018) [6] analyzed anti-armor systems with the aim of implementation in the units of the Serbian Army. David J. (1995) [7] in his master's thesis performed a comparative analysis of the ATACMS (Army Tactical Missile System) and the Javelin system with the aim of arming units with this system. Radovanović et al. (2018) [8] realized the selection of the most effective ATMS using numerical analysis of tactical-technical and combat characteristics (Randjelovic et al. (2019)) [9]. The application of the AHP method realized the selection of the best alternative (anti-tank missile system) for the needs of the army. Ramakrishna et al. (2018) [10] compared guidance systems of anti-armor rocket systems in relation to belonging to a certain generation of anti-armor rocket systems. Gordon at al. (2015) [11] performed a comparative analysis of the military systems of the US Army and other armies of the world, by comparing key combat characteristics. Radovanović et al. (2021) [12], using the multi-criteria decision hybrid model AHP-VIKOR, chose the most effective anti-aircraft missile system for the needs of the army. Pamučar and Dimitrijević (2021) [13] selected the most effective anti-tank guided missiles using the TOPSIS – MABAC multi-criteria model. Koruba and Nocon [14] showed the algorithm of the programmed guidance of the flat track anti-tank missile onto a target, both motionless and moving, by means of a system called SACLOS. Nocon and Koruba presented modification of control actuation systems of anti-tank guided missile [15]. Bahaaeldin et al. (2018) represented a model for reducing the operator's effort during optical ATGM tracking through a built-in tracking system where System on Chip technology provides excellent opportunities for the design and implementation of a real-time tracking system[16]. Bahaaeldin et al. (2017) [17] represented design and implementation of embedded tracking system capable of dealing with slow motion ground vehicle, which is carried out to upgrade the second-generation anti-tank guided missile system (ATGM), which is based on manual target tracking, to the third generation ATGM (Fire and Forget system), which is based on automatic target tracking. Ćosić et al. (1999) [18] showed HIL simulation presented through the very complex problem of modernization of the semi-automatic command to line of sight (SACLOS) missile system. The presented examples illustrate the importance of the HIL simulation technology for the cost-effective, non-destructive prototype development of such SACLOS systems. In his book Anti-Tank Weapons, Gander describeed different types of anti-tank systems[19]. Nocon et al. (2022) showed a hypothetical anti-tank guided missile (ATGM) with an innovative rocket engine thrust vectorization system [20].

Development of anti-armor missile systems

Anti-armor missile systems with anti-tank guided missiles (ATGM) represent an indispensable segment in modern combat operations. These systems have demonstrated their effectiveness and efficiency in many modern conflicts such as the conflict in Syria, in Nagorno-Karabakh and the special military operation in Ukraine. Anti-armor missile systems with ATGM have very simple electronics and mechanisms and possess an extremely high level of accuracy and precision during the realization of firing tasks.

Anti-tank guided missile has a cumulative (tandem-cumulative) warhead, which penetrates the armor by directing the cumulative jet at one point and in that way destroys and neutralizes the target. The cumulative effect of an explosion represents the focusing of energy on a surface larger than the outer surface of the explosive charge. Direction of energy is obtained by the correct form of explosive charge. If the outer surface is shaped by a conical cavity (the so-called cumulative cavity), detonation products are focused in the center of the cavity. In this way, an accumulation of energy is created on a smaller surface and therefore an effect of a larger size is created. The coating of cumulative cavities also increases the possibility of penetration. Copper is most often used for coating, but steel cans are also used as well as sintered metals.

In modern anti-tank missile systems, the most common is the use of a tandem-cumulative warhead that can form two cumulative jets that follow each other. These jets form two separate cumulative cavities. The purpose of the primary beam is to activate the explosive reactive armor (ERA), and then the secondary beam penetrates the main armor. With the development of the second generation of anti-armor systems, ATGMs were also developed, which could penetrate over 1200 mm of homogeneous steel behind the ERA.

Experiences from modern combat operations condition the implementation of electronic countermeasures in the anti-armor system, which would prevent jamming of ATGM guidance. In addition to immunity to jamming, the reliability of the weapon system is also required. So far, five generations of anti-tank missile systems have been developed, and the classification is based on the ATGM guidance system. According to the type they can be Portable Anti-Tank Guided Missiles (FGM – 148 Javelin, Spike, Kornet) with a launcher for single or multiple use, Anti-Tank Guided Missile Vehicle (M1134 Anti-Tank Guided Missile Vehicle, Véhicule de l Avant Blindé, BOV - 1 POLO M83), unmanned ground anti-armor platforms, anti-armor helicopters, Fig.2. The focus of the work is on the analysis of the development of portable anti-armor systems.

Fig.2a. M1134 ATGM Vehicle

Fig.2b. Véhicule de l'Avant Blindé

Fig.2c. Anti-tank launcher M83

Fig.2d. SA.342 Gazelle

Fig.2e. The Warfighter Spike UGV

Figure 2. Different types of anti-tank launchers

Anti-armor systems of the first generation "MCLOS" (Manual Command to Line of Sight) represent a system in which anti-armor guided missiles are guided by a manual guidance system. The mentioned systems require the engagement of operators and devices at the launching site during the entire flight of the rocket. The soldier, with the naked eye or through the scope, tracks both the target and the missile [12], which represents the three-point method. The soldier-operator operates the control stick of the guidance device based on the observed deviation of the missile's trajectory from the predicted line of sight and thereby corrects the missile's trajectory until the missile meets the target. In the first generation system, the control signal is sent from the control stick from the launcher to the missile using a cable, for example the Russian system 9K11 Malyutka (AT3-Sagger - Western designation), Fig.3. Training and maintaining the level of proficiency of the operators of these systems are extremely expensive and time-consuming, and the shooting process itself is extremely complex. These systems have a significantly lower hit percentage than newer generation systems. During the Arab-Israeli conflict in 1973, the combat efficiency of the first generation system was up to 25%, which represents an extremely poor combat system efficiency[13]. The development of the first generation of anti-armor missile systems began in the early 1950s, and the modernization and development of missiles for systems with the MCLOS guidance system is still ongoing (Malyutka - 2 9M14P1B1 missile). Typical representatives of the first generation of anti-tank missile systems are the 9K11 "Malyutka" with the 9M14 missile and the SS10 with the SS10 missile.

Figure 3. 9K11 Malyutka

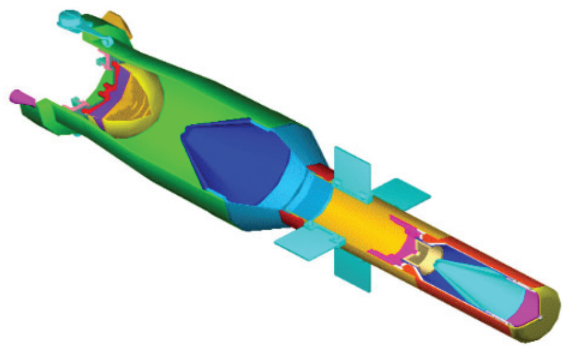


Figure 4. Malyutka - 2 9M14P1B1 [21]

The key disadvantages of the first generation anti-tank missile systems are as follows:

- A three-point matching method in which it is necessary for the soldier to track the target (armored vehicle, tank, anti-aircraft defense system, MRAP, etc.) and the missile simultaneously and to correct deviations from the line of sight (LOS) via the control stick. Commands are transmitted to the missile via the guidance cable (Manual command to line of sight - MCLOS), Fig.5. The training, ability and skill of the operator to act on the battlefield in a different environment directly affects the probability of hitting.

- Prolonged flight time of the missile due to the relatively low and limited cruise speed of 100-180 m/sec, because of the necessary operator response time and the need to transmit the signal from the control stick to the missile via the guidance cable. During the operation of the first generation system when the missile is in flight, the operator of the system is detected and there is a risk of enemy counterattack, since the LOS is a stationary system.
- With the first generation systems and their predicted missile flight path, it is possible to hit targets from the front and side, where armor protection is significantly greater, because these systems do not have the possibility of "Top attack".
- The minimum distance at which it is possible to shoot targets with these systems is 500 m, which represents an extremely long distance at which the operator accepts the missile for guidance and limits the use of these systems in combat operations in urban areas.
- The possibility of using one type of missile, only missiles with a cumulative warhead, significantly reduces the combat capabilities of the first generation system.
- The mentioned shortcomings of the MACLOS system caused the development of the second generation of anti-armor missile systems with anti-armor guided missiles.

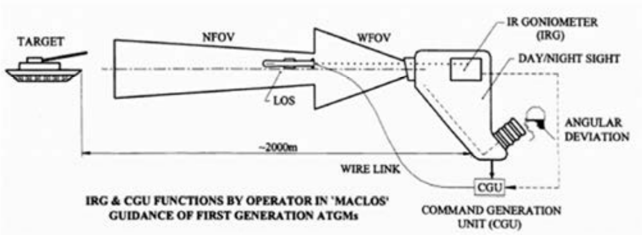


Figure 5. SACLOS / MACLOS Guidance System [22]

The second generation anti-armor system "SACLOS" (Semi-Automatic Command to Line Of Sight) represents a system with semi-automatic missile guidance, where, as with the MACLOS system, the operator and the device are engaged in the firing position during the entire flight of the missile, but the execution of shooting with these systems is facilitated. The guidance system represents the so-called two-point method (around the operator-reticle and the target), where the operator only needs to set the reticle on the target, without the need to follow the flight of the missile [5]. Using the guidance block in these systems, the signal is automatically sent from the sight, via the guidance block, to the missile via the guidance cable and thus the missile is directed to the target. The position of the rocket is tracked using an infrared lamp placed in the tail of the rocket. Control signals are sent to the rocket by the tracking system, and in this way the rocket's flight path is corrected. The connection between the rocket and the guidance block is made by a cable or by radio waves.

Focused beam guidance systems (usually laser beams) use a two-point guidance method, where a system is installed on the missile itself that provides "missile riding on the beam" and therefore no wired connection to the launch device is required. The missile is tracked by means of an infrared goniometer connected to an optical sight. Angular deviations of the missile are detected by means of a goniometer, after which commands are automatically generated in the control block. This significantly reduces the operator’s engagement, which leads to a higher probability of hitting. Due to significantly reduced and simplified role of the operator, training is cheaper and faster. Also, by practically eliminating human participation in the guidance process, opportunities are opened for the development of systems with significantly better performance (higher probability of hitting, greater range and higher speed of the missile).

Typical examples of AAMS of this generation are: 9K111 Fagot, 9K113 Konkurs, 9K115 Metis, Missile d'Infanterie Léger Antichar (MILAN), BGM-71 TOW, 9K135 Kornet with ATGM 9M133 (The NATO reporting name AT-14 Spriggan). Examples are shown in Fig.6. Based on the available literature for the second generation of anti-tank guided missiles, the probability of hitting is 90% [13].

Fig.6a. MILAN

Fig.6b. BGM-71 TOW

Fig.6c. 9M133 Kornet

Figure 6. Anti-armor missile systems 2nd generation

These systems are controlled by keeping the reticle of the optical sight on the target being fired, the missile indirectly flies along the line of sight. It is possible to define three types of control of anti-armor guided missiles using the SACLOS method:

- *Lamp/Flare*: When an infrared lamp or flare is built into the tail of the rocket. The infrared tracking system follows the infrared lights on the tail of the missile and thus determines the position of the missile in flight. To control the flight direction of the rocket along the line of sight, the position of the infrared lamp is used, which is a feedback signal for control. The mentioned rocket control model is used in the Milan, Fagot, Metis and Konkurs systems.
- *Laser Beamriding:* The operator directs the laser beam towards the target via the guidance device. A laser receiver is located on the tail of the missile and it receives the laser beam and translates it into flight control commands for the missile. This model of anti-armor guided missile management is represented by the Ataka, Ingwee, Kornet, Kombat, Falarick, Khrizantema, Shershen, and other systems.
- *Laser Illuminator:* With this anti-armor guided missile control model, the target is illuminated by an infrared laser, which is at a certain frequency, and is illuminated by a laser illuminator. In the nose of the rocket there is a laser receiver sensor that directs the rocket to the target. This management model is represented by the Hellfire and Cirit systems [23].

The disadvantages of the second generation of anti-armor missile systems with the SACLOS guidance system are as follows:

- although the flight time of the missile is reduced compared to the first generation systems due to the increase in speed, but there is a risk of enemy counterattacks because the operator and the anti-armor missile system are exposed in the firing position during the launch and guidance of the missile to the target in the second generation system.
- With the systems of the second generation and their predicted flight path of the rocket, as with the systems of the first generation, it is possible to shoot targets from the front and side, where the armor protection is significantly greater, because the mentioned systems do not have the possibility of "Top attack", which still represents a significant disadvantage.

"Fire and forget" is an anti-armor missile system of the III generation where the automated guidance system is fully used. With these systems, when the missile is launched, there is no longer any engagement of soldiers or devices that are outside the missile [24]. They represent technologically better and significantly more sophisticated means compared to the first and second generation systems. The requirement to reduce the exposure time of the system and the service on the battlefield led to the development of the "fire and forget" system, in which the service is required to define, i.e. aim at, the target, after which it is forwarded to the missile control unit and the missile is launched without the need for engaging the operator in tracking the target until meeting the missile. There has been a development of qualitative as well as quantitative armor protection of tanks and combat vehicles, where it is very difficult to penetrate the armor protection from the front. The probability of hitting a target with a single projectile is further reduced when a tank or armored vehicle has explosive reactive armor. The weakest protection of tanks and combat vehicles is on the upper side, which is why the ability of the third-generation missiles to perform a "Top attack" is operationally very significant. The ability of anti-armor missiles to carry out a dive attack is made possible by the use of a kinematic scheme and the shaping of the missile's flight path using a tracer. The American FGM-148 Javelin, European PARS 3 LR (Third Generation Anti-Tank-Long Range, TRIGAT-LR), Indian Nag and Israeli Gill represent the third generation 'Top attack' anti-tank missile system with 'Fire and forget' and ' Top attack' capabilities based on 'Lock on Before Launch' (LOBL) concept using Imaging Infra Red (IIR) seeker.

The advantages of this model are reflected in the fact that, after spotting the target, the soldier can select the aiming point and hand the target over to the HR seeker. Using the versatile "multi-mode" built-in Image Processor (IP) and passive guidance system, the anti-armor system has protection against electronic jamming. The Hellfire and Brimstone systems, which use active millimeter wave seekers, have an extended range and use the Lock on after launch (LOAL) concept. The human factor is completely excluded because the warhead of the missile contains cameras, thermal detectors, infrared rays, laser rays and a large number of signal receivers and emitters that provide the possibility of very accurate and precise self-guidance of the missile. Much simpler training allows any soldier to be an operator with minimal training. They have been in the armament of the units of the world since the beginning of the XXI century. Based on the experience from modern combat operations where the use of means for electronic jamming is more significant, the conclusion is reached that the mentioned systems are significantly more susceptible to electronic jamming compared to SACLOS and MCLOS systems. When the soldier selects the target and launches, the automatic system follows the target and guides the missile to meet the target. Representatives of the "fire and forget" system are FGM - 148 Javelin and 9M133M Kornet-M. The automated system performs target tracking and focuses the laser beam to the target, based on which the missile is guided. The launch pad is capable of tracking two targets simultaneously. In addition to the anti-armor effect, it can also be used for anti-aircraft defense at low altitudes (e.g. against low-flying helicopters, unmanned aerial vehicles and drones).

The FGM-148 Javelin anti-armor system is one of the most sophisticated combat systems and one of the most effective anti-armor systems that has been proven in combat. These systems were used massively in the conflict in Ukraine. A significant feature of this anti-armor system is the ability to attack the target from above, where the armor is thinnest, which greatly increases the probability of destroying or neutralizing the target.

In anti-armor missiles, the Seeker Section is represented, which is composed of an infrared recording system (I2R) and a contact fuse intended to detonate the warhead. In the warhead of the missile there are cameras, thermal detectors, IR rays, laser rays and various signal receivers and emitters that provide opportunities for accurate and precise self-guidance of the missile and there is no human participation in this process, and the I2R system enables "fire and forget" that uses automated guidance system. The I2R system during missile flight tracks the target and collects and sends data to the electronic unit located in the missile. Figures 7a and 7b show target acquisition. When a target is detected, the operator engages by aiming at the target with a narrow field of view, after which the seeker detects the target's thermal reflection, i.e. performs "target lock", after which the rocket's flight to the target continues, and the soldier can change the firing position [23].

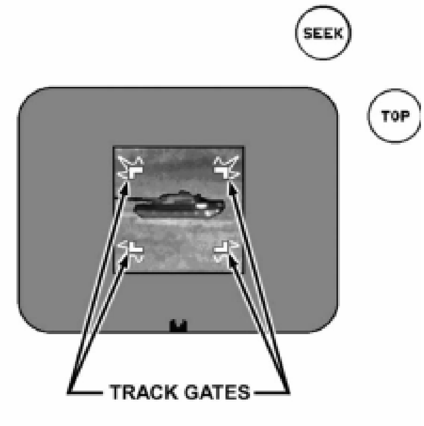


Figure 7a. Target thermal reflection detection – “Target lock”

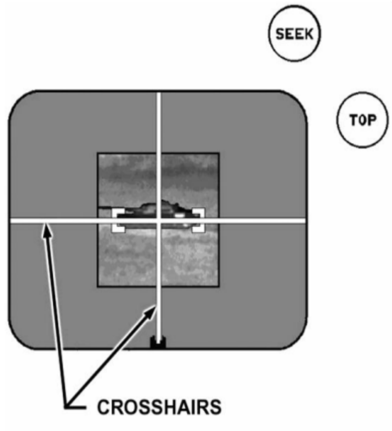


Figure 7b. Target “Locked” firing conditions fulfilled; system ready to launch a missile

Typical representatives of the third generation of anti-tank missile systems with anti-tank guided missiles are: Javelin (Fig.8), Kornet EM, NAG, NLAW (Fig.9), HJ-12.

Figure 8. FGM -148 Javelin

Figure 9. NLAW (Next generation Light Anti-tank Weapon)

Anti-armor guided missiles with the ability to work in the modes Fire and forget, Fire, Observe and Update and Predicted Line Of Sight (PLOS) / inertial guidance are anti-armor missile systems of the IV generation, and rely on a combination of tracers for guidance. They use dual seeker configuration of electro-optical thermal imager (EO/IR) and millimeter-wave active radar homing for control and guidance with lock-on before launch and lock-on after launch capabilities. The development of these systems began at the beginning of the XXI century, and their official use in the armed forces began in the 2010s. They represent technologically perfected systems, where the soldier has the ability to change the flight parameters after launching the missile, as well as the ability to launch the missile at hidden targets that one cannot observe. In relation to the systems of the older generations, it has significantly longer shooting distances, and the possibility of "Top Attack" due to the use of OTA missiles.

The Fire, Observe and Update projectile group is equipped with an IIR (Imaging InfraRed) head that has the ability to record the battlefield, so that the operator has an image of the battlefield in real time on the monitor, and the image is sent via an optical cable unwound during the flight, and it also has the ability to distinguish targets. The operator can change the trajectory of the missile during the flight by sending different signals to change the flight parameters of the missile through the guidance cable, until hitting the target or the point from which the missile is homing to the target. It needs to be emphasized that in that case the missile is equipped with a head with stabilized TV and/or IIR camera and during the flight, it sends the picture "seen" by the camera to the control station through the fiber-optic cable. The soldier, after seeing the picture from the battlefield, selects the target after which the missile control signal (manual control) is sent via an optical cable. By analyzing the image from the battlefield in real time, the missile is guided from the control station, where it is possible to correct the flight path of the missile in relation to the conditions on the battlefield [25].

The system with "a man in the control loop" defines many capabilities when attacking a tank, armored vehicle, anti-aircraft defense system, ship or building. The deployment of soldiers and the use of fiber-optic cable reduce the possibility of electronic jamming. Anti-armor systems of the fourth generation have the ability to shoot targets that are not visible from the firing position, that is, from the control station, they can shoot targets that are behind natural or artificial obstacles, and even at some aerial (slow-moving) targets. In order to be able to launch a missile, the approximate location of the target is required. The length of the optical cable limits the range of the missile, but the use of homing to the target in the final phase of the missile's flight can increase the range. We say that controlling the missiles through the fiber-optic cable is done on the basis of the "fire-observe-correct" principle. It allows not only for precise guiding to the target, but also for changing the target during flight.

Limitations that occur when the missile is controlled via fiber optic cable are defined:

- The length of the optical cable also limits the final range of the missile,
- The cruise speed of the projectile is limited due to the fact that at speeds higher than 200 m/s, the optical cable would break during unwinding,
- Limitations of the rate of fire resulting from longer time to target,
- Servicing the guidance head and fiber optic cable reels increases the operating costs of the system,
- Constant observation of the target is necessary because when we lose the target for more than few seconds, we are not able to continue guiding the missile.

The fourth-generation anti-armor missile systems are similar to the third-generation systems, yet after the launch of the missile, the operator has the opportunity to change the target and update new parameters because the missile is connected to the system via an optical cable, as is the case with the Israeli Spike and the South Korean Raybolt system [23].

Figure 10. OMTAS

Figure 11. AT – 1K Raybolt

Anti-armor missile systems of the fifth generation with anti-armor guided missiles of the fifth generation (ATGM5) are the most sophisticated means that have features such as LOBL mode (Lock On Before Launch), Beyond Line Of Sight (BLOS) mode code when locking the target is done after firing the missile; Lock-on after launch (LOAL) for non-line-of-sight (NLOS) and using the third party target designation mode where the target is locked during the flight of the missile using the GPS coordinates of the target that is not visible from the firing position; Predicted Line of Sight (PLOS) / inertial guidance, fire and forget, a man in the loop mode, re-assignment in flight, and even seeker lock-on after launch. These systems have a new generation infrared seeker that has a smart target seeker with artificial intelligence features and elements. This tracker is built to defeat and penetrate armor that has active protection. The fifth generation systems have the capability of "Top attack". They have the ability to launch in two modes, namely fire-and-forget mode, as well as fire-observe-and-update mode. It is possible to launch the missile even when the target is out of sight and use a third-party target designation using a wireless data link. It uses television guidance of the fifth generation. Anti-armor systems of the fifth generation possess diverse capabilities thanks to the development of: /1/ New generation passive dual-band browser (color TV and uncooled IR); /2/ New generation, multi-purpose tandem warhead, /3/ Smokeless propellant that provides concealed ignition; /4/ Maintenance-free projectile (more than 10 years) [26].

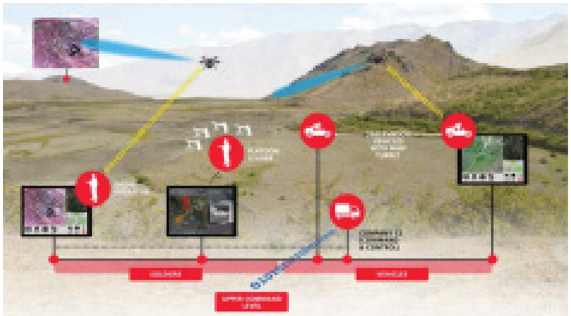


Figure 12. Akeron MP (*Akeron Moyenne Portée*)

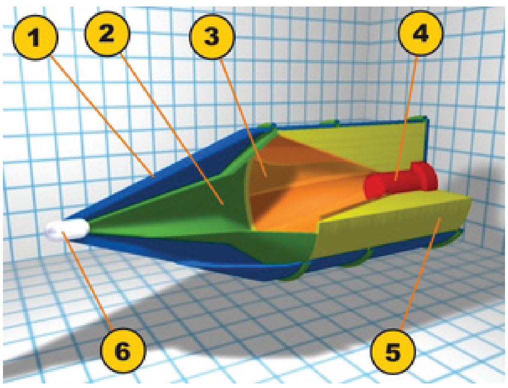
AKERON MP is a fifth-generation anti-armor missile system that has been proven in combat operations. The system design includes the ability to upgrade the system and implement various software necessary for the future of modern ground combat systems [27]. The fifth generation AKERON MP anti-armor system is qualified for deployment on a wide range of firing positions in different operational environments and in different operational conditions. It is planned to continue the development of the mentioned system and its implementation on reconnaissance vehicles of the French army. A wide range of capabilities and excellent operational capabilities allowed the AKERON MP system to be positioned significantly ahead of the third and fourth generation anti-armor systems that are in operational use [26].

The SPIKE LR2 variant of the Spike anti-tank missile system with an anti-tank missile has been upgraded to the level of the fifth generation of these systems.

Analysis of the characteristics of anti-armor missile systems of significance for the performance of combat actions

In this part of the paper, the most important characteristics of anti-armor missile systems are defined, which are important for the performance of anti-armor actions in modern combat operations. An analysis of the defined characteristics was performed in relation to the system generation to which they belong and in relation to modern tanks and armored fighting vehicles.

Penetration [12] is a combat characteristic that directly affects the use of anti-armor means in combat operations and has a direct impact on the performance of anti-armor operations. The goal of an anti-armor missile system is to successfully penetrate and destroy or neutralize a target (tank, armored fighting vehicle, MRAP, non-combat vehicle, anti-aircraft defense system, fortification, bunker, etc.) [6], and this enables a high level of the system penetration. Anti-armor missile systems of the newer generation in most cases have tandem-cumulative warheads (which provide the ability to penetrate armor that has active and active-reactive protection). This feature has an advantage compared to classic missiles with a cumulative effect and thermobaric warheads (intended to penetrate and destroy fortifications, buildings and bunkers). The penetration is measured in millimeters (mm) and in regard to the possibility of breaking through explosive reactive armor (ERA - explosive reactive armor). The penetration is a characteristic that is directly correlated with the caliber of the anti-armor missile and the mass of the explosive charge, because larger caliber and greater mass of the explosive charge achieve greater penetration. Fire and combat capabilities of anti-armor missile systems increase with increasing penetration. Anti-armor missile systems of the first generation have a penetration of up to 400 mm RHA (Rolled Homogeneous Armour), and a certain number of systems of the second generation have only a HEAT (High-explosive anti-tank – Fig.13) warhead and their penetration ranges up to 1000 mm of RHA, while more modern systems of the second generation have a tandem-cumulative and thermobaric warhead, and their penetration ranges up to 1200 mm of RHA behind ERA (Explosive Reactive Armour).



1: Aerodynamic cover; 2: Air-filled cavity; 3: Conical liner; 4: Detonator; 5: Explosive; 6: Piezo-electric trigger

Figure 13. Cumulative head

The third, fourth and fifth generation systems have approximately the same penetration and it ranges up to 1300mm RHA behind the ERA depending on the type of anti-armor missile system.

The effective range [12] of an anti-armor missile system with an anti-armor guided missile is the horizontal distance at which it is possible to hit the target under normal ballistic conditions. The shape, mass, mass distribution of the rocket, the mass and type of rocket fuel, the type of sight, as well as the structural characteristics of the anti-armor missile system directly affect the size of the effective range. Conducting anti-armor combat at medium and long distances enables a greater effective range, which increases the level of security and protection of soldiers in the firing position. The modern way of conducting anti-armor attacks in modern combat operations requires that anti-armor missile systems respond to the requirements on the battlefield where there is a large number of fast-moving targets of different types and degrees of threat. For the successful performance of anti-armor operations in modern combat operations, it is necessary that anti-armor missile systems have the ability to shoot at long distances [9]. Effective range directly affects the effectiveness of a combat system where greater effective range increases the fire and combat capabilities of the system.

The effective range of the first generation of anti-armor systems ranges from 500 - 3000 m, the second generation up to 6000 m, the third and fourth generation have an effective range that goes up to 10000 m. Anti-armor systems with anti-armor guided missiles of the fifth generation have the ability to shoot at distances of 25000 m.

The cruise speed of the missile is one of the significant characteristics of the ATGM. The speed of anti-tank guided missiles is most often expressed in meters per second (m/s) and ranges from 80 m/s (ATGM of the first generation, e.g. 9M14 Malyutka) to 350 m/s (ATGM of the third, fourth and fifth generations, e.g. ATGM 9M133M Kornet-M). It is evident that the speed of the projectile is an important characteristic considering the place and role of anti-armor systems in the performance of modern combat operations where multiple targets appear. From the previous example, it can be concluded that from the third generation ATGMs have a speed almost four times higher than the first generation. The analysis of the content and available data leads to the conclusion that with the third, fourth and fifth generation systems, it is possible to perform two to three launches and guide the missile to the target, compared to the MCLOS guidance systems, where it is possible to perform one launch and guidance at the same time and where modern anti-armor missile systems possess greater fire and combat capabilities.

Reliability [28] is an essential operational characteristic of a combat system for anti-tank warfare, which is measured by the number of successful launches per 100 launched anti-tank guided missiles. Reliability should enable the defined functions in the intended conditions of use and during the defined time interval, so that the values of the basic parameters are within the given limits [29]. Here it is important that these combat systems can be used in different conditions of combat use, in the temperature range from - 30 to + 50 ° C, with dirty parts, at different positions of the anti-armor missile system, in conditions of electronic and infrared jamming, etc.

Anti-armor missile systems with anti-armor guided missiles are safe weapons, but after prolonged use malfunctions may occur, causing delays and failures during firing. The most common causes that lead to a stoppage-failure when shooting are: wear and tear of parts, malfunction of the rocket, poor maintenance and careless and unprofessional handling, the expiration of the resources of the exploitative use of anti-armor guided missiles. Stoppages result in the cessation of shooting. The reliability of anti-armor systems with ATGM is in the range of 80 -99%, and belonging to a certain generation of anti-armor systems does not have a significant impact on the percentage of reliability.

The probability of hitting [30] is a numerical measure of the objective possibility of hitting the target in certain shooting conditions (depending on the type of target and the number of fired missiles). The results of the probability of hitting enable determining the required expenditure of rockets and the mathematical expectation of the number of direct hits, where the degree of efficiency of direct, semi-indirect and intermediate shooting is defined based on the time required for shooting. By launching one or more missiles at different types of targets, it is possible to determine the probability of hitting.

The size of the probability of hitting depends on:

- the position of the middle hit in relation to the center of the target. When the middle hit is closer to the center of the target, then the probability of hitting is higher, because the target will be covered by that part of the scattering surface where the hits are denser;
- size of the target, when the middle hit coincides with the middle of the target under conditions of the same images of the hits, the probability of hitting is higher when the dimensions of the target are larger,
- the size of the hit image, the probability of hitting targets of the same dimensions is higher when the area of the hit image (dispersion ellipse) is smaller,
- the shooting direction, when the target has a small depth and a large width and vice versa, the highest probability of hitting will be when the shooting direction coincides with the longer axis of the target.

Bringing the medium hit to the center of the target and keeping it in the center of the target increases the probability of hitting. When firing a projectile, the probability of hitting can be determined in several ways. According to the conditional division, and depending on the type of target, the probability of hitting is calculated for targets: small dimensions (elementary), circular and rectangular, three-dimensional, belt-shaped, and irregular. It is expressed in percentages. Based on experience from combat operations, the first-generation anti-armor systems with ATGMs have a 25% hit probability, while the second-generation systems have a 90% hit probability. Third, fourth, and fifth-generation systems have a probability of 90 - 99%.

The minimum firing distance is the minimum distance at which it is possible to hit the target and has a direct impact on: the fire and combat capabilities of anti-armor systems, the effectiveness of the system and the conduct of anti-armor combat in all conditions, especially in urban areas at short distances. Experiences from modern combat operations require anti-armor systems to have a minimum shooting distance and that their minimum shooting distance is a few tens of meters [12] and the possibility of soft launch. The mentioned characteristic is important for the successful execution of firing tasks when the space for the realization of the firing task is limited and has a large number of objects on a small surface. Only the first generation of anti-tank systems with ATGM has an impact on this characteristic and the minimum shooting distance for the mentioned systems is 500 m. Anti-armor missile systems from the second to the fifth generation have the ability to shoot from 25 m, and belonging to a certain generation of anti-armor systems does not have a direct impact on this characteristic, except for the first generation of these systems.

The difficulty of training [28] represents an important characteristic and criterion for military leaders because it is reflected in the time, simplicity, economy and effectiveness of the implementation of soldier training and service of anti-armor missile systems, as well as in the efficiency of these systems in performing anti-armor operations. The duration of the training also represents a significant characteristic during the execution of combat operations. The first generation of anti-armor systems is distinguished by a very complex and complicated training process, while the training for other types of anti-armor systems is simplified, the operator's influence on the guidance of anti-armor missiles is reduced, and the time required for training is reduced to a minimum. Thus, operators on the first-generation anti-armor systems participate 100% in the process of aiming, i.e. guiding the missile, operators on the second-generation anti-armor systems participate in the aiming process about 30%, operators on the third-generation systems participate about 10%, operators on the fourth-generation anti-armor systems participate up to 8%, and operators on systems of the fifth generation participate about 3%.

The technical characteristics of anti-armor missile systems represent the technical characteristics of anti-armor systems that are important for the selection of an anti-armor system for the needs of military units and include: caliber [8], mass of AAMS and missiles [9], the type and number of missiles different purposes that are used, the mass of the explosive charge, the initial speed of the projectile and the maximum speed of the projectile, the field of action of the weapon by direction and height. It is necessary that the mentioned characteristics enable the greatest efficiency of the projectile on the target. The effectiveness of the projectile [30] is the performance of its effect on the target and depends on the purpose of the projectile and the type of target. Efficiency is measurable and quantitatively determines the ratio of output to input; it is defined as a percentage compared to the ideal case when 100% efficiency is defined.

The guidance system is a technical characteristic of the anti-armor missile system, on the basis of which the system is classified into a certain generation of anti-armor systems. The first generation of anti-armor systems has the MCLOS (Manual Command to Line of Sight) guidance system. The second generation of systems are systems with semi-automatic missile guidance SACLOS (Semi-Automatic Command to Line Of Sight). With the third generation systems, after the launch of the missile there is no influence of the operator or launcher on the flight of the missile and they represent "fire and forget" systems with automatic guidance [5]. The third-generation "fire-and-forget" missiles rely on a laser electro-optical imager (I2R), seeker, or V-band radar seeker in the warhead of the missile. "Fire, Observe and Update" represents the IV generation anti-armor missile guidance system where it is possible to change the target and change the missile's flight parameters during the missile's path to the target. IV generation anti-armor guided missiles with the "Fire, Observe and Update" system have a longer range and rely on a combination of guidance trackers. Predicted Line Of Sight (PLOS) is a system of the IV and V generations where it is possible to predict the path of the target, to target a target that is obscured Beyond Line Of Sight (BLOS), which includes "fire and forget", man in the loop mode, re-assignment in flight, and even seeker lock-on after launch. Fire-and-Forget Man In The Loop with fiber optic data-link Lock-on after launch (LOAL) for non-line-of -sight (NLOS) and using third party target designation are the most modern, advanced and sophisticated anti-armor systems of the fifth generation**.**

The next generation of anti-armor missile systems

Based on everything presented in the paper, it can be concluded that the further development of anti-armor systems will be accelerated. Combat experiences from modern combat operations have a significant impact on the development of the next sixth generation of anti-armor systems, where it is necessary to improve the capabilities of the fifth generation systems and to create conditions for a more massive application of artificial intelligence in order to improve efficiency on the battlefield.

The standard that has been set, which is the use of a tandem-cumulative warhead and a thermobaric warhead, should remain with an increase in penetration over 1500 mm behind the ERA, with the capability of "Top attack", which would significantly increase the probability of hitting the target and the effectiveness of anti-armor system.

The effective range of the rocket needs to be increased from the current few kilometers (up to 10 km) to several tens of kilometers (50-70 km), in order to meet the requirements of modern combat operations. Increasing the effective range would enable the conduct of anti-armor operations outside of combat contact with the enemy, which directly affects the increase in fire and combat capabilities of the system.

Reliability is a technical characteristic that always requires maximization, regardless of the combat vehicle in question. The use of composite materials and artificial intelligence would increase the reliability of anti-armor systems of the sixth generation.

Anti-armor systems of the sixth generation should enable the launch and tracking of multiple missiles, launched from one system and tracked by one operator. This capability would significantly increase the probability of hitting the target and the efficiency and effectiveness of the shooting. This capability would significantly improve combat capabilities and the degree of resistance and protection on the battlefield.

The length and weight of combat training for the use of anti-armor systems requires minimization and should be as short and light as possible so that training for the use of these assets on the battlefield can be carried out in a short period of time.

In relation to the existing anti-armor missile guidance models, it is necessary to improve and upgrade them so that anti-armor systems are fully networked into command and information systems C4ISR, C5ISR or C6ISR, which should enable the ability to transfer control over the missile during the flight of the missile to another system on the battlefield thereby maximizing the effect on the target. The stated ability of the missile should allow, after the missile is launched and its exit from the effective range of the launcher, if there is another launcher or platform nearby, to allow taking control of the missile and directing it to the target. By installing cameras and receivers in the warhead and networking in some of the command and information systems, it is possible to transmit images from the battlefield in real time and to select and change the target during the flight of the missile.

The new generation of anti-armor systems with anti-armor guided missiles should allow to simultaneously neutralize multiple targets at different distances that are variable and to increase the degree of use of artificial intelligence in the development of these systems, with the aim of increasing the efficiency of the system in performing anti-armor actions in a combat operation.

Placing launchers on light combat vehicles increases the possibilities of maneuver and mobility in the area of operation, the degree of resistance and protection of the crew, increases the effective range, the possibility of launching and tracking several different targets at variable distances, increases the combat set of the system, creates the possibility of networking with the command -information systems, real-time video display and real-time image display from the battlefield, and the supply of missiles was facilitated.

Conclusion

Arming units with these systems is a significant task for the armed forces of many countries. A significant number of the world's armies have several different types and models of anti-armor missile systems in their range of weapons, all because of their different characteristics. The characteristics of these systems that the military puts before the manufacturers of anti-armor systems with anti-armor guided missiles are different.

The third, fourth and fifth generation anti-armor missile systems with ATGMs with 'fire and forget' and 'gun attack' capabilities are necessary to penetrate modern armor equipped with explosive reactive armor (ERA) protection systems, and the deployment of anti-armor systems on attack helicopters is necessary, armored vehicles and unmanned ground vehicles, i.e. drones. In many countries, the mentioned systems are in the final stage of development. Based on the analysis of the available literature, the conclusion is reached that Russia does not possess anti-tank guided missiles with "top attack" capabilities.

Significantly higher prices of anti-armor systems and anti-armor guided missiles of the III, IV and V generation, require the achievement of extremely high SSKP with these systems, where the wear of the launcher is minimal. This is made possible by the exceptional precision of the guidance of the I2R/MMW tracer, the possibility of "Top attack" when the target is targeted where it is least protected, with the possibility of a "fire and forget" missile launch system. Due to their high cost, systems with these capabilities are used against purposeful goals. Targets with a lower threat probability can be destroyed or neutralized with second-generation anti-armor systems using tandem-cumulative warheads or even modernized and improved first-generation missiles.

For the use in LOS mode up to an effective range of 4-5 km, the LOBL scheme is the most effective because the target is identified and selected by the soldier and the probability of the soldier accidentally selecting friendly tanks/targets in battlefield combat conditions is minimal compared to LOAL scheme. In LOBL mode, except for "all the time" an IIR based system is more acceptable to an MMW system.

Modern combat operations require a high level of equipment and training of military units of all armies of the world. The modern way of conducting combat operations and the more massive use of armored, mechanized and motorized units requires the use of highly efficient anti-tank missile systems of newer generations. In ground operations, special importance is attached to anti-armor combat, and in connection with that, the choice of anti-armor means with which the units will be equipped. The requirements set before the decision-maker are that anti-armor means have the ability to perform anti-armor actions in all weather and infrastructure conditions and at short, medium and long distances. The development of anti-armor systems records the development of the V generation, which showed effective results against the tanks of the III generation.

Further research should be focused on the selection of the most effective anti-armor missile system that is integrated on a vehicle as well as anti-armor missile systems integrated on unmanned ground vehicles, in order to implement them in ground army units, as well as the calculation of the anti-armor capabilities of anti-armor units, which represents a complex and complex problem. The technological development of armored vehicles and their tactical use in the conduct of modern combat operations have influenced the improvement of the tactical and technical characteristics of anti-armor vehicles, which directly affects the level of anti-armor capabilities of the unit. Increasing the level of anti-tank capabilities of the unit is a constant and always current problem, the solution of which ensures an equal relationship in anti-tank operations against the armored and mechanized forces of the enemy.

Acknowledgments

This paper was written by compiling results from two scientific research projects funded by the Ministry of Defence of the Republic of Serbia, number: VA-DH/1/22-24 "Management model of Defence system capability development" and VA-DH/1/21-23 "Influence of contemporary environment on the conduct of combat activities in urban spaces".

Literature

[1] Kleiner, J., Bajer, M., Zelinková, N., Vojenské R.: *The Third and Fourth Generation Tanks and Their Role In Modern Warfare*, Vol. 28, No. (2), pp. 50-66, DOI: 10.3849/2336-2995.28.2019.02.050-066,

[2] Žnidaršič, V., Radovanović, M., Stevanović, D.: *Modeling the organisational implementation of a drone and counter-drone operator into the Serbian Armed Forces rifle section*, Vojno delo, 2020, Vol. 72, No. (3), pp. 84-109, DOI: 10.5937/vojdelo2003084Z, ISSN0042-8426,

[3] Petrovski, A., Radovanović, M.: *Application of detection reconnaissance technologies use by drones in collaboration with C4IRS for military interested*, Contemporary Macedonian Defence, 2021, Vol. 21, No. (40), pp. 117–126

[4] Ranđelović, A., Kokelj T.: *Protivoklopne mogućnosti mehanizovanog bataljona uodbrani*, Novi Glasnik, 2010, Vol. 3, No. (4), pp. 77-90.

[5] Radovanović, M., Ranđelović, A., Milić, A.: *Komparativna analiza protivoklopnih sistema korišćenjem AHP metode*, Vojno delo, 2019, Vol. 71, No. (7), pp. 234-250, DOI: 10.5937/vojdelo1907234R

[6] Jokić, Ž., Jotić, S., Lazić, G: *Analiza protivoklopnih raketnih sistema u ciljuopremanja jedinica Vojske Srbije*, Zbornik radova sa 21. Međunarodne DQM konferencije:Upravljanje kvalitetom i pouzdanošću ICDQM – 2018, Prijevor, Srbija, 2018, pp. 411-418.

[7] David, W. J. *A comparative analysis of the acquisition strategies of army tacticalmissile system (ATACMS) and Javelin medium anti-armor weapon system*, (master's thesis), Naval postgraduate school, Monterey, California. 1995, DOI: 10.1.1.960.7831

[8] Radovanović, M., Ranđelović, A., Blagojević A.: Komparativna analiza protivoklopnih raketnih sistema, 21. Medjunarodna DQM konferencija Upravljanje kvalitetom i pouzdanošću ICDQM – 2018, Istraživački centar za upravljanje kvalitetom i pouzdanošću, Prijevor, 2018, str. 452–459.

[9] Ranđelović, A., Radovanović, M., Stevanović M.: *Uporedna analiza protivoklopnih raketnih sistema upotrebom AHP metode u cilju opremanja jedinica Vojske Srbije*, 22. Medjunarodna DQM konferencija Upravljanje kvalitetom i pouzdanošću ICDQM – 2019, pp. 336-344.

[10] Ramakrishna, G, Prasanna, V., G. K. D.: *A Literature Study on Command to Line of Sight Missile System*, International Journal of Engineering Sciences & ResearchTechnology, Vol. 7, No. (1), pp. 350–356. DOI: 10.5281/zenodo.1147484

[11] Gordon, J., Matsumura, J., Atler, A., Boston, S. S., Boyer, M. E., Lander, N., Nichols, T. W.: *Comparing U.S. Army Systems with Foreign Counterparts: Identifying Possible Capability Gaps and Insights from Other Armies*, Santa Monica, USA: RAND Corporation, 2015.

[12] Radovanović, M., Milić, A., Stevanović, M.: *Analysis of anti-armor missile systems using the hybrid model AHP - VIKOR method of multi-criteria decision-making*, Serbian Journal of Engineering Management, 2021, Vol. 6, No. (1), pp. 37-44, DOI: 10.5937/SJEM2101037R

[13] Pamucar, D., Dimitrijević, S.: *Multiple-criteria model for optimal Anti-Tank Ground missile weapon system procurement*, Military Technical Courier, 2021, Vol. 69, No. (4), pp. 792-827.

[14] Koruba Z. and Nocoń, C *Programmed control of the flat track anti-tank guided missile*, Proceedings of the 2014 15th International Carpathian Control Conference (ICCC), 2014, pp. 237-242, doi: 10.1109/CarpathianCC.2014.6843604.

[15] Nocon, Ł., Koruba, Z. *Modification of control actuation systems of ATGM.* In Proceedings of the 23rd International Conference on Engineering Mechanics, Svratka, Czech Republic, 15–18 May 2017; pp. 714–717

[16] Bahaaeldin, G. A., Mohamed A. S.L.: *Ahmed Nasr Ouda. Reducing Human Effort of the Optical Tracking of Anti-Tank Guided Missile Targets via Embedded Tracking System Design*, American Journal of Artificial Intelligence, 2018, Vol. 2, No. 2, pp. 30-35. doi: 10.11648/j.ajai.20180202.13

[17] Bahaaeldin G.A., Ahmed N. O., Yehia Z. E., Gamal A. E.: *Embedded Tracking System for Ground Moving Vehicle*, 17th International Conference on AEROSPACE SCIENCES & AVIATION TECHNOLOGY, ASAT -17 – April 11 - 13, 2017, 145.

[18] Ćosić, K., Kopriva, I., Kostić, T., Slamić, M., i Volarević, M.: *Design and implementation of a hardware-inthe-loop simulator for a semiautomatic guided missile system*, Simulation Practice and Theory, 1999, Vol. 7, No. (2), 1999, pp. 107–123. https://doi.org/10.1016/S0928- 4869(98)00027-5

[19] Gander, T.: *Anti-tank Weapons (1st ed.),* Ramsbury: Crowood Press, 2000.

[20] Nocon, Ł., Grzyb, M., Szmidt, P., Koruba, Z., Nowakowski, Ł.: *Control Analysis with Modified LQR Method of Anti-Tank Missile with Vectorization of the Rocket Engine Thrust*, Energies, 2022, 15, 356. https://doi.org/10.3390/en15010356

[21] https://www.yugoimport.com/en/proizvodi/malyutka-2-anti-tank-guided-missile-family

[22] Narayana, R. I., *Recent advances in antitank missile systems and technologies*, Proc. SPIE 3898, Photonic Systems and Applications in Defense and Manufacturing, (4 November 1999); doi: 10.1117/12.368467

[23] Al Fadli, H. M., Gunawan, D., Bura, O. B., Nugroho, L.: *Design and Implementation of Anti-Tank Guided-Missile (ATGM) Control System Using Semi-Automatic Command Line of Sight (SACLOS) method based on digital image processing*, Jurnal Pertahanan, 2021, Vol. 7, No. 2, pp. 217-231, DOI: http://dx.doi.org/10.33172/j p.v7i2.755

[24] Harrisa, J., Slegers, N.: *Performance of a fire-and-forget anti-tank missile with a damaged wing***,** Mathematical and Computer Modelling: An International Journal, 2009, Vol. 50, Issue 1-2J uly, pp. 292–305 https://doi.org/10.1016/j.mcm.2009.02.009,

[25] Koruba, Z., Nocoń, L., *Automatic Control of an Anti-Tank Guided Missile Based on Polynomial Functions*, JOURNAL OF THEORETICAL AND APPLIED MECHANICS, 2015, 53, 1, Warsaw 2015 DOI: 10.15632/jtam-pl.53.1.139

[26] ATGM5 -Fifth-generation, multi-target land combat weapon, dostupno dana 20.03.2022 www.Lntmbda.com

[27] Akeron MP Close Combat Weapon Systems, MBDA missile system.

[28] Tešić, D., Radovanović, M., Božanić, D., Pamucar, D., Milić, A., Puška, A.: *Modification of the DIBR and MABAC Methods by Applying Rough Numbers and Its Application in Making Decisions*, Information, 2022, Vol. 13, No. 8: 353. https://doi.org/10.3390/info13080353.

[29] Božanić, D., Ranđelović, A., Radovanović, M., Tešić, D., *A hybrid LBWA - IR-MAIRCA multi-criteria decision-making model for determination of constructive elements of weapons*, Facta Universitatis Series Mechanical Engineering, 2020, Vol. 18, No. (3), pp. 399-418, DOI: 10.22190/FUME200528033B.

[30] Kokelj, T., Randjelovic, A.: *Teorija gađanja*, Global Security, Belgrade, 2018.

Received:20.04.2023.
Accepted:23.07.2023.