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VERSION OF LOITERING MUNITIONS CLASSIFICATION BASED ON THE STATE-OF-THE-ART AND TRENDS ANALYSIS

At present, objects of the rocket and space industry and strategic nuclear forces of the leading countries of the world, as well as other expensive infrastructure objects, can be attacked by air attack units belonging to the newest class of weapon — loitering munitions. This type of weapons combines low cost and easy development and production, which makes them available for illegal armed formations and the conduct of hybrid warfare. According to their design features and performance characteristics, loitering munitions occupy a place between cruise missiles and unmanned aerial vehicles.

To analyze the threats from this type of weaponry to objects of the rocket and space industry and other sectors of the economy and to determine potential countermeasures, a version of classifying modern and future loitering munitions is proposed based on their operating range and typical destruction objectives. Specifically, loitering munitions can be divided into anti-aircraft munitions and munitions to target ground objectives. The latter category is additionally divided into tactical, medium-range, and long-range loitering munitions. Technical features, typical munitions and development trends are given for each category of loitering munitions. The dependence of the loitering munition warhead mass on the launch mass was studied, and the effect of the installed engine type was shown. The dependence of the main engine type on the loitering munition category is identified, which is a determining factor that forms the configuration and performance characteristics of a munition.

An analysis of modern armed conflicts shows that loitering munitions are gaining more and more importance for successful accomplishment of combat missions. It is shown that depending on the enemy, nature of hostilities, technological and economic capabilities of the parties to the conflict, loitering munitions of different categories can be used. Examples are given of the prominent role of loitering munitions in such conflicts as the current conflict in Yemen and the recent war in Nagorno-Karabakh.

Based on the proposed classification of loitering munitions and the experience of their tactical employment in armed conflicts of the 21st century, a vision was formed for the development of loitering munitions for the Armed Forces of Ukraine.

Keywords: *loitering munitions, operating range, armed conflict.*

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INTRODUCTION

The experience of local armed conflicts of the 21st century, measures for the development of the armed forces, as well as the views of the military leadership of leading countries on the preparation and conduct of hostilities testify to the growing role of complexes with unmanned aerial vehicles (UAV) of various types and applications. Attack and multi-purpose UAVs, which, in addition to reconnaissance, are capable of destroying enemy targets, are becoming more and more essential. Among the aircraft of this category, kamikaze UAVs are widely used, equipped with a warhead and reconnaissance and surveillance equipment. Thanks to the ability to stay in the air for a long time while waiting for the moment to strike, the UAVs of this class were named "loitering munitions" (LM).

The most vivid examples of massive and coordinated use of the attack UAVs are the Second Karabakh War, where up to 39 % of all targets destroyed by the Armed Forces of Azerbaijan were accounted for by these means of air strike, as well as the war in Yemen, during which the Yemeni rebels carried out a series of strikes on military bases, airfields, oil production facilities and oil refineries using loitering, probably Iran-made munitions.

The start of the development of loitering munitions in Ukraine is connected with the anti-terrorist operation in the east of Ukraine. Specialists of the State Research and Testing Center of the Armed Forces of Ukraine, jointly with Pershiy Kontakt LLC, conducted research tests of domestic loitering munitions [10]. A particularly urgent task today, after the start of the full-scale invasion, is to identify the priority areas of development of this type of weapon.

PROBLEM STATEMENT

Before giving practical recommendations for the development of a line of domestic loitering munitions, it is advisable to analyze existing and future world counterparts, their typical use in armed conflicts, and identify the principal global trends in the development of this class of aircraft.

PRESENTATION OF THE MAIN MATERIAL

Loitering munitions (LM) are a relatively new class of weapons that have occupied an intermediate niche between cruise missiles (CM) and unmanned aerial vehicles (UAV). A comparison of the above classes of weapons is shown in Table 1.

At the same time, the tendency of blurring the lines between the above classes of weapons can be mentioned. Tomahawk and Deliah cruise missiles can loiter in the target area with a target change, with information transmitted via Link 16 tactical data transmission network. In addition, some UAVs that used to be reconnaissance are now equipped with a warhead (for example, Orbiter-1K). LMs with long flight duration can be used to transmit data before attacking a target.

Modern LMs can be divided into the following categories according to their operational range:

- Tactical (up to 50 km);
- Medium range (from 50 to 150 km);
- Long range (over 150 km).

Infantry units at the platoon-company level and special forces are equipped with tactical loitering munitions. As a rule, this type of LMs is launched manually or from launch containers, which are transported by the personnel. In addition, tactical LMs can be installed on off-road passenger cars, combat boats, and aircraft. Some tactical LMs (Lancet, RAM UAV, etc.) are launched from a catapult. Tactical LMs are characterized by low cruising speed and short flight duration (not more than 2 hours), which is ensured by electric motors and low-capacity on-board power sources. The development of tactical LMs is aimed at

Table 1. **Comparison of cruise missiles, loitering munitions, and unmanned aerial vehicles**

Weapon class	Warhead	Return and reuse	Loitering capability	Flight controllability	Cruising speed	Target search and acquisition
CM	yes	no	no or limited	no or limited	>750 km/h	terminal phase
LM	yes	rarely	yes	yes	100 to 150 km/h	whole flight
UAV	no	yes	yes	yes	100 to 900 km/h	whole flight

Figure 1. LM Switchblade 300 configuration

Figure 2. LM Hero-120 configuration

Table 2. **Basic specifications of tactical LMs**

Name	Manu-facturer	Length, m	Wingspan, m	Launch mass, kg	Warhead mass, kg	Altitude, m	Flight velocity, km/h	Operational range, km	Time of loitering, min
Green Dragon	Israel	1.6	1.7	15	3	n/a	up to 185	40—50	90
Hero 30	Israel	0.8	0.5	3	0.5	up to 3100	100—160	5—40	30
Hero 70	Israel	1	0.565	7	1.2	up to 3100	100—150	40	45
Hero 120	Israel	1.5	0.85	12.5	3.5	up to 3100	100—120	40	60
Rotem L	Israel	n/a	n/a	4.5—6	0.9—1.2	n/a	up to 100	10	45
Switchblade 300	USA	up to 0.61	n/a	2.5	0.23	152	102—161	10	15
Switchblade 600	USA	n/a	n/a	23	n/a	200	112—185	40	40
Coyote	USA	0.9	1.5	5.9	0.9	n/a	102—130	n/a	up to 120
CH-901	China	1.2	1.5	9	2.7	up to 1500	70—120	15	up to 120
RF-70	China	0.885	n/a	7	1.5	up to 5000	108—144	10	60
RF-90	China	1.07	n/a	10	3	up to 5000	108—144	up to 15	60
RF-200	China	1.86	n/a	20	4.5	up to 5000	100—126	up to 30	120
BG-201 v.1	China	0.739	n/a	3.5	0.5	n/a	108—144	10	30
BG-201 v.2	China	1.069	n/a	9	1.5	n/a	108—144	10	30
S570	China	n/a	n/a	7	n/a	n/a	n/a	10	25
KUB-BLA	Russia	0.95	1.2	n/a	3	n/a	up to 130	n/a	30
Lancet-1	Russia	n/a	n/a	5	1	n/a	80—110	40	30
Lancet-3 v.51	Russia	n/a	1.65	n/a	5	n/a	up to 110	40	40—60
Lancet-3 v.52	Russia	n/a	n/a	12	3	n/a	80—110	40	40
Kargu	Turkey	0.78	0.78	6.285	1.3	500	72	5	15
ALPAGU	Turkey	n/a	n/a	3.7	1.3	125	92—120	5—10	10—20
Warmate	Poland	1.1	1.6	5.3	1.4	100—500	50—150	12	50
Warmate 2	Poland	n/a	n/a	30	4.8	200—500	up to 150	20	120
Meraj-521	Iran	n/a	n/a	n/a	0.5—1	n/a	n/a	5—10	5—15
HRESH	Armenia	n/a	n/a	7	1.6	1000	n/a	20	n/a
Enrol Pilot	Indonesia	n/a	1.2	3	0.8	n/a	up to 250	40	20
RAM UAV	Ukraine	1.78	2.3	8	up to 3	n/a	70	up to 30	up to 40
RAM II	Ukraine	1.45	2.584	9.8	3	n/a	70	30	up to 60
ST-35 Thunder	Ukraine	n/a	n/a	9.5	3.5	800—1200	120—140	30	up to 60
UJ-31/32	Ukraine	n/a	n/a	n/a	up to 2	n/a	120	20	up to 30

Figure 3. LM Ababil-T configuration

Figure 4. LM Shahed-136 configuration

Table 3. **Basic specifications of medium-range LMs**

Name	Manufacturer	Length, m	Wing-span, m	Launch mass, kg	Warhead mass, kg	Altitude, m	Flight velocity, km/h	Operational range, km	Time of loitering, h
Mini Harpy	Israel	2.5	2.9	40	8	up to 1500	102—370	100	2
Orbiter-1K	Israel	1	2.2	10.3	up to 2.5	up to 3100	up to 140	up to 100	3
Sparrow	Israel	2.14	2.44	45	up to 12	n/a	up to 185	up to 120	up to 6
Hero 250	Israel	1.8	1.2	25	5	up to 4100	100—120	up to 120	3
Hero 400	Israel	2.2	1.5	40	8—10	up to 4100	100—120	up to 120	4
Jackal	USA	n/a	n/a	n/a	4.5	n/a	~480	100	0.25
Fire Shadow	Great Britain	4	n/a	200	100	up to 4600	150—300	100	up to 6
WS-43	China	3.421	2.1	60	20	n/a	370	up to 60	0.5
CM-501X/G	China	2	n/a	100—150	8—40	n/a	up to 980	up to 70	up to 0.5
Ababil-T/Qasef	Iran	2.88	3.25	up to 90	up to 30	3000	250—305	120	1.25—2
Raad-85	Iran	2.91	3.8	up to 85	up to 15	3350	25	100	1.5

Table 4. **Basic specifications of long-range LMs**

Name	Manufacturer	Length, m	Wing-span, m	Launch mass, kg	Warhead mass, kg	Altitude, m	Flight velocity, km/h	Operational range, km	Time of loitering, h
Harpy	Israel	2.7	2.1	125	32	up to 3000	185—250	400—500	2—3
Harop	Israel	2.5	3	135	16—23	up to 4600	up to 417	up to1000	6
Harpy NG	Israel	n/a	n/a	160	15	n/a	up to 417	up to 1000	9
Hero 900	Israel	2.5	1.8	97	20	up to 4100	100—120	up to 250	7
Hero 1250	Israel	n/a	n/a	125	30	n/a	n/a	200+	10
LOCAAS	USA	0.91	1.18	39	7.7	230	370	185	up to 0.5
Gremlin	USA	4.2	3.47	680	up to 65.7	up to 12000	650	up to 556	up to 3
ASN-301	China	2.5	2.2	135	n/a	n/a	up to 220	280	4
Kargi	Turkey	n/a	n/a	n/a	n/a	n/a	n/a	up to 1000	6
Chien Hsiang	Taiwan	1.2	2	n/a	n/a	n/a	185	up to 1000	5
N/a	Armenia	n/a	2.88	n/a	10 – 12	up to 4000	n/a	500	n/a
Samad-2	Yemen	2.8	4.5	87,5	18	n/a	150—250	1000—1200	up to 7
Samad-3	Yemen	2.8	4.5	107.4	18	n/a	150—250	~1500	up to 13.5
Arash/Arash-2	Iran	4.5	4—4.5	n/a	n/a	n/a	n/a	1000 – 2000	7—8
Shahed-131 (Geran-1)	Iran	2.6	2.2	135	15	n/a	n/a	up to 900	n/a
Shahed-136 (Geran-2)	Iran	3.5	2.5	200	36—50	n/a	up to 200	up to 2000	~10

further reduction of mass, dimensions, and cost. It is also possible to distinguish two subclasses of tactical LMs, viz. anti-personnel ultra-light LMs with high-explosive fragmentation warheads weighing up to 1.5 kg (Type 1, for example, Switchblade300, Rotem L) and LMs for hitting lightly armored vehicles with a warhead weighing up to 4 kg (Type 2, for example, Hero-120, Lancet-3, ST-35). Overall configurations of typical Type 1 and Type 2 tactical LMs are shown in Figs. 1, 2. Table 2 shows the basic specifications of tactical LMs.

Medium-range loitering munitions can be used for both direct support to military units and destroying enemy targets in the depth of defense. Medium-range LMs are placed on land, at sea, and on various aviation platforms. Electric motors and piston engines are usually used as propulsion in such LMs; some LMs feature turbojet engines (WS-43, Jackal). Turbojet and, to a lesser extent, piston engines provide a higher cruising speed and can supply power to onboard electrical equipment (if a built-in generator is available); however, they are less easy to operate and increase the LM acoustic and thermal visibility. As a rule, such engines are used for LMs with a significant launch mass (~50 kg and more). The development of medium-range LMs is aimed at improving flight and performance characteristics, payload modularity, and improving control and guidance systems. A configuration of a typical medium-range LM is shown in Fig. 3. The basic specifications of medium-range LMs are shown in Table 3.

Long-range loitering munitions are designed to hit particularly important targets in the depth of the enemy's defenses. Thanks to long flight duration and autonomous target detection and capture equipment placed on board, this class of LMs can stay in a patrol area for a considerable time and hit targets such as components of long-range air defense systems and short-range ballistic missile systems, as they are advancing and deploying at firing points; aircraft on open tarmacs; communication, command, and control facilities; administrative institutions, infrastructure objects, etc. Today, three design schools can be distinguished: Israeli, American, and Iranian. Israeli LMs are placed on ground launchers and equipped with piston engines. Harpy/Harop LMs were actively exported to different countries [4], some of which developed their unlicensed copies (ASN-301, Kargi). Long-range LMs developed in the United States are aircraft-based and equipped with turbojet engines. A separate area of development is long-range LMs developed in Iran or with Iran's assistance. Like the Israeli munitions, they are equipped with piston engines and launched from a ground launcher, but they do not have a guidance system in the terminal flight phase; their targets are stationary objects whose coordinates are set before launch or transmitted in flight from an external reconnaissance device. According to the tactical employment profile and performance characteristics, these LMs can be compared with long-range cruise missiles; however, they have a much lower speed (up to 200 km/h). The improvement of long-range LMs is aimed at increasing the maximum flight range, time of loitering, and warhead power. A configuration of a typical long-range LM is shown in Fig. 4. The basic specifications of medium-range LMs are shown in Table 4.

Figure 5. LM 358 configuration

A rather promising area is the development of anti-aircraft missile systems based on loitering munitions to counter low-speed aircraft (primarily UAVs). A representative of this LM class is Coyote Block2, used as part of the M-ATV-based air defense system. The Coyote Block2 LM has a range of about 15 km, other characteristics are unknown. This type of weapon also includes an Iranian anti-aircraft loitering missile, which is designated as "358" according to the U.S. classification. This LM has a 10-kg warhead and an approximate range of 150 km. A feature of these anti-aircraft LMs is the use of a turbojet as the main engine, which provides high subsonic speed. The prospects for the development of this class of LMs are the expansion of the range of targets and the improvement of flight and performance characteris-

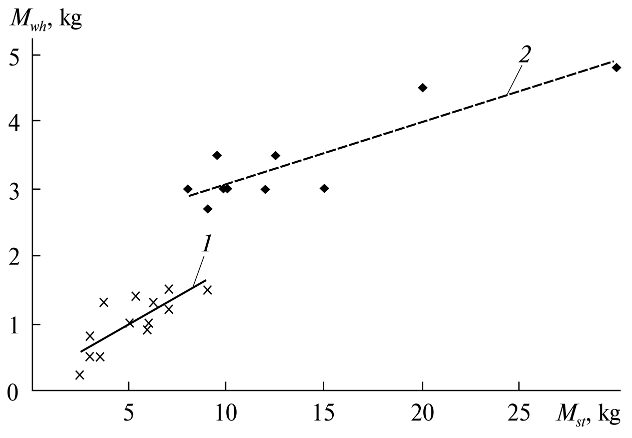

Figure 6. Dependence of warhead mass on launch mass for tactical loitering munitions (curve *1* is for Type 1 tactical LMs, curve *2* is for Type 2 tactical LMs)

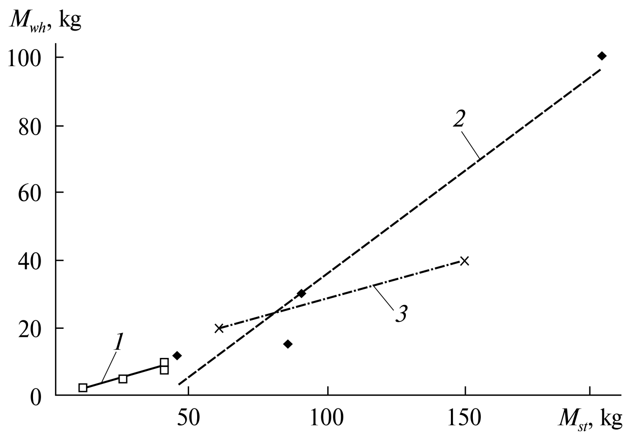

Figure 7. Dependence of warhead mass on launch mass for medium-range loitering munitions (curve *1* is for medium-range LMs with an electric motor, curve *2* is for medium-range LMs with a piston engine, curve *3* is for medium-range LMs with a turbojet)

tics. A configuration of a typical anti-aircraft LM is shown in Fig. 5.

Based on the analysis of the available characteristics of loitering munitions, dependences of the loitering munition warhead mass on the launch mass were made. Fig. 6 shows the dependence for tactical loitering munitions. A clear division between Type 1 and Type 2 LMs can be seen, which is due to the deployment of a rather powerful warhead to destroy armored targets by Type 2 tactical LMs. Fig. 7 shows this dependence for medium-range loitering munitions, indicating the type of main engine. It can be seen from Fig. 7 that the nature of the dependence is approximately the same for LMs with any type of engine, but using an electric motor is advisable for loitering munitions with a launch mass of not more than 50 kg. Fig. 8 shows the dependence for long-range LMs. It can be seen from the Figure that LMs with piston engines have a slightly higher relative warhead mass, which is compensated by a lower cruising speed. Since the main engine type has a significant impact on the LM characteristics, its dependence on the LM type was compiled in accordance with the proposed classification. This dependence is shown in Fig. 9.

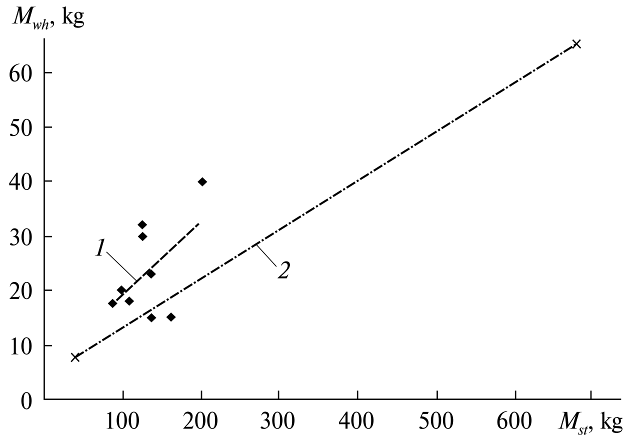

Figure 8. Dependence of warhead mass on launch mass for long-range loitering munitions (curve *1* is for long-range LMs with a piston engine, curve *2* is for long-range LMs with a turbojet)

The LMs have been widely used in armed conflicts of the 21st century (in Afghanistan, Libya, Syria, Yemen, Nagorno-Karabakh, and Ukraine). In Afghanistan, the U.S. Army used mostly light tactical LM Switchblade 300 [3], which was determined by the existing threat, i.e., personnel on unarmored vehicles.

Using LMs by the Government of National Accord, supported by Turkey, was reported during the civil war in Libya. Fragments of Kargu tactical LMs, which were used against the enemy, were discovered, and long-range Harpy LMs were also probably used to defeat the Pantsir-S anti-aircraft missile defense system [2].

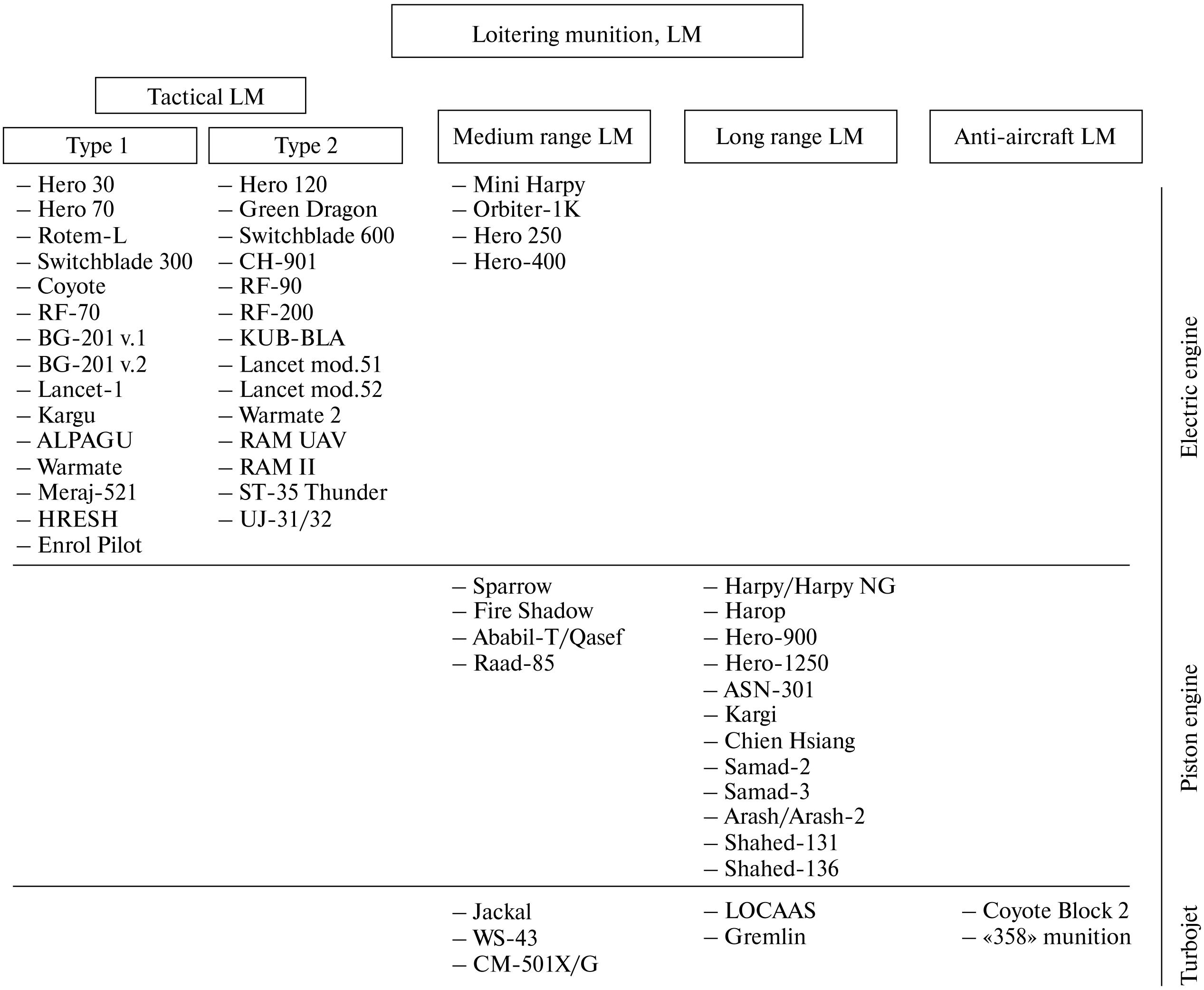

Figure 9. Dependence of main engine type on loitering munition category

The civil war in Syria led to the intervention of the armed forces of the United States, Israel, Turkey, the Russian Federation, and Iran, most of whom used LMs [8]. In particular, the United States, Turkey, and the Russian Federation used tactical LMs, Switchblade 300, Kargu, and Lancet-3, respectively, to destroy personnel and vehicles, while Israel used an unspecified type of LMs to destroy enemy air defenses.

During the civil war in Yemen, the Houthi rebels used LMs supplied by Iran. Medium-range (Qasef) and long-range (Samad-2/3, Shahed-131) LMs are used, their principal targets being infrastructure objects and stationary and mobile military facilities [1, 6]. In addition, LM “358” is used to defeat MALE-class UAVs [7].

In Nagorno-Karabakh, LMs were first used in 2016, but the massive use started during the Second Karabakh War. The Armed Forces of Azerbaijan used a large number of tactical (Kargu, SkyStriker), medium-range (Orbiter-1K), and long-range (Harop) LMs [5], which hit at least 48 different targets (mainly armor and vehicles). The Armed Forces of Armenia episodically used HRESH tactical LMs, mainly targeting personnel.

During the Russian invasion of Ukraine, LMs were used by both sides. The Armed Forces of Ukraine use tactical LMs (Switchblade 300, Warmate, RAM II, etc.) to destroy enemy personnel and equipment and improvised long-range LMs, based on civil-use UAVs, for strikes on infrastructure objects. The Armed Forces of the Russian Federation use tactical LMs (KUB-UAV, Lancet-1/3) to destroy equipment and long-range LMs (Shahed-131/Gheran-1, Shahed-136/Gheran-2) to destroy infrastructure objects [9, 11].

CONCLUSIONS

The analysis of the LMs' basic specifications, development trends, and features of tactical employment in armed conflicts showed that it is important for the Armed Forces of Ukraine to have a line of LMs of different classes to perform the following missions:

- Hit personnel and unarmored equipment (Type 1),
- Hit lightly armored and armored vehicles, howitzers, etc. (Type 2),
- Hit infrastructure objects and military facilities in the depth of defense (Type 3),
- Hit airborne targets (Type 4).

The needs of the Armed Forces for Type 1 LMs can be accommodated by Switchblade 300 and Warmate, for Type 2 LMs, by Switchblade 600, RAM UAV, RAM II, ST-35 Thunder, etc. Loitering munitions converted from civil-use UAVs (e.g., Mugin-5 Pro) are currently used as Type 3 LMs. In addition, the domestic military-industrial complex is developing special-purpose Type 3 LMs with a range of up to 1000 km. At the same time, Type 4 LMs are not currently in service nor being developed, although their use would provide a significant increase in the capabilities of the Air Defense Forces to hit low-speed airborne targets, such as reconnaissance UAVs, medium-range and long-range LMs, helicopters.

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ВАРІАНТ КЛАСИФІКАЦІЇ БАРАЖУВАЛЬНИХ БОЄПРИПАСІВ НА ОСНОВІ АНАЛІЗУ СУЧАСНОГО СТАНУ ТА ТЕНДЕНЦІЙ РОЗВИТКУ

У теперішній час об'єкти ракетно-космічної галузі та стратегічних ядерних сил розвинених країн світу, як і інші дороговартісні об'єкти інфраструктури, можуть зазнати атак засобами повітряного нападу, що належать до новітнього класу озброєння — баражувальних боєприпасів. Даний тип озброєння поєднує в собі низьку вартість і простоту розробки та виготовлення, що робить їх доступними для незаконних збройних формувань та ведення гібридних бойових дій. За своїми конструктивними особливостями та технічними характеристиками баражувальні боєприпаси займають нішу між крилатими ракетами та безпілотними літальними апаратами.

Для аналізу загроз з боку даного типу озброєнь для об'єктів ракетно-космічної та інших галузей економіки з метою подальшого визначення шляхів протидії запропоновано варіант класифікації сучасних та перспективних баражувальних боєприпасів за оперативним радіусом дії та типовими об'єктами ураження, зокрема розділення баражувальних боєприпасів на клас протиповітряних та клас боєприпасів, призначених для ураження наземних цілей. При цьому останній клас додатково розділяється на підкласи тактичних, оперативно-тактичних та оперативних баражувальних боєприпасів. Для кожного класу баражувальних боєприпасів наведено технічні особливості, типові представники та тенденції розвитку. Досліджено залежність маси бойової частини баражувального боєприпасу від стартової маси, показано вплив на неї типу встановленого двигуна. Визначено залежність типу маршового двигуна від класу баражувального боєприпасу, що є визначальним фактором, який формує загальний вид та характеристику боєприпасу.

Аналіз сучасних військових конфліктів показує, що баражувальні боєприпаси набувають все більшого значення для успішного досягнення бойових задач. Показано, що в залежності від противника, характеру бойових дій, технологічних та економічних можливостей сторін можуть застосовуватися баражувальні боєприпаси різних класів. Наведено приклади визначної ролі баражувальних боєприпасів у таких конфліктах, як війна у Ємені та війна у Нагорному Карабаху.

На основі запропонованої класифікації баражувальних боєприпасів та досвіду їхнього бойового застосування у військових конфліктах XXI ст. сформовано візію розвитку баражувальних боєприпасів у складі Збройних сил України.

Ключові слова: баражувальний боєприпас, оперативний радіус дії, військовий конфлікт.