11TH INTERNATIONAL SCIENTIFIC CONFERENCE ON DEFENSIVE TECHNOLOGIES
OTEH 2024
Serbia, Tara, 9-11 October 2024

HIGH ACCURACY WEAPONS

DRAGAN KNEŽEVIĆ
Military Technical Institute, Belgrade, dragan.knezevic@vti.vs.rs

MILAN POPOVIĆ
SAF GeneralStaff, Belgrade, popovicmilan184@gmail.com

MILOŠ SIMIĆ
CNT, Belgrade, cnt.beograd@gmail.com

GORAN MARJANOVIĆ
Military Technical Institute, Belgrade, gmarjanovic1961@gmail.com

Abstract: *Weapons and weapon systems of high accuracy, as well as the means to fight with them, represent the front and back of a new page in the development of military science and the construction of the armed forces. The mentioned weapons will define the character of the armed struggle in the near future. In this review paper, selected tube and missile systems were analyzed from the point of view of lethality, probability of destruction of targets and guidance systems.*

Keywords: *high-precision weapons, barrel system, missile system, lethal effects, target destruction probability, guidance system.*

1. INTRODUCTION

With the development of the necessary technologies and techniques, that make it possible to approach of the ideal of "one grain for one goal", the human factor gains special importance in the outcome of armed combat, especially in frontal contact. Although the very term the high-accuracy weapons (HAW) is associated with the appearance of anti-tank submunitions, these weapons can to destroy targets of various types: mobile and stationary, large-sized and point-based, regardless of whether they are on land or water surface, in the air or under water. The high accuracy of hitting these assets is ensured by modern technical solutions and coupling with systems for: observation, guidance and destruction. The most common sensor systems for battlefield observation are television, thermal imaging, radar and laser sensors with high spatial resolution. They are mainly installed on satellites and/or platforms of aircraft, vessels and motor vehicles. Military geographic information and intelligence information of battlefield are also of great importance.

The representation of the HAW weapons and systems significantly contributes to changes in the form and methods of combat operations (c/o). Their application enables the destruction of objects of the interest (OI) both on the battlefield itself and in the areas of their concentration, in the depth of the territory. This combat technique becomes the main tool for the implementation of the deterrence strategy. This is due to the ability to respond quickly and precisely, directly to the elements of the enemy's development. The accuracy of hits is achieved based on previously set elements for shooting, and on the basis of varying trajectories, time and direction of impact, types and characteristics of selected ammunition. These ordnance also have the capability for selective destruction.

By perfecting of lethality ordnance (LO) with a cumulative effect, penetration are increased, and this led to new armoring techniques, starting from steel with increased resistance of the breakthrough and ending with complex laminar armors based on ceramic and composite materials. This progress led to the improvement of the LO using a double cumulative head, increasing the caliber of the means, the use of grains with a kinetic effect, and therefore a different tactical application of these means. All of this were increased the probability of hits, and by introducing sensors into the target acquisition process, the effectiveness of conventional weapons were increased, too. With the introduction of microprocessors in the missile flight manage system, a new class of the LO, known as "smart ammunition", has emerged.

Strategic responses using HAW against aggressors are completely different from those that involve the use of weapons of great destructive power, primarily based on nuclear explosive dispositives, and/or weapons of mass destruction, which includes other chemical agents and biological agents, too. It is important to emphasize that the strategy, which implies the application of a different spectrum of HAW, does not exclude the possibility of protecting one's interests and rights by using weapons of great destructive power.

Corresponding author: D. Knežević;
E-mail: dragan.knezevic@vti.vs.rs
DOI: 10.5937/OTEH24057K

2. ANALYZED CRITERIA OF LO

2.1. Classification of LO

1) Unguided LO
2) precision-guided LO:
   a) guided LO – correction of the projectile/missile's flight path is performed and a human is included in the control loop;

   b) self-guided LO (smart) – correction of the projectile/missile's flight path is performed automatically based on target detection, its acquisition and determination of target and projectile/missile movement parameters using sensors on the missile/missile, and
   c) fully automated self-guided LO (brilliant) - in addition to automatic detection, acquisition and definition of the necessary LO parameters for accurate hitting of the target, built-in algorithms define the way of activation and use of these weapons.

Self-guided LO (smart) can also be implemented as a submunition: with sensor igniter (MSU), with target detection (SMTD) and self-guided (SGM). Self-guided submunition with target detection can be implemented with a sensor igniter (SMSI) and with self-guidance in the final part of the trajectory (SMSGFPT).

2.2. Accuracy and precision of the LO

Achieving a high degree of accuracy and precision, from the various used weapons systems, it's of the utmost importance, if the aim is to transfer the effects of its LO to a specific target and hit nothing but the target. There are significant differences between indirect and direct fire weapon systems. In order to hit the target, it is necessary to know the exact positions of the target and the weapon. Also, before using any weapon system, it is necessary:
• for the selected weapon system to be configured, LO need to adapted to the size and type of the selected target,
• to adjust variables related to weather conditions, as well as
• to performe distancing and weapon alignment, among other factors.

In fig. 1, an illustration of the impact of systematic and random errors on precision and accuracy is given through the red circle, which represents the target area of action [1].

The accuracy of the hits indicates the degree of matching between the expected position of the mean value of the group of hits and the realized one. Accuracy, i.e. repeatability, represents the degree to which repeated hits under unchanged conditions show the same result. The illustration in Fig.1 also shows us that the elimination of systematic error improves the accuracy, but the precision does not change. If both accuracy and precision were achieved with the selected tool system and its LO, then we consider the applied weapon system with its LO as valid.

Weapon systems that use indirect fire (howitzers, mortars, unguided rockets, unguided aerial bombs, various cluster munition dispersal systems) on targets are designed with a natural dispersion in relation to the mean point of impact (MPI) of the applied LO (Fig. 1).

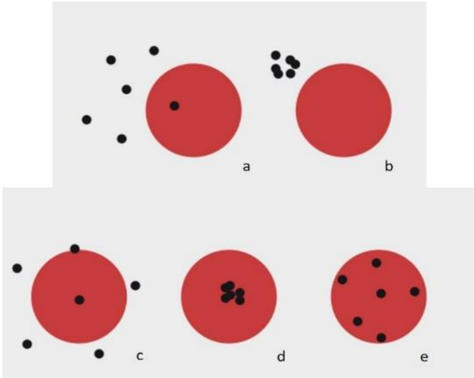

Figure 1. Illustration of the influence of systematic and random errors on the achieved precision and accuracy: a) low and accuracy and precision, b) low accuracy and high precision, c) high accuracy and low precision, d) high and accuracy and precision, e) high accuracy and optimal precision [1].

In these systems, accuracy refers to the weapon's ability to hit the desired MPI, while accuracy is a measure of the standard deviation from the MPI. For this purpose, the Circular Error Probable (CEP) was introduced to measure the accuracy of the weapon system. These calculations for determining the CEP of a weapon system are complex in terms of modeling, field testing, and statistical analysis of shot drop data under known conditions. A common approximation is the radius of the circle around the MPI, within which the impact points of 50% of the LO should be located. In practice, it is assumed that hits are achieved with an approximately normal distribution. In other words, this means that half of the ammunition fired, launched or thrown at the target would fall into the CEP of the weapon system, that is, 68% of the value is within the interval of plus-minus one standard deviation from the arithmetic mean; 93.7% will fall within twice the CEP radius, which corresponds to the case where 95% of the values lie within the interval of plus-minus two standard deviations; and 99.8% will fall within three times the CEP radius of the MPI, which corresponds to the case where about 99.7% of the values are within plus-minus 3 standard deviations (Fig.2). Clearly, a higher CEP indicates an increased uncertainty in the accuracy of the weapon system [1,2].

2.3. Lethality effect

Lethal effect will be considered as a criterion:
- estimated danger distance (RED, Risk-Estimate Distance) of suffering a lying soldier in winter clothes with a helmet during a 5-minute attack (physical incapacitation means that the soldier is physically unable to function in combat within a period of 5 minutes after the attack) at the value of the probability of incapacitation (PI, probability of incapacitation) less than 0.1%, i.e. less than 10%, and
- the degree of destruction of OI after the effect of LO is expressed in % [1,2]

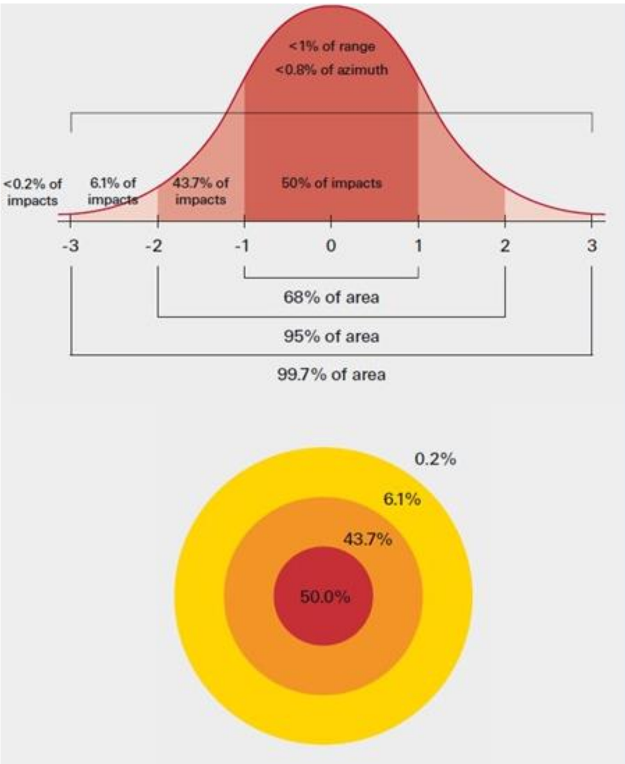

Figure 2. Error around MPI - Gaussian distribution and circular error probability (CEP) diagram [1].

2.4. HAW guidance systems

LO guidance refers to the various methods of guiding a missile/missile or guided bomb to a target. The accuracy of LO is a critical factor for its effectiveness. Guidance systems improve the accuracy of the LO by improving its guidance probability [2]. Guidance technologies can generally be divided into several categories: active, passive, preplanned and combined guidance. Projectiles, rockets and guided bombs generally use similar types of guidance systems, the difference between them being that projectiles follow a ballistic trajectory after being fired from the barrel of the weapon; rockets are propelled by an onboard motor, while guided bombs rely on the speed and altitude of the launcher aircraft for propulsion. They can also be categorized according to whether they are designed for static or dynamic purposes. With GOT (go onto target) the missile aims at both a moving and a fixed target, while with GOLIS (go onto location in space) the guidance system aims at a stationary (or almost stationary) target [3]. As a moving target can be an immediate threat to the missile launcher, its rapid elimination is necessary, while with the GOLIS system the problem is simpler due to the non-moving target.

The following ways of conducting LO are differenced:

Command guidance, when there is visual contact with the target, can be manual, semi-automatic or automatic. Semi-automatic guidance means that the tracking of the target is automatic, and the control and management of the missile is manual or vice versa. With the anti-aircraft defense system, we have command guidance beyond the visual field. In this case, the target seeker and the missile seeker can be oriented differently. The guidance system ensures target interception.

Proportional Navigation (PN), a guidance principle that dictates that the missile's velocity vector should rotate at a rate proportional to the line-of-sight rotation rate and in the same direction.

Активно радарско навођење, користи радарски систем на ракети да обезбеди сигнал за навођење.

Semi-active guidance uses a passive radar receiver on the missile and a radar target illuminator on the platform from which the projectile/missile is launched, or a laser receiver is used to guide the spot of the laser target illuminator.

Passive guidance uses either passive radar or detectors in the visible (VID) and infrared (IR) regions of the spectrum to detect the signature of the target being guided. Optoelectronic (OE) monitoring uses cameras in the appropriate part of the spectrum.

Retransmission guidance (TVM, Track via missile) is a hybrid command - semi-active - active radar guidance, in which the missile transmits the information of the reflected radar radiation of the target to the guidance station, which immediately transmits the corrected commands back to the missile.

We distinguish between self-directed LOs:
1. Fully autonomous systems, where the following stand out:
a) Pre-set guidance systems, before firing/launching, where based on information about the distance and direction of the target, the flight path is determined and programmed in the missile guidance system, which during the flight maneuvers the missile according to the defined trajectory without external information (uses its integrated accelerometers or gyroscopes), and
b) Inertial navigation systems (INS), which continuously receive incoming signals from sensors of translational motion, accelerometers, and rotational motion, gyroscopes, and based on them software calculates the necessary parameters of navigation in real time and compares the obtained results in relation to the reference or new spatial position ordnance in space.
2. Systems dependent on the nature of external sources (astronomical, astro-inertial, Earth's surface - topographical or photographic maps, magnetic), where the following stand out:
a) Astro-inertial navigation, which serves to correct small errors in determining position and speed resulting from the uncertainty of launch conditions in the submarine navigation system and errors accumulated during flight due to imperfect instrument calibration. It is used in submarine-launched ballistic missiles that do not have a stationary launch point, unlike silo-based intercontinental ballistic missiles.
b) Navigation according to the contour of the terrain, or topographically, (TERCOM, terrain contour) based on height maps of the country belt, or via a full 3D map, enables the management of the complex route of the missile from the launch site to the target. The correction of this data is done on the basis of assigned surveillance radar altimeters that track the missile during flight or by

using the Global Positioning System (GPS) or the Digital Scene Matching Area Correlator (DSMAC), photographically, which it uses a camera to monitor the terrain, digitize and compare the images with the stored scenes in the computer of the base station that guides the missile to the target.

3. Systems dependent on artificial sources in which we distinguish:

a) Satellite navigation systems: GPS and GLONASS (Global navigation satellite system), and

b) Long-range hyperbolic navigation systems, such as: Decca, LORAN, Omega, Chayka, Alpha.

3. ANALYZED SYSTEMS ACCORDING TO SELECTED CRITERIA LO

HAW of the weapons with the tube system caliber up to 30 mm are achieved by remotely controlled gyrostabilized weapons systems, which, in addition to the basic armament, are also equipped with a suitable system for target acquisition and fire control. They are installed on ground combat vehicles or on combat platforms of vessels and aircraft. These systems use unguided LO and weapons elements for firing are picked out directly.

HAW of the weapons with the tube system caliber up to 125mm, which by direct fire achieve hits on the target with unguided ammunition (e.g. a tank, with an optoelectric day-night aiming device), have a CEP≤1.1m. The same CEP values are achieved with pipe systems whose projectiles are guided by the laser beam.

In the case of multi-barrel HAW systems, using the example of the 122mm Grad missile, the lethal surface is about $700m^2$ for each high-explosive warhead that detonates upon impact with the ground, which corresponds to the surface of a circle with a radius of 15m. It should be taken into account that only the detonation of one missile warhead is considered here; when a beam of rockets hits one area, there is usually an overlapping of lethal areas. For the lethal area of the 122 MM 9M22 rocket, the probability of incapacitation at a distance of 15m from the detonation point is 36%. Modern multi-barrel high-accuracy rocket systems M270 (MLRS, Multiple Launch Rocket System) on tracks and M142 (HIMARS, High Mobility Artillery Rocket System) on wheels fire rockets: M57 with CEP≤9m, M30/M31 with CEP≤10m (GPS guidance CEP≤5m). The M30/M31 rockets can be adjusted to operate above the ground from 3m and 10m. Modern multi-barrel HAW systems have the possibility of individual selection of the impact point of the system's effect zone [3,4,5].

A comparative view of the estimated distance of the danger of injury to a lying soldier from the effects of a mortar, tank and artillery projectile, a 122mm rocket, a classic MK 82 bomb and a cruise missile is shown in table 1.

Table 1 Comparative view of the estimated distance of the danger of injury to a lying soldier [1,2,4]

Lethality Ordnance	RED 10	RED 0.1
80mm mortar projectile	80m	175m
120mm mortar projectile	100m	400m
120mm tank gun projectile	90m	250m
122mm artillery rocket	150m	500m
152/155mm art. gun projectile	125m	450m
MK 82 bomb230 kg	250m	425m
Tomahawk cruise missile	80m	200m

The advantage of HAW on the example of the MK 82 bomb shows that with the unguided variant CEP≤94.5m, and with the guided variants: CEP≤1.1m with laser guidance, CEP≤5m with GPS and inertial guidance, CEP≤30m if the GPS guidance has jammed signal on trajectory and CEP≤1.1m when using the combined GPS-inertial-laser guidance method.

A comparative representation of circular fire deviation (CFD) accuracy is shown for several different air-to-ground HOWs in Table 2.

Table 2. Comparison of CFD accuracy [5]

Lethality Ordnance	CFD accuracy	SGH
AGM-65, Maverick,	2,5m	TI, TV, LR
Martel	3m	TV
AGM-84H/K SLAM-ER	2,5m	TI, GPS, 2wdt
ALARM	6-9m	-

SGH – self-guided head
TI - thermal imaging
TV - television
LR - laser receiver
2wdt – two-way data connection

A comparative presentation of the probability of a hit for several different HAW air-ground is shown in Table 3.

Table 3. Comparison display of accuracy with hit probability [5]

Lethality Ordnance	hit probability	SGH
Панцирь-С1,	1 rocket, p≥0,92	I, radar
Roland	1 rocket, p≥0,92	radar
С-300В	2 rockets, p≥0,96	radar
MIM-104 Patriot	2 rockets, p≥0,96	radar

Mines with a sensor fuze are a specific the HAWs intended for anti-armor combat at short distances, with blocking narrow passages in the most likely directions of enemy armoured fighting vehicle. The sensor module of these devices uses several different sensors: IR, acoustic, seismic, active electromagnetic. The best results are obtained by using multiple sensors simultaneously. The average target detection range is about 100m. These sensors enable automatic observation of the area of effect and determination of movement parameters and target position during the programmed time of mine activity. Two secondary modules are also often used: a module for manually programming the mine's activity time and a module for protection against unwanted mine reuse.

4. LO WITH SMART SUBMUNITION

Submunition with target detection is a high-precision munition intended to destroy hard, point and armored targets at long distances with the aim of disorganizing, slowing down or breaking the concentration of armored vehicles in the depth of the combat deployment (II and III echelon) or in the waiting area (collection zone). It makes it possible to carry out anti-armor combat at long distances with an effect on the upper surface of armored vehicles, which are the least protected by armor. These systems use a large number of different sensors at different levels and efficient systems for transmitting and processing information. Application of the "smart" system of submunitions in c/o implies the following:

- Detection and tracking of targets at the depth of the enemy's combat deployment (up to 100 km);
- Reliable and fast (in real time) transmission of intelligence data in sufficient volume to make a decision on the use of SMTD;
- Quick processing of intelligence data, decision-making for use;
- Launching of carrier missiles (dispensers) from HAW that ensures accurate delivery of dispensers to the target area;
- Distribution (discharge) of SMTD ensures sufficient coverage of the target area with a satisfactory density of action on it;
- Use of target detection sensors on submunitions for target selection, missile flight control and lethal effect of OI.

Submunitions are intended for impact on the upper surface of the target, which is usually the weakest protected by armor. The lethal effect on the target is achieved by cumulative jet (SMSGFPT), kinetic grain (Mishay-Shardin effect) and destructive effect..

Focusing of the jet of combustion products during the combustion of the explosive charge, a primary cumulative jet with a temperature of about 3.000 ºC is formed in the focal point, which spreads at a speed of about 10,000 m/s. After breaking through the armor due to melting by this jet, its effect on the living force inside the armor continues with increased pressure and causing explosive fire.

A kinetic grain is formed by an explosion behind a specially shaped disk, after which that disk is transformed into a projectile with an initial speed of more than 2000m/s. The mechanical destruction of the obstacle occurs due to the high speed (kinetic energy), shape and material of the projectile thus formed. For the optimal condition for the reshaping of the disk and the effect on the target, the activation of the warhead must be ensured at a distance of about 1000 caliber projectiles.

The destructive effect of submunitions is a backup variant of the lethal effect, if the conditions for the basic cumulative effect or kinetic grain effect are not met. Depending on the design of the warhead, this effect can disable armored vehicles by contacting through vehicle openings and acting on external sensor subsystems..

5. WEAPONS OF MASS DESTRUCTION AT THE BASE OF NED[1]

A fission weapon is a weapon whose explosive contribution is based solely on the fission reaction (often referred to as an atomic bomb or A-bomb). In common types of such weapons, the explosion reaches a power of about 1kT to 500kT (the power of a nuclear explosion is measured by the equivalent of the classic TNT explosive and is expressed in kilotons - kT). This weapon can be employed using large caliber barrel systems.

A thermonuclear weapon, fusion weapon or hydrogen bomb (H bomb) consists of two main components: a primary nuclear fission stage (fueled by ^{235}U or ^{239}Pu) and a secondary nuclear fusion stage. Thermonuclear fuel is used for nuclear fusion: heavy isotopes of hydrogen (D, i.e. ^{2}H and T, i.e. ^{3}H) as a pure element or in modern weapons LiD (lithium deuteride). A fusion explosion begins with the detonation of the primary fission stage. The distance separating the primary and secondary assembly ensures that fragments of debris from the primary fission (which move much slower than X-ray photons) do not tear the secondary assembly apart before the explosive fusion process is fully completed. During the secondary stage of fusion, the nuclear effective cross section[2] increases. In modern weapons, lithium deuteride is used for fuel, so that the tritium component of the thermonuclear fuel is provided in collisions of free neutrons, emitted from the fissile plutonium explosive mixture, with lithium nuclei. The case of the thermonuclear weapon is also made of fissile material, in order to achieve a second fission with fast thermonuclear neutrons. Those bombs are classified as two-stage weapons (fission-fusion-fission). The rapid fission of the tamper case and radiation make the biggest contribution to obtaining radioactive fission products. The tamper is a layer of dense material surrounding the fissile material. It serves to reduce the critical mass of nuclear weapons and to delay the spread of the reacted material by keeping it longer in a supercritical state due to its inertia. This material also serves as a neutron reflector. In common types of such weapons, the explosion reaches a power of 50kT to 10MT.

A neutron weapon is a low "yield" thermonuclear weapon. It is projected that during the complex development of the thermonuclear phase of the reaction, the neutron effect in the area of the explosion will increase compared to the effect of the blast wave[3]. Projectiles with this tool are also used tactically with 155mm and 203mm tube systems, due to more effective armor penetration than conventional warheads (they pass through concrete, iron, earth, lead, human body). In common types of such weapons, the explosion reaches a power of 1kT to 20kT. When the power is greater than 10 kT, the radius of the lethal blast and thermal effect begins to exceed the radius of the lethal ionizing radiation. If a

[1] NED, nuclear explosive dispositives

2 The concept of a " nuclear cross section" of the order of 10^{-28} $m^2 = 10^{-24}$ cm^2 or 100 fm^2, where a larger surface area indicates a higher probability of interaction. Total cross-sections refer to overall interaction processes, and for specific processes, such as elastic and inelastic scattering, in addition to neutron cross-sections, absorption cross-sections are of particular importance.

[3] Thus, it was achieved that the lethal radius of the neutron effect was greater than the radius of the explosion itself. Prompt neutrons created in this process quickly leave the further reaction, so that a large wave of prompt neutrons is obtained.

neutron weapon is designed for an anti-ballistic missile, the role of prompt neutrons after the explosion is to cause partial fission of nearby warheads and thus prevent the proper explosion process. The radius of the maximum distance from the dynamic target is about 100m.

A cobalt bomb is a nuclear weapon designed to radioactively contaminate a large area through radioactive fallout. Cobalt in the housing of this device, after the secondary phase of the thermonuclear reaction, interacts with prompt neutrons and changes to its isotope ^{60}Co [4], and then to its gas phase through atmospheric condensation. Contamination is achieved by extreme radioactive fallout, which falls to earth along with residual cobalt debris.

A radiological bomb (or dirty bomb) combines conventional explosives and radioactive material. These means are used for radioactive dispersal of NED and contamination of as large an area as possible. Contamination over a large area can also be achieved by using depleted uranium ammunition.

6. DEVELOPMENT TRENDS

For the purposes of analysis and development of the HAW systems, it is necessary to possess a powerful intellectual potential for the development of high-precision control systems and drives for weapon systems in the areas of: control systems, information technologies, precision mechanics, optics, electronics, hydraulics and computer technologies.

On the other hand, for the development, synthesis, integration and production of high-precision tools, it is necessary to master knowledge and dispose of technologies for the development or integration of the following subsystems and systems: inertial control systems and correlation-extreme guidance systems for aircraft, electric and electro hydraulic control and servo drives of different powers, optical-electronic systems, remote control systems, computer systems and their software, stationary and mobile automated complexes for receiving, interactive processing and transmission of video information, and multifunctional amplitude precise digital angle converters..

7. CONCLUSION

Compared to HAW, NED-based LO cover large areas and have a longer duration of action over them. From the point of view of the accuracy, NED-based weapons have significantly less limitations. If these assets are used as mines or as part of tactical LO, they can certainly be included in HAW.

In weapons with the tube system using unguided LO and bombs with sensor guidance achieve CEP≤1,1m.

Multiple rockets launchers of the HAW systems are characterized by the ability to adjust the effect above the ground up to 3m, as well as the selection of the point of impact of an individual projectile in the system's effect zone. Greater lethality is achieved with systems with a vertical or near-vertical attack path.

The high accuracy of missile systems was also achieved thanks to precise sensor systems for acquisition, software tools for precisely defined movement trajectory and flight control to the point of encounter with a dynamic target or the point of falling on a stationary target, as well as sensors for the most favorable assumption of LO activation in the close vicinity of the target.

Analyzing the LO effects on the target, the application of mines gives the highest accuracy, because they can always be placed in the selected position, and the corresponding LO effects can always be adjusted in relation to the preset time and space of the target's appearance in the waiting zone.

Analyzing the effects of lo on the target, the application of mines gives the highest accuracy, because they can always be placed in the selected position and the appropriate effects of LO can always be adjusted in relation to the time and spatial assumption of the appearance of the target in the waiting zone. The placement of mines makes it easier to achieve a horizontal effect, and their modular construction enables quick assembly and simple masking.

In ground systems, submunitions are used in shells of large-caliber tube systems (H155mm and H203mm).

For the development of the HAW system, in addition to intellectual potential, it is necessary to master knowledge and dispose of technologies for the development or integration of modern optoelectronic and inertial sensor systems, as well as other automated controllable systems for guiding and correcting the path for the LO.

References

[1] GICHD: *Explosive weapon effects – final report*, Geneva, February 2017

[2] JAMES N. C.: *Fundamentals of Strategic Weapons: Offense and Defense Systems*, Volume 1, Martinus Nijhoff Publishers, HaGUE/Boston/London, 445 pages, 1981.

[3] PAUL Z.: Tactical *and Strategic Missile Guidance*, Sixth Edition, Progress in Astronautics and Aeronautics, Vol 239, 2012.

[4] PROJECT OF ALSA: *Multi-Service Tactics, Techniques*, Procedures For The Joint Application Of Firepower, USA, 2007

[5] ГОЛОВИН С. А. И ДР: *Высокоточное оружие и борьба с ним*, Изд-во“Б.П.К“, 1996

[4] This isotope is a strong emitter of gamma radiation with a half-life of 5.26 years. Comparing the gamma radiation of the fission products of the equivalent uranium bomb in the outer shell after one year, the radiation of ^{60}Co is 8 times stronger than the fission products of uranium, and after five years 150 times stronger.