UDC 355.5

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METHODOLOGY FOR DETERMINING THE COMPLEX INDICATOR OF THE TRAINING OF AN ANTI-AIRCRAFT GUNNER

A methodology for calculating a comprehensive indicator of the preparedness of anti-aircraft gunners is proposed, which considers the significant factors influencing the effectiveness of the actions of an anti-aircraft gunner during the combat use of portable anti-aircraft missile systems.

Keywords: *anti-aircraft gunner, portable anti-aircraft missile system, anti-aircraft guided missile, ground power supply, thermal optical homing head, partial indicator, comprehensive indicator of training of an anti-aircraft gunner, training complexes.*

Statement of the problem. Since the beginning of hostilities against our country by the invading forces of the russian federation and until now, the latter have been widely using air defence systems (ADS) (missiles, guided bombs, unmanned aerial vehicles, etc.) to strike critical infrastructure, defence positions and civilian objects. Traditionally, man-portable air defence systems (MANPADS) with automated guidance systems have played a significant role in destroying ROMs. Such systems are not cheap and require strong skills and abilities to be used effectively. That is why the training of the personnel of the air defence units of the Defence Forces uses MANPADS training systems of various types and types, the main ones being Stinger, Strela-2, Igla. Almost all man-portable air defence systems of this type have the same structure and operating principle: they are assembled using the "duck" aerodynamic system, the method of guidance is proportional convergence, the method of guidance is the use of a thermal optical homing head, etc. This makes it possible to unify them somewhat when developing training programmes. The learning outcomes in most of these programmes are determined by the assessment of theoretical knowledge and practical firing exercises using simulators. However, firing results do not fully reflect the training of an anti-aircraft gunner, as there are many significant factors that influence them. That is why there is a need to determine a partial and comprehensive indicator of the degree of training of an anti-aircraft gunner, which would consider the main of such factors and could be used to assess the actions of the gunner at other complexes.

Analysis of recent research and publications. The procedure for organising the training of the National Guard of Ukraine, including air defence units, is described in publications [1, 2, 3]. The analysis of the main trends and directions of development of the training base of the Armed Forces of Ukraine is considered in article [4]. The methodology for conducting training on Triggle-type training equipment and proposals for determining a comprehensive indicator of training of operators of such complexes are given in [5, 6, 7]. However, this assessment methodology can be applied only partially, as it does not reflect some significant factors of the actions of the AF during the combat use of man-portable air defence systems.

The purpose of the article is to develop a methodology for calculating a comprehensive indicator of the preparedness of anti-aircraft gunners, which would consider the significant factors affecting the effectiveness of the actions of an anti-aircraft gunner during the use of the complex.

Summary of the main material. The result of the training is the compliance of the knowledge, skills and abilities acquired by the trainee with the relevant criteria that satisfy certain conditions for the use of weapons in various types of combat. In this regard, in order to assess the training of anti-aircraft gunners, whose training is conducted using training complexes with visualisation of the firing process of the Triggle type, the methodological manual [5] contains proposals for improving the methodology of training and evaluation of the actions of the SZ.

There are the following conditions for defining an evaluation function:

1) the anti-aircraft gunner has mastered the theoretical part of the training programme with a grade of at least satisfactory, knows the algorithm of actions of the SZ during the preparation of MANPADS for firing and the basics of combat use of the complex;

2) the anti-aircraft gunner does not know the actual flight plan of the target, it is indicated by the training leader (operator) using the software interface;

3) assessment of the actions of the SOF involves the use of certain initial information available to it at the time of deciding to perform certain actions (for example, flight characteristics, size and characteristics of air attack assets);

4) in the absence of additional information (other than possible target type, altitude and speed), it is assumed that the target crosses the launch area in a straight line without changing flight parameters.

Considering the peculiarities of combat operation and design features of man-portable air defence systems, a comprehensive indicator of readiness should consider the following significant factors that affect the effectiveness of the actions of an anti-aircraft gunner [5]:

– to detect targets and determine the likely area of destruction by visual observation, in particular, using the system's sighting devices;

– determine the moment of switching on the ground power supply (GPS) depending on the time the target is in the sensitivity zone of the optical homing head (OHS);

– to meet the conditions for an effective launch of an anti-aircraft guided missile (AAGM), depending on the time of operation of the ground power source and the time the target is within the sensitivity zone of the AAGM;

– choose the priority mode of fire on oncoming or catch-up courses;

– to provide accurate tracking of the target.

In view of this, the overall training rate of an anti-aircraft gunner (*R*) can be determined by the following formula

$$P = P_{visdetec} \cdot P_{gps} \cdot P_{eff\ launch} \cdot P_{pc}^{*} \cdot P_{trac}, \quad (1)$$

where $P_{visdetec}$ is a partial indicator of the implementation of the anti-aircraft gunner's skills in visual target detection;

P_{gps} is a partial indicator of the implementation of the skills of an anti-aircraft gunner to meet the conditions for the effective launch of an anti-aircraft guided missile, depending on the time of operation of the ground power supply;

$P_{eff\ launch}$ is a partial indicator of effective launch, which characterises the moment of switching on the LBW and its operation depending on the time the target is in the sensitivity zone of the optical homing head;

P_{pc} is a partial indicator of the priority of the choice of fire mode on the oncoming and catch-up courses (for Igla, Arrow MANPADS);

P_{trac} is a partial indicator that characterises the quality of the SOF's skills in targeting and tracking.

An effective launch is the exit of a missile from the launch tube, which ensures that the target can be hit at least with a specified probability.

SAMs are launched at a target under the following conditions:

1) the moment the LPG is switched on depends on the range to the target, the far limit of the sensitivity zone of the GSS;

2) the total time from the moment of switching on the ground power supply of the SP to the effective start-up shall not exceed the UPS operation time $t_{launch} \le t_{ups}$;

3) time for stable target acquisition and tracking in manual and automatic modes of operation t_{acqu} must be within the limits: $t_{acqu\,\min} \le t_{acqu} \le t_{chuch\ OGSN}$;

4) time of entering the combat mode $t_{cb\ nbj}$ must be less than the time the target is in the sensing zone of the OGSN and the following conditions must be met $t_{cb\ nbj} + t_{acqu} \le t_{sens\ OGSN}$;

5) possible launch delays caused by design errors of the launch tube and components of the launch vehicle are not considered.

To engage a target with an air defence system, it must, of course, be visually detected. The $P_{visdetec}$ indicator is a partial indicator of the implementation of the anti-aircraft gunner's skills in visually detecting a target against a homogeneous background, identifying and recognising it.

To determine the estimate, we will make certain assumptions.

1. Air targets do not use the "I AM MY AIRCRAFT" signal or the ground radar requester is not activated.
2. The airspace is monitored without optical devices.

3. The anti-aircraft gunner has completed a training course and knows the signs of enemy aircraft – their types, types, and modes of action.

4. The visual search for a target takes place on a single-line background [dark (light) dot in a light sky and vice versa at night].

The process of visual target detection can be divided into 3 stages (events): event A – target detection (confirmation of the presence or absence of a target in space, separation of an object from the general background, in which it is characterised as an "object" [3]); event B – target identification (determination of the target's affiliation by certain characteristics, for example, by its affiliation or importance: bomber, fighter, etc.); event C – target recognition (confirmation or simplification of data on the presence of an enemy target: by colour, insignia, hostile actions, etc.) Therefore, a partial indicator of the implementation of the skills of an anti-aircraft gunner in visual detection of a target against a homogeneous background, its identification and recognition will be determined by the following expression:

$$P_{visdetec}= P_{detec}(A)\cdot P_{id}(B/A)\cdot P_{rec}(B/A,B), \quad (2)$$

where $P_{detec}(A)$ is the target detection probability;

$P_{id}(B/A)$ is the probability of target identification if it is detected;

$P_{rec}(B/A,B)$ is the the probability of recognising a target if it is detected and identified.

It is known from [10] that the probability of visual detection of a search object can be written as follows:

$$P_{\det ec} = 1 - exp\left(-\frac{t_{\det ec}}{t_{\det ec\_ave}}\right), \quad (3)$$

the average detection time, if no fire mission time is set, will be equal to

$$t_{\det ec\_ave} = \frac{(2\beta)^2}{C\cdot K_1^2\cdot\gamma^3\cdot L^{0,3}}, \quad (4)$$

where β is the angle of the observation sector, deg;

C is a coefficient that depends on the search conditions and is determined during monocular observation at $C = 12 - 36 angle^2 (\text{cd/m}^2)^{-0,3} (angle.min)^{-3} c^{-1}$ and reflects the skills of the anti-aircraft gunner in conducting the search;

K_1 is the contrast ratio between the object and the background ranges from 0.1 to 1;

γ is angular dimensions of the object, angles, min;

L is the background brightness, lm.

Thus, formula (5) takes the form

$$P_{\det ec} = 1 - exp\left(-\frac{C\cdot K^2\cdot\gamma^3\cdot L^{0,3}\cdot t_{\det ec}}{(2\beta)^2}\right). \quad (5)$$

It is proposed to evaluate the indicator of the implementation of the skills of an anti-aircraft gunner in visual target detection under the following conditions: "*excellent*" if $0.7 < P_{\det ec} \le 1$; "*good*" if $0.5 < P_{\det ec} \le 0.7$; "*satisfactory*" if $0.3 < P_{\det ec} \le 0.4$.

A partial indicator of the implementation of the skills of an anti-aircraft gunner to fulfil the conditions for the effective launch of an anti-aircraft guided missile, depending on the operation time of the ground power supply, can be defined as the ratio of the time to launch by an anti-aircraft gunner ($t_{launch\ of}$ the $_{SAM}$) to the maximum possible launch time ($t_{launch\ time}$) determined by the characteristics of the complex, taking into account the peculiarities of the operation of the power supply:

$$P_{gps} = \frac{t_{launch\ AAG}}{t_{launch\ PAAMA}}, \quad (6)$$

where

$$t_{launch\ sz} = t_{br\ nbj} + t_{posh\ sz} + t_{acco\ sz}, \quad (7)$$

where $t_{br\ nbj}$ is the average time of operation of the MANPADS ground power supply from the moment of switching on the UPS t_{inje} until the SAM enters combat mode;

$t_{posh\ sz}$ is the time from the moment the SAM enters combat mode to the moment the optical homing head acquires the target when it is aimed at the target of the SZ;

$t_{acco\ sz}$ is the time from the moment of acquisition of the SA target by the optical homing head to the moment of launch, it must be equal to or greater than the minimum possible tracking time and determined by the characteristics of the system $t_{acco\ sz} \le t_{acco\ \min}$.

$$t_{launch\ of\ man\text{-}portable\ air\ defence\ systems} = t_{nbj} - (t_{br\ nbj} + t_{acco\ \min}), \quad (8)$$

where t_{nbj} is the total operating time of the UPS;

$t_{br\ nbj}$ is average operating time of the MANPADS ground power supply from the moment of switching on the UPS t_{inje} until the SAM enters combat mode;

$t_{acco\ \min}$ is the minimum possible time from the moment of acquisition of the target by the optical homing head to the moment of launch, determined by the characteristics of the system.

It is proposed to determine the grade under the following conditions: "excellent", if 0.7<P≤1; "good", if 0.5< P≤0.7; "satisfactory", if 0.35< P ≤0.5; "unsatisfactory", if $P \leq 0.35$.

It is proposed to determine the grade under the following conditions: "excellent", if 0.7< P ≤1; "good", if 0.5< P ≤0.7; "satisfactory", if 0.35< P ≤0.5; "unsatisfactory", if $P \leq 0.35$.

The next indicator that will allow us to assess the skills of an anti-aircraft gunner, even with the maximum possible P_{nbj}, is the indicator that characterises the moment of activation of the LBW and its operation depending on the time the target is in the sensing zone of the GWS, the effective launch indicator $P_{eff\ launch}$.

To determine the estimate, we will make certain assumptions.

1. The target is fired at, and moves perpendicular to, the NW at the maximum speed at which the MANPADS are effective.
2. Time of LEO entering combat mode $t_{br\ nbj}$.
3. The ground power supply can be switched on in advance of the target entering the sensing area of the GWS, but this time should not exceed the total operating time of the ground power supply, taking into account the minimum possible tracking time for stable target acquisition.
4. If the launch of the SAM took place, the target will be hit with a given probability of hitting such a target – P.
5. The longer the target is in the sensing area of the JTF, the more likely it is to be captured, tracked and effectively launched.

Then the effective launch rate $P_{eff\ launch}$ will be calculated as the ratio of time $t_{launch\ sz}$ to the optimal time $t_{launch\ time}$, at which it is possible to switch on the UAS for an effective launch with a given probability of defeating a specific target P_i (Figure 1):

$$P_{eff\ launc} = \frac{t_{launc\ \ sz}}{t_{launch\ time}}. \qquad (9)$$

For some man-portable air defence systems (most of them domestically produced), an important factor affecting the effectiveness of target engagement is the choice of firing mode on oncoming or pursuing courses.

As noted in [5, 7, 8], P_{pr} is a partial indicator of the priority of target firing mode selection for the Igla MANPADS, which characterises the degree of priority of the target firing mode selected by the gunner on the oncoming or catch-up course.

When selecting this valuation function, the approach based on the following assumptions was chosen.

1. Under equally acceptable conditions of firing at the target on the oncoming and catch-up courses, the priority of firing at the target on the oncoming course is 0.6.
2. When determining the priority of firing at a target on a counter or catch-up course, the main indicators are the target's flight speed and the time the target is in the launch zone.
3. A linear dependence in the definition area 0÷1 was chosen as the evaluation function.

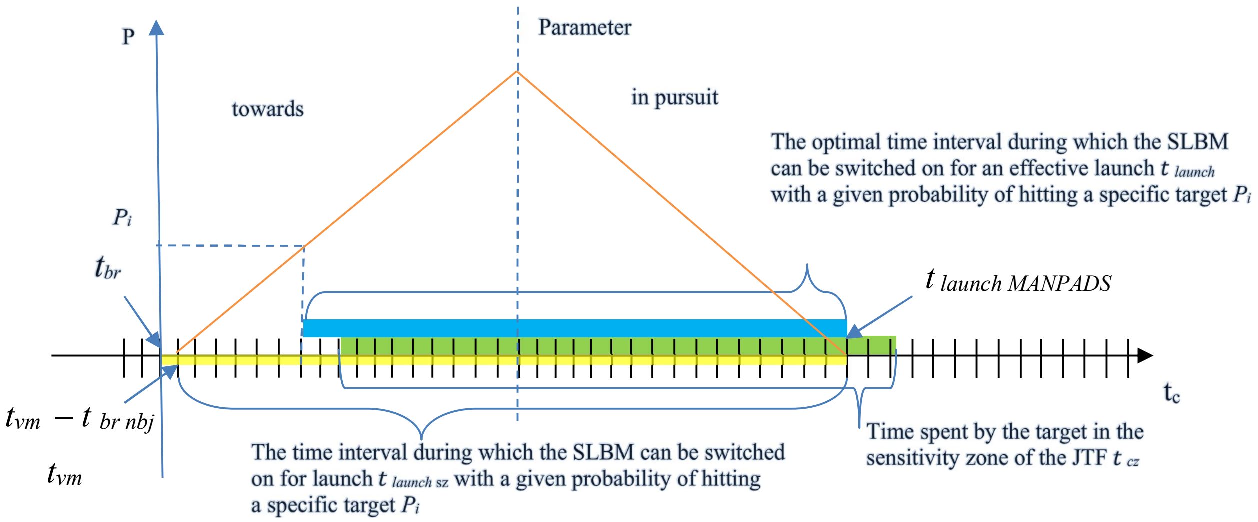

Figure 1 – Graphic representation of the definition of the effective start-up indicator

The priority indicator P_{pr} can be defined as follows:

a) when starting in the "FORWARD" mode:

$$P_{prf} = \frac{S_1 - S_3}{S_1 + S_2}; \qquad (10)$$

b) during the start-up in the "Catch-up" mode:

$$P_{prc} = \frac{S_2 - S_3}{S_1 + S_2}, \qquad (11)$$

where S_3 is the area of the segment, which is considered on the oncoming course only if the "PASS" button is pressed while the target is being fired on the oncoming course;

S_1 and S_2 are the respective sectoral areas;

the timeliness of switching on the "Catch-up" mode is taken into account by the area S_3, which can be taken into account as a segment in a circle centred on t_1 or t_4 depending on t_{br}.

The area of a sector (S_1 or S_2) can be generally calculated as

$$S = \frac{\pi R^2 \cdot Vt}{4\mathrm{V_{tmax}}}, \qquad (12)$$

where R is the radius of the sector proportional to the time the target is in the launch zone on the oncoming or catching course;

V_t is the current value of the target speed, m/s;

V_{tmax} is the maximum value of the target speed, both on the oncoming and catch-up courses, depends on the target characteristics and the MANPADS capabilities, m/s.

For example, for the Igla MANPADS, when launched at a target with speed parameters of 320 m/s < V_t ≤ 360 m/s and in the "TOWARD" mode –P_{pr} =1, and in the "Catch-up" mode – P_{pr} = 0. When launching at a target moving at a speed of V_t ≥360 m/s, and the "TOWARD" or "Catch-up" mode is selected P_{pr} = 0. The timeliness of switching on the "Catch-up" mode is taken into account by the area S_3.

In terms of priority, a gunner can be assessed as follows:

1) if the gunner selects the "FORWARD" mode: "*excellent*" if 0.4< P_{pr} ≤1; "*good*" if 0.35< P_{pr} ≤0.4; "*satisfactory*" if 0.3 < P_{pr} ≤ 0.35;

2) in case the gunner selects the "PURGE" mode: "*excellent*" if 0.6< P_{pr} ≤1; "*good*" if 0.55< P_{pr} ≤0.6; "*satisfactory*" if 0.5< P_{pr} ≤0.55.

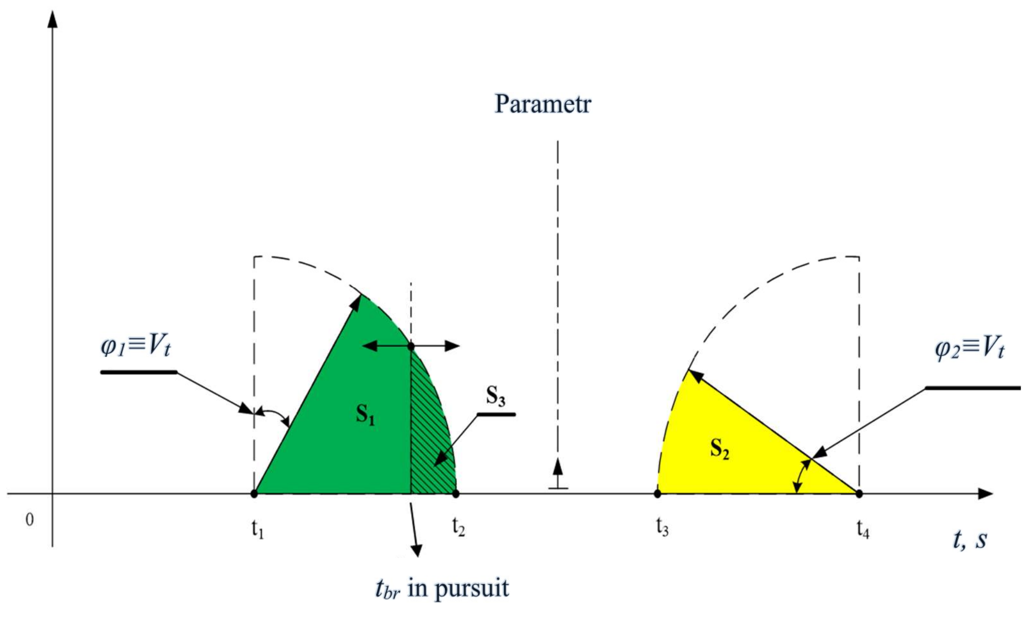

Figure 2 – Graphical representation of the calculation of the priority indicator P_{pr}

Accurate and consistent tracking of the captured target is the key to a successful launch.

Indicator P_{acco} is a partial indicator that characterises the stability of the anti-aircraft gunner's skills in steady aiming and tracking the target (aiming stability indicator). It characterises the time ($t_{acco\ sz}$) spent by the anti-aircraft gunner from the moment of target acquisition to the achievement of the event: continuously holding the target on the line of sight with a maximum permissible angular error of no more than ξ during some testing time (ΔT), with no more than one departure from the body angle (ω) for a time not exceeding Δt:

$$P_{acco} = \frac{\Delta T}{t_{acco\,SZ}}. \qquad (13)$$

For the sustainability indicator, the score will be as follows: "excellent" if $0.7 < P_{acco} \le 1$; "good" if $0.45 < P_{acco} \le 0.7$; "satisfactory" if $0.3 < P_{acco} \le 0.45$.

Conclusion

The proposed improved methodology for determining partial indicators of the readiness of an anti-aircraft gunner can be used to assess the readiness of anti-aircraft gunners in the conditions of completing a full training course and the number of training launches specified in it.

The aim of further research on this issue is to provide a more complete breakdown of some partial indicators.

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The article was submitted to the editorial office on 28.09.2024

УДК 355.5

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МЕТОДИКА ВИЗНАЧЕННЯ КОМПЛЕКСНОГО ПОКАЗНИКА ПІДГОТОВЛЕНОСТІ СТРІЛЬЦЯ-ЗЕНІТНИКА

З початком ведення бойових дій проти нашої країни загарбницькими військами російської федерації і дотепер останні широко використовують повітряні засоби ураження (ракети, керовані авіабомби, безпілотні літальні апарати тощо) для завдання ударів по критичній інфраструктурі, позиціях сил оборони та цивільних об'єктах. Традиційно значну роль у знищенні повітряних засобів ураження відіграють переносні зенітні ракетні комплекси ближньої дії з автоматизованою системою наведення. Такі комплекси є доволі не дешевими та потребують твердих навичок і вмінь для їхнього ефективного застосування.

Результатом навчання стрільців-зенітників є відповідність знань, умінь та навичок, які здобув слухач, відповідним критеріям, що задовольняють певні умови застосування озброєння у різних видах бою. При цьому є такі умови визначення оціночної функції:

– стрілець-зенітник засвоїв теоретичну частину програми підготовки на оцінку не нижче ніж задовільно, знає алгоритм дій стрільця-зенітника під час підготовки зенітно-ракетного комплексу до стрільби та основи бойового застосування комплексу;

– стрілець-зенітник не знає реального плану польоту цілі, його (план польоту) зазначає керівник заняття (оператор) з використанням інтерфейсу програмного забезпечення;

– оцінка дій стрільця-зенітника припускає використання ним наявної певної вихідної інформації на момент прийняття рішення на виконання якихось певних дій (наприклад, характеристики польоту, розміри та особливості дій засобів повітряного нападу);

– за браком додаткової інформації (крім можливого типу, висоти та швидкості цілі) вважається, що ціль пересікає зону пуску прямолінійно без зміни параметрів польоту.

У статті запропоновано методику розрахунку комплексного показника підготовленості стрільців-зенітників, який ураховує значущі чинники, що впливають на ефективність дій стрільця-зенітника під час бойового застосування переносних зенітних ракетних комплексів, серед яких візуальне виявлення цілі, навченість пуску зенітної керованої ракети за час роботи наземного блоку живлення, момент вмикання наземного блоку живлення, пріоритетність вибору режиму вогню на зустрічному та догонному курсах, якість навичок стрільця-зенітника в прицілюванні та супроводженні цілі.

Ключові слова: *стрілець-зенітник, переносний зенітний ракетний комплекс, зенітна керована ракета, наземний блок живлення, теплова оптична головка самонаведення, частковий показник, комплексний показник підготовки стрільця-зенітника, тренажерні комплекси.*

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