Advances in Military Technology
Vol. 17, No. 1, 2022, pp. 107-120
ISSN 1802-2308, eISSN 2533-4123
DOI 10.3849/aimt.01486

Methodology for Assessing the Level of Threats when Using Small Arms against Unmanned Aerial Vehicles

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The manuscript was received on 22 February 2021 and was accepted after revision for publication as research paper on 1 May 2022.

Abstract:

The article considers a methodical approach to assessing the level of threat to the civilian population in the case of the use of small arms for shooting at unmanned aerial vehicles (UAVs). This approach is based on modeling the process of bullet flight in the vertical plane, based on the algorithm for determining the probability of accidental human impact, which allows, depending on the kinetic energy of the bullet, to calculate the probability of accidental death and probability of accidental injury. Based on the simulation, the indicators of the probability of human injuries depend on the angles of the shot, which allows to justify the restrictions when firing UAVs from small arms.

Keywords:

death, model, probability, threat, trauma, weapon

1 Introduction

The experience of combat operations in eastern Ukraine shows that along with anti-aircraft missile systems (AMS), portable SAMs and anti-aircraft guns, and fire from regular small arms are used to hit UAVs operating at low and extremely low altitudes [1, 2].

By their nature and maneuverability, air targets such as UAVs have significant peculiar features compared to mobile ground targets, which leads to the need of developing special rules for firing at them from small arms. The small size of a UAV

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and the continuous and rapid change of its position in space causes significant difficulties in aiming small arms which may lead to misses. As a result, there is a threat to life and health of civilian population within the range of the bullets, due to the possibility of the wounding or injuring of people with accidental bullet impacts. This circumstance in accordance with [3, 4] is unacceptable.

Therefore, there is a need to ensure a certain level of safety for civilian population in the event of the use of small arms against UAVs.

2 Formulation of Problem

To ensure the required level of safety for civilian population, there is a necessity to develop a common approach to the evaluation of the threats level to population in case of the use of small arms against air targets, including UAVs, and to refine (clarify) the documents regulating the use of small arms. In particular, the firing rules common to all types of small arms, including firing at mobile and air targets, are systematized and set out in [5]. However, the safety issue of civilian population during firing at air targets is not considered in [5].

The basic aspects concerning the ballistics theory on shooting from small arms are given, and the ways of determining the probability of engaging the target, which is a stationary body length target or chest target, are considered in [6]. The evaluation of probability of a bullet accidentally hitting a civilian in the process of engaging the target was not conducted in [6]. Moreover, there are not any restrictions concerning the safe use of small arms during shooting at air targets in the existing guidelines [6] and firing rules [5].

Data on forces and moments influencing a projectile (missile) during its flight are given in [7]. Methods of trajectory research are offered, and the influence of external factors on a flight stability, trajectories dispersion and firing errors are estimated.

Issues of creating modern materials to protect personnel from the use of small arms are discussed in [8, 9]. Ballistic tests of the obtained materials are carried out for different types of projectiles with different kinetic energy and hardness of the core, features of the penetration of the hitting elements are performed depending on the material structural state.

The issue of the evaluation of shooting efficiency indicators for single and group targets is considered, and the corresponding calculated ratios are given in [10]. Indicators that characterize the level of threat of accidental injuring of people with a bullet during shooting at UAVs are not considered in [10].

Moreover, the resources [11-19] analyze and consider a wide range of global approaches to countering unmanned aerial aviation through destroying them directly by various means of destruction or interception of UAV control, as well as they deal with the ways to protect people and objects from the actions of UAV. In recent years, many UAVs of various classes and types have been developed and actively used in almost all current armed conflicts.

However, the use of inconspicuous means of air attack like UAV operating at low or extremely low altitudes, considering the terrain specifics, makes it difficult to detect them. In fact, the most logical way to do away with the enemy's UAV is to destroy it.

At the same time, various weapons could be used for UAV destruction. Thus, small light UAVs (and the vast majority of them are used, for example, in the area of operation in eastern Ukraine) can be shot down with small arms, which was demonstrated by units of the Armed Forces of Ukraine on several occasions. However, fulfilling such a task required enormous effort and consumption of ammunitions. Moreover, hitting the device actually did not guarantee that it was shot down (The known cases of UAVs loss demonstrated a damage to the engine or the battery).

Alternative means of destroying UAVs are anti-aircraft guns (machine guns) which are able to create fairly dense fire. An example of an anti-aircraft machine gun is the AFU-23-4 "Shylka" anti-aircraft self-propelled unit with a radar station and four-barrel 23-mm guns [20].

Thus, the analysis shows that the scientific works address the specifics of modern warfighting, the development of modern types of weapons and military equipment and equipping troops, and countering unmanned aerial vehicles for various purposes. However, the problem of evaluation of the level of threat posed to civilians by the use of small arms against UAVs is unresolved; therefore, the topic of the article is relevant.

3 Setting Objective

The influence of internal and external factors in local wars and armed conflicts, aimed at choosing relevant methods of warfighting, requires from military leaders at all levels that they provide steady safety and security for civilian population in the combat zone. That is why there is a need for the scientific justification of determining the indicator for the evaluation of the level of threats to the civilian population in cases when small arms are used against air targets (including UAVs).

Thus, the scientific task is to improve the methodological approach to predicting the level of threats to civilians in case of the use of small arms at air targets (including UAVs).

The purpose of the article is, based on the probability theory, to develop a scientific and methodological apparatus for predicting the level of threats to civilian population in case of use of small arms against air targets (including UAVs).

4 Description of the Method and Basic Mathematical Equations

One of the characteristics of small arms shooting at the UAV is the low penetration rate of bullets in such targets. Under these conditions, bullets, especially those that do not hit the target when falling, can cause damage to human life and health within reach.

As an indicator that can be used to assess the level of threat to civilians when small arms are used to engage a UAV, we use the probability of a bullet accidentally hitting a person. At the same time, depending on the kinetic energy of the bullet, it is possible to distinguish the probability of accidental killing and accidental injury to a person.

The probability of a bullet accidental hitting a person located at a certain distance from the shooter when firing a short burst at a UAV can be calculated by the ratio:

$$P_{\mathrm{B}}(d) = P_{\beta}(d) P_{\mathrm{D}}(d) \tag{1}$$

where $P_{\beta}(d)$ – the probability of shooting in the azimuths interval in a direction towards a person located at a distance d [m]; $P_{\mathrm{D}}(d)$ – the probability of shooting in the angles interval of the firing position, which ensures the impact of the bullet on a person located at a distance d [m], on the condition of shooting in the direction towards the person.

The small UAVs can appear from any direction relative to fire groups, so it is possible to consider the azimuth of shooting relative to a person as random variable with a uniform distribution density in the range from 0° to 360°.

Hence, the probability of shooting in the azimuths interval in the direction towards a person can be determined as follows (Fig. 1):

$$P_{\beta}\left(d\right)=\frac{\Delta\beta}{2\pi}=\frac{L}{2\pi d} \tag{2}$$

where $\Delta\beta = L/d$ – the value of the azimuths interval of shooting in the direction towards a person, depending on the distance to a person (expressed in radians); L – the average size of a person in the horizontal plane [m].

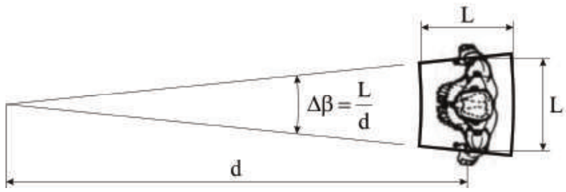

Fig. 1 Scheme for determining the probability of shooting in the azimuths interval in the direction towards a person

The suddenness of use (detection) of small UAVs leads to the fact that the shooter can shoot at the target at any angle (from 0° to 90°), therefore, the angle of the firing position can considered a random variable with a uniform distribution density. Hence, the probability of shooting in the angle interval of the firing position that ensures that a bullet hits a person under the condition of firing in the direction towards a person can be determined as follows (Fig. 2):

$$P_{\mathrm{D}}\left(d\right)=\frac{2}{\pi}\Delta\varepsilon\left(d\right) \tag{3}$$

where $\Delta\varepsilon(d)$ – the value of the angles interval of the firing position that ensures that a bullet hits a person under the condition of firing in the direction towards the person in the azimuth (in radians).

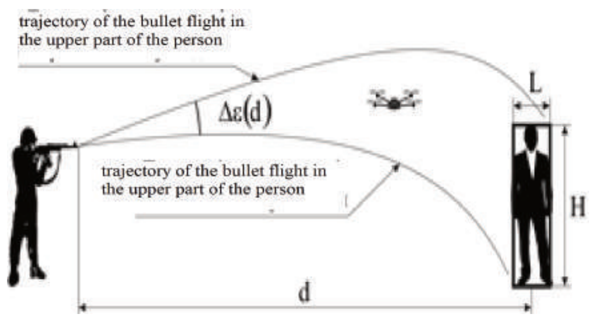

Fig. 2 Scheme for determining the probability of performing a shot within the angles interval of the firing position that ensures that a bullet hits the person

The value of the angles interval of the firing position $\Delta\varepsilon(d)$ which ensures that a bullet hits a person is quite difficult to determine due to the fact that its value depends on the trajectory of the bullet and the distance towards a person. Moreover, the action of gravity on the ball leads to the existence of two values of the elevation angle at which the bullet flies at a certain distance (except for the case of firing at the maximum range).

Therefore, taking into account the uniform law of distribution of the angle of the shooting position, it is advisable to determine the probability $P_D(d)$ by the counting method, according to the ratio

$$P_D(d) = \frac{N_{\varepsilon_B}(d)}{N_\varepsilon} \tag{4}$$

where $N_{\varepsilon B}(d)$ – the number of angles of the shooting position at which it is ensured that a bullet hits a person at a distance d [m]; $N_\varepsilon = \mathrm{int}[\pi/(2\Delta\varepsilon)]$ – the total number of shooting angles ranging from 0° to 90°; int(x) – the function of rounding a number x down to the nearest integer; $\Delta\varepsilon$ – the interval of division of the shooting sector in the vertical plane.

That is, to determine the probability (3) we need to:

- divide the shooting sector in the vertical plane from 0° to 90° into equal intervals of size $\Delta\varepsilon$,
- determine the fact of a bullet hitting a person located at a distance d, for each angle of the shooting location $\varepsilon_k = k\Delta\varepsilon$, where $k = \overline{1, N_\varepsilon}$,
- calculate the number of angles of the place of fire, at which the bullet hits the person $N_{\varepsilon B}(d)$.

Determining the fact of a bullet hitting a person located at a distance d when shooting with elevation ε_k in its direction in azimuth is carried out by:

- building the trajectory of the bullet with a given angle of the shooting position,
- checking the fact that its intersection with a rectangle of size L by H (Fig. 2) is at range d and approximates the shape of a person.

Since the size of the ball is much smaller than the path that it overcomes in flight, then its movement can be considered as the movement of a material point (center of mass) $\boldsymbol{P}(t) = \{X(t), Y(t)\}$ in time, which, as a rule, is set in a tabular way according to the results of research firing under normal conditions of their execution.

Considering the limitations of the conditions for performing research test firing (where the angle of the shooting position changes in the range of only a few degrees), there is a need to construct a mathematical model of the movement of the ball in the vertical plane at a given angle of the shooting position, with the adoption of the following simplifications (Fig. 3):

- the change in the movement of the ball in space is carried out under the influence of gravity $\boldsymbol{F}_T$ and air resistance forces $\boldsymbol{F}_C$, which add up to the resulting force $\boldsymbol{F}$,
- the vector of the air drag force is applied to the center of mass of the ball and is directed opposite to the vector of its velocity $\boldsymbol{V}$,
- given the insignificant ranges and heights of small arms bullets, it is advisable to represent the Earth's surface as a plane, the force of gravity is considered to be directed opposite to the normal of this plane and such that does not depend on the height of the bullet.

In general, the bullet trajectory can be obtained by integrating its velocity (considering its initial position) as follows:

$$\left.\begin{aligned} X(t) &= X(0) + \int_0^t V_X(\tau)\mathrm{d}\tau \\ Y(t) &= Y(0) + \int_0^t V_Y(\tau)\mathrm{d}\tau \end{aligned}\right\} \tag{5}$$

where $X(0)$, $Y(0)$ – the initial coordinates (shot coordinates) in a rectangular right-handed coordinate system (hereinafter - in the starting coordinate system); $V_X(t)$, $V_Y(t)$ – the components of the bullet velocity vector $\boldsymbol{V}(t) = \{V_X(t), V_Y(t)\}$ at moment t.

Accordingly, the components of the bullet velocity vector change in time as follows:

$$\left.\begin{aligned} V_X(t) &= V_X(0) + \int_0^t W_X(\tau)\mathrm{d}\tau \\ V_Y(t) &= V_Y(0) + \int_0^t W_Y(\tau)\mathrm{d}\tau \end{aligned}\right\} \tag{6}$$

where $V_X(0)$, $V_Y(0)$ – the initial components of the bullet velocity vector at the moment of the shot (the moment the bullet exits the bore); $W_X(t)$, $W_Y(t)$ – the components of the ball acceleration vector $\boldsymbol{W}(t) = \{W_X(t), W_Y(t)\}$ at the moment t.

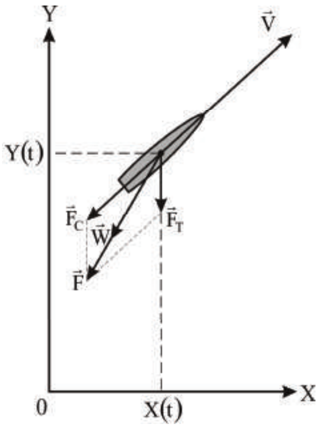

Fig. 3 Inflight forces affecting a bullet

The initial components of the bullet velocity vector at the time of the shot are determined as follows:

$$\left.\begin{aligned} V_X(0) &= V(0)\cos\varepsilon_k \\ V_Y(0) &= V(0)\sin\varepsilon_k \end{aligned}\right\} \tag{7}$$

where $V(0)$ – is the modulus of the bullet velocity vector at the time of the shot (the moment the bullet exits the bore).

Given the accepted simplifications, the components of the bullet acceleration vector can be obtained as follows:

$$\left.\begin{aligned} W_X(t) &= \frac{V_X(t)C\left(\sqrt{V_X^2(t)+V_Y^2(t)}\right)\rho_0\,\mathrm{e}^{-\eta Y(t)}\sqrt{V_X^2(t)+V_Y^2(t)}S_\mathrm{m}}{2m} \\ W_Y(t) &= \frac{V_Y(t)C\left(\sqrt{V_X^2(t)+V_Y^2(t)}\right)\rho_0\,\mathrm{e}^{-\eta Y(t)}\sqrt{V_X(t)^2+V_Y(t)^2}S_\mathrm{m}}{2m} - g \end{aligned}\right\} \tag{8}$$

where $C(V)$ – is a dimensionless aerodynamic coefficient of air resistance of the bullet depending on the speed V; ρ_0 – is the density of air on the Earth’s surface; η – is an indicator of decreasing air density with height; S_m – is the largest transverse area of the bullet with a relation to the motion direction; m – is the bullet mass. $C(V)$ – the function, as a rule, has a tabular form and is formed by the results of experimental shootings under certain conditions.

Numerical integration methods can be used to solve Eq. (6), for example, the trapezoid method [21].

The trajectory of the bullet must be determined in certain time frames within regular intervals:

$$t_i = i\,\Delta t \tag{9}$$

where $i = \overline{1, N_T}$ is the time count number; N_T – is the number of bullet flight time counts; Δt – is the time interval between time counts.

The number of bullet flight time counts N_T is determined by the time of the bullet falling on the Earth’s surface.

Since the components of the velocity vector and the position of the bullet are used for the determination of the bullet acceleration (8) which for the same time are unknown values when determining the bullet acceleration at a certain point in time, it is proposed to replace them with predicted values as follows:

$$\left.\begin{aligned} W_X(t_i) &= \frac{\hat{V}_X(t_i)\,C\big(\hat{V}(t_i)\big)\,\rho_0\, e^{-\eta \hat{Y}(t_i)}\,\hat{V}(t_i)\,S_m}{2m} \\ W_Y(t_i) &= \frac{\hat{V}_Y(t_i)\,C\big[\hat{V}(t_i)\big]\,\rho_0\, e^{-\eta \hat{Y}(t_i)}\,\hat{V}(t_i)\,S_m}{2m} - g \end{aligned}\right\} \tag{10}$$

where $\hat{V}(t_i) = \sqrt{\hat{V}_X(t_i)^2 + \hat{V}_Y(t_i)^2}$ – is the predicted value of the modulus of the bullet velocity vector at a time point t_i; $\hat{Y}(t_i)$ – is the predicted value of the bullet flight altitude at a timepoint t_i.

The predicted value of the components of the bullet velocity vector at the timepoint t_i can be determined by assuming their uniform change as follows:

$$\left.\begin{aligned} \hat{V}_X(t_i) &= 2\,V_X(t_{i-1}) - V_X(t_{i-2}) \\ \hat{V}_Y(t_i) &= 2\,V_Y(t_{i-1}) - V_Y(t_{i-2}) \end{aligned}\right\} \tag{11}$$

where $V_X(t_{i-1})$, $V_Y(t_{i-1})$ – are the components of the bullet velocity vector at a point in time t_{i-1}; $V_X(t_{i-2})$, $V_Y(t_{i-2})$ – are the components of the bullet velocity vector at a point in time t_{i-2}; $V_X(-\Delta t) = V_X(0)$; $V_Y(-\Delta t) = V_Y(0)$.

The predicted value of the bullet's height in trajectory at a point in time t_i, accepting a hypothesis of its uniform change, is determined as follows:

$$\hat{Y}(t_i) = 2\,Y(t_{i-1}) - Y(t_{i-2}) \tag{12}$$

where $Y(-\Delta t) = Y(0)$.

 DOI 10.3849/aimt.01486

$$\left.\begin{aligned} V_X(t_i) &= V_X(t_{i-1}) + \frac{W_X(t_{i-1}) + W_X(t_i)}{2}\Delta t \\ V_Y(t_i) &= V_Y(t_{i-1}) + \frac{W_Y(t_{i-1}) + W_Y(t_i)}{2}\Delta t \end{aligned}\right\} \tag{13}$$

where $W_X(0) = W_Y(0) = 0$ – the initial acceleration of the bullet is assumed to be zero.

The position of the bullet at a certain point in time in the starting coordinate system is determined as follows:

$$\left.\begin{aligned} X(t_i) &= X(t_{i-1}) + \frac{V_X(t_{i-1}) + V_X(t_i)}{2}\Delta t \\ Y(t_i) &= Y(t_{i-1}) + \frac{V_Y(t_{i-1}) + V_Y(t_i)}{2}\Delta t \end{aligned}\right\} \tag{14}$$

Checking the hit conditions, i.e. the fact of intersection of the trajectory (14) with a rectangle of size L by H, located at range d is carried out by sequentially checking the following three conditions:

$$Y(t_{i-1}) \le H \text{ or } Y(t_i) \le H \tag{15}$$

$$X(t_i) \ge d - \frac{L}{2} \text{ and } X(t_{i-1}) \le d + \frac{L}{2} \tag{16}$$

$$Y_{\mathrm{n}} \le H \text{ or } Y_{\mathrm{f}} \le H \tag{17}$$

The heights of the intersection of the lines of the beginning and end of the rectangle Y_{n} and Y_{f} with the trajectory are determined as follows:

$$\left.\begin{aligned} Y_{\mathrm{n}} &= Y(t_{i-1}) + \frac{d - \frac{L}{2} - X(t_{i-1})}{X(t_i) - X(t_{i-1})}\left[Y(t_i) - Y(t_{i-1})\right] \\ Y_{\mathrm{f}} &= Y(t_{i-1}) + \frac{d + \frac{L}{2} - X(t_{i-1})}{X(t_i) - X(t_{i-1})}\left[Y(t_i) - Y(t_{i-1})\right] \end{aligned}\right\} \tag{18}$$

This hit condition may be supplemented by a check for exceeding a certain bullet velocity at the time of the hit to assess the probability of accidental killing or injury, as follows:

$$\sqrt{V_X^2(t_i) + V_Y^2(t_i)} \ge V_1 \tag{19}$$

where V_1 – is the limit value of the bullet velocity for inflicting injury, under consideration.

That is, the hit condition is considered fulfilled when all the specified conditions are met Eqs (15)-(17) and (19).

Thus, the determination of the probability of a bullet accidentally hitting a person located at a certain distance from the shooter firing a short burst at UAV could be done according to the algorithm shown in Fig. 4.

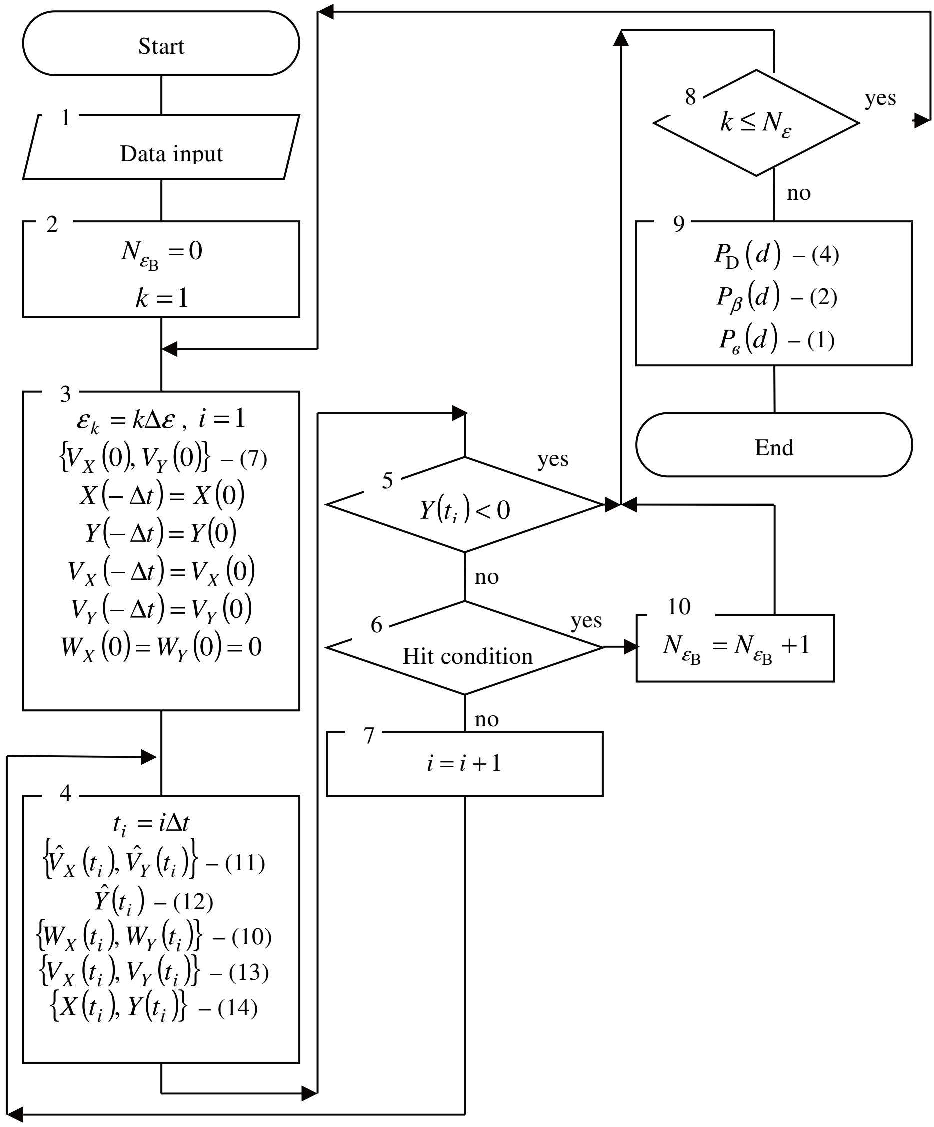

Fig. 4 Algorithm for determining the probability of a bullet accidentally hitting a person, located at a certain distance from the shooter firing a short burst at UAV

In block 1 of the algorithm (Fig. 4), the input data is entered, which includes: ρ_0 – the air density on the Earth's surface, kg m^{-3}; η – the indicator of decreasing air density with increasing height; $\Delta\varepsilon$ – the interval of division of the firing sector in the vertical plane, rad; Δt – the interval between time readings when constructing trajectories, [s]; $X(0)$, $Y(0)$ – the initial coordinates (shot coordinates) in the starting coordinate system, [m]; $V(0)$ – the bullet velocity vector modulus at the moment of firing (bullet exit from the bore), [m s^{-1}]; $C(V)$ – the dimensionless aerodynamic coefficient of air resistance of the bullet depending on the speed $\boldsymbol{V}$, table values; S_m – the largest transverse area of the bullet relative to the direction of motion, [m^2]; m – the mass of the bullet, [kg]; d – the distance to the person, [m]; L, H – the geometric dimensions of the person, [m]; V_l – the limiting value of the bullet velocity for inflicting damage, which is considered, [m s^{-1}].

The result (block 9) reflects the degree of damage to a person in accordance with the entered limit value of the bullet velocity V_l, and it can be:

- the likelihood of accidental killing of a person. In this case, the limiting value of the bullet velocity is entered in accordance with the force lethal to human for a bullet of a certain caliber,
- the likelihood of accidental injury to a person. In this case, the limiting value of the bullet velocity can be significantly less than in the previous case.

Using the developed algorithm (Fig. 4), the results were obtained on assessing the threat to life and health of a person within reach of a bullet with a steel core, of calibers (5.45 and 7.62) mm, fired in short burst from Kalashnikov LMG at UAV.

The graphs of the probability of accidental killing and the probability of causing accidental injury to a civilian person, depending on the range of location, are shown in Fig. 5.

Graphs (Fig. 5) were obtained with the following initial data: $\rho_0 = 1.2058$ kg m^{-3}; $\eta = 1.41 \times 10^{-4}$ m^{-1}; $\Delta\varepsilon = 1.57 \times 10^{-6}$ rad; $\Delta t = 0.1 \times 10^{-3}$ s; $X(0) = 0$ m; $Y(0) = 1.5$ m; $V(0) = 960$ m s^{-1} – for bullets of 5.45 mm; $V(0) = 745$ m s^{-1} – for bullets of 7.62 mm; $S_m = 2.3 \times 10^{-5}$ m^2 – for bullets of 5.45 mm; $S_m = 4.56 \times 10^{-5}$ m^2 – for bullets of 7.62 mm; $m = 0.0034$ kg – for bullets of 5.45 mm; $m = 0.0079$ kg – for bullets of 7.62 mm; $L = 0.5$ m; $H = 1.75$ m; $V_l = 198$ m s^{-1} – for killing with 5.45 mm bullet, $V_{ep} = 142$ m s^{-1} – for killing with 7.62 mm bullet; $C(V)$ – from calculations based on the research firing data, which are given in the corresponding firing tables [22].

The probability of a bullet accidentally hitting a person increases sharply with a distance of less than 100 m and firing angles of no more than 3 arc minutes. Such conditions are extremely unlikely due to the fact that the person is in the same line with the shooter's target and is hardly invisible. Therefore, such a hit is not accidental, given the need to comply with safety rules when firing.

That is, the graphs shown in Fig. 5 can be used when assessing threats when firing at UAV starting from a range of 400 m and more (the range at which you can accidentally fail to notice a person).

Analysis of Fig. 5 shows that the probability of accidental hit of one bullet in a person varies in the range 0.2×10^{-7} to 6×10^{-7}. At the same time, the probability of accidental killing remains up to a range of 1 366 m – for 5.45 mm bullets, and by 1 697 m – for 7.62 mm bullets, which corresponds to the firing angles, respectively, 2°8’ and 5°41’. If we restrict shooting at UAV to these angles, then the graphs of the probabilities of accidental injury to a person take the form shown in Fig. 6.

An unevenly curved trajectory of a bullet flight influenced by air resistance and gravity forces leads to non-linearity in the functional dependence of the bullet range on the firing angle. There is an increase in the value of the probability of accidental injury of a person at a distance corresponding to the maximum range of the bullet.

Analysis of Fig. 6 shows that the probability of accidental injury to a person does not exceed 0.6×10^{-7}, with the exception of intervals which correspond to the maximum range of 5.45 mm bullets (3 040-3 080) m and 7.62 mm bullets

(2 830-2 880) m. For these intervals, the probability of accidental injury to a person is 6×10^{-7}.

Thus, the problem of calculating the level of threat to the civilian population due to use of small arms against UAV can be considered solved.

The obtained results are recommended to substantiate safety zones (sectors) when firing from small arms at air targets and to clarify the relevant sections of the firing rules.

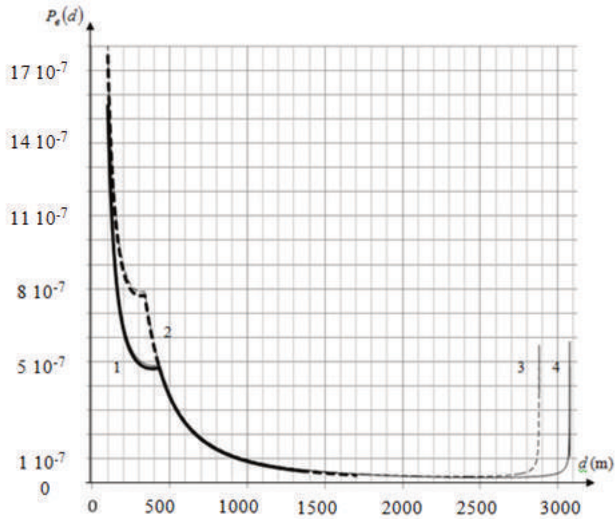

Fig. 5 Probabilities of accidental killing and injury of a person when shooting from standard small arms with steel-core bullets (1 – probability of accidental killing with 5.45 mm *bullets; 2 – probability of accidental killing with* 7.62 mm *bullets; 3 – probability of accidental injury with* 7.62 mm *bullets; 4 – probability of accidental injury with* 5.45 mm *bullets)*

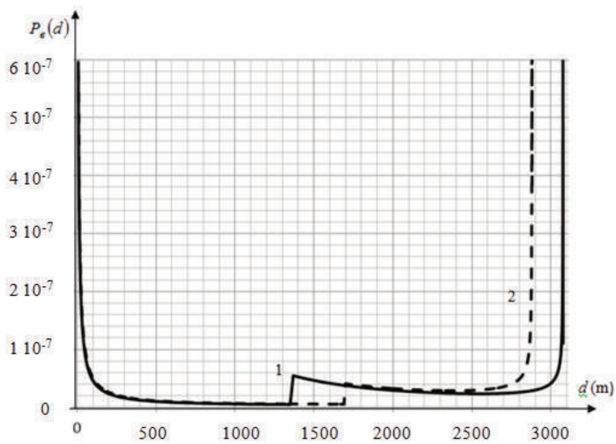

Fig. 6 The probability of accidental injury to a person when firing from a regular small arms with restrictions on the angle of the place (1 – probability of accidental injury with bullets 5.45 mm*; 2 – probability of accidental injury with bullets* 7.62 mm*)*

5 Conclusions

It is proposed to use the probability of accidental hitting a person with a bullet as an indicator of assessing the level of threats to civilian population when using small arms against UAVs.

A methodical approach to assessing the level of threats to civilian population has been developed, which is based on simulation of the process of bullet flight in the vertical plane. The basis of the methodological approach is an algorithm for determining the probability of accidental hitting a bullet in a person, which allows, depending on the kinetic energy of the bullet, to calculate the probability of accidental killing and the probability of accidental injury.

It is established that the probability of accidental hitting a person with one bullet when firing a short burst at a UAV from Kalashnikov LMG varies in the range from 0.2×10^{-7} to 6×10^{-7}. In this case, the possibility of accidental killing remains for the angles of fire up to 2°8' and for bullets 5.45 mm and up to 5°41' for bullets 7.62 mm. Provided the firing at UAVs is limited to these angles, the probability of accidental injury ranges from 0.6×10^{-7} to 6×10^{-7}.

Based on the proposed methodological approach, the direction of further research is to determine the probability of accidental hitting a person with a bullet when firing from a standard weapon caliber 5.56 mm and 12.7 mm at air targets such as UAVs, which will allow to take measures for minimization of threats to civilians.

The results of the research published in the article will be useful for the leaders of military teams at all levels who are responsible for ensuring the safety of civilian population during the use of weapons.

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