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DETERMINATION OF THE TRAJECTORY ELEMENTS FOR THE REUSABLE TRAINING-PRACTICE MORTAR ROUND INTENDED FOR SHORT DISTANCE FIRING

Conyu Grigorov CONEV*, Hristo Angelov HRISTOV**

***"Vasil Levski" National Military University, Veliko Tarnovo, Bulgaria**
****"Bishop Konstantin Preslavsky" University, Shumen, Bulgaria**

Abstract: *The paper presents an analytical method for calculating the initial velocity and flight distance of a reusable training-practice mortar round for short distance firing intended as a simulator for mortar teams. This is the first stage in the overall development of the simulator and the results obtained will be used to determine the elements of the mortar's internal ballistics. The paper also presents a simulation model developed with MATLAB software program, with which calculations were made for 60 mm, 82 mm and 120 mm training-practice mortars.*

Keywords: mortar, training-practice mortar mine

1. Introduction

The changes that have taken place during the last decade, considering how combat operations are performed, continue to introduce changes in the structures and weaponry of the armed forces. The need for increased unit mobility and well-equipped units armed with modern weaponry with increased capabilities must be made a priority. It is increasingly necessary to conclude that in the future the importance of armaments quality will rise at the expense of its quantity.

These conclusions are also supported by the historical analysis of armed conflicts, which clearly indicate that in most cases two of the main factors influencing the outcome of an armed conflict are the technical characteristics of the weapons used by the parties and the practical training of the personnel.

In order to increase the practical training of personnel, a scientific team from the Faculty of Artillery, Air Defense and CIS from Bulgarian National Military University "Vasil Levski" started a project aimed at the creation of training practice simulator intended for training of mortar crews.

The main goal of the project is to modernize the technical means for training of mortar crews in the Bulgarian Army and to develop capabilities for practical skills at reduced financial costs.

Some of the main requirements for the simulator are:

- the construction of the simulator must include the basic components that are required for live firing: mortar, training-practice mortar round, fuze and ignition cartridge;
- to enable the simulator to most accurately mimic the activities performed by the mortar crew during real combat operations.
- the training-practice mine must resemble, as much as possible, it's combat counterpart in terms of appearance, weight and dimensions. The abovementioned criteria

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are required in order for the round to provide better practical training and to create a true picture of the round's operation;

- the maximum firing distance must be 100 m, allowing the system to be used on firing ranges and training grounds;
- the minimum firing distance must be 20 m, ensuring the safety of the mortar team.

Based on these requirements, the main elements of the simulator include:

- launcher - combat mortar;
- launched body performing flight - reusable training-practice mortar mine intended for short distance firing
- firing charge;
- device imitating the explosion.

One of the first tasks in performing the design calculations of the simulator is to determine the elements of the trajectory for the reusable training-practice mortar mine intended for short distance firing.

2. Determining the elements of the external ballistics of the flight trajectory for the reusable training-practice mortar mine

Based on the analysis conducted on developed practical simulators for the training of mortar crews in different countries the following basic requirements for the designed simulator can be identified:

- the construction of the simulator must include the basic components that are required for live-firing: mortar, training-practice mortar round, fuze and ignition cartridge;
- to enable the simulator to most accurately mimic the activities performed by the mortar crew during real combat operations.
- the training-practice mine must resemble, as much as possible, its combat counterpart in terms of appearance, weight and dimensions. The abovementioned criteria are required in order for the round to provide better practical training and to create a true picture of the round's operation;
- the construction of the training-practice mortar round must have simple technological design that incorporates already manufactured elements from its combat counterpart;
- the training-imitational fuze must be able to mark the area where the round has made impact with the ground. The fuze must be unable to cause fire, but at the same time, must still be capable of clearly indicating the area where the round has made impact;
- the training-practice fuze must fiction reliably and have a simple design and reliable action;
- the construction of the training-practice fuze must incorporate a safety mechanism that does not allow detonation before the round is fired;
- the ignition cartridge must resemble the ignition cartridge used in the live round as much as possible in terms of appearance and dimensions;
- the maximum firing distance must be 100 m, allowing the system to be used on firing ranges and training grounds;
- the minimum firing distance must be 20 m, ensuring the safety of the mortar team.

In accordance with the requirements listed above, it is first necessary to determine the elements of the external ballistics of the flight trajectory for the reusable training-practice mortar rounds.

The mathematical model required for the determination of the elements of the external ballistics for short-distance mortar flights - up to 100 m has the following form:

$$\ddot{x} = -A.\dot{x}.v$$
$$\ddot{y} = -A.\dot{y}.v - g \qquad (1)$$

where:

$\ddot{x}$ - horizontal component of acceleration;

$\ddot{y}$ - vertical acceleration component;

$\dot{x}$ - horizontal component of velocity;

$\dot{y}$ - vertical velocity component;

v - velocity;

g – acceleration of gravity;

A – coefficient that is calculated by the formula:

$$A = \frac{1}{2.m} C_x.\rho.S \qquad (2)$$

where:

m – mass of the mortar[kg];

ρ – air density at sea level (normal artillery atmosphere) [kg/m3];

S – maximum mortar diameter[m];

Cx – drag coefficient for speeds less than 200 m/s.

The initial conditions are set at $t = 0$ и $x = 0, y = 0$ as follows:

$$\dot{x}_0 = v_0.\cos(\theta_0)$$
$$\dot{y}_0 = v_0.\sin(\theta_0) \qquad (3)$$

where:

$\dot{x}_0$ - horizontal component of the initial velocity [m/s];

$\dot{y}_0$ - vertical component of the initial velocity [m/s];

v_0 - the initial velocity of the mortar [m/s];

θ_0 - angle of firing (elevation angle) [deg].

In calculating the coefficient A from the formula 2 for the 120 mm mortar round the following result is obtained – A = 0,0000546.

The coefficient value for the 82 mm mortar round is - A = 0.000127476.

The coefficient value for the 60 mm mortar round is - A = 0.000135646.

From the data presented above, this coefficient is of very low value, which results in low air resistance forces, which in turn allows these forces to be neglected in the calculation for short distance mortar firing.

In order to solve the main problem of the external ballistics on the basis of formulas 1, 2 and 3, a simulation model of MATLAB - SIMULINK program was developed, the sheet of which is as shown in figure 1.

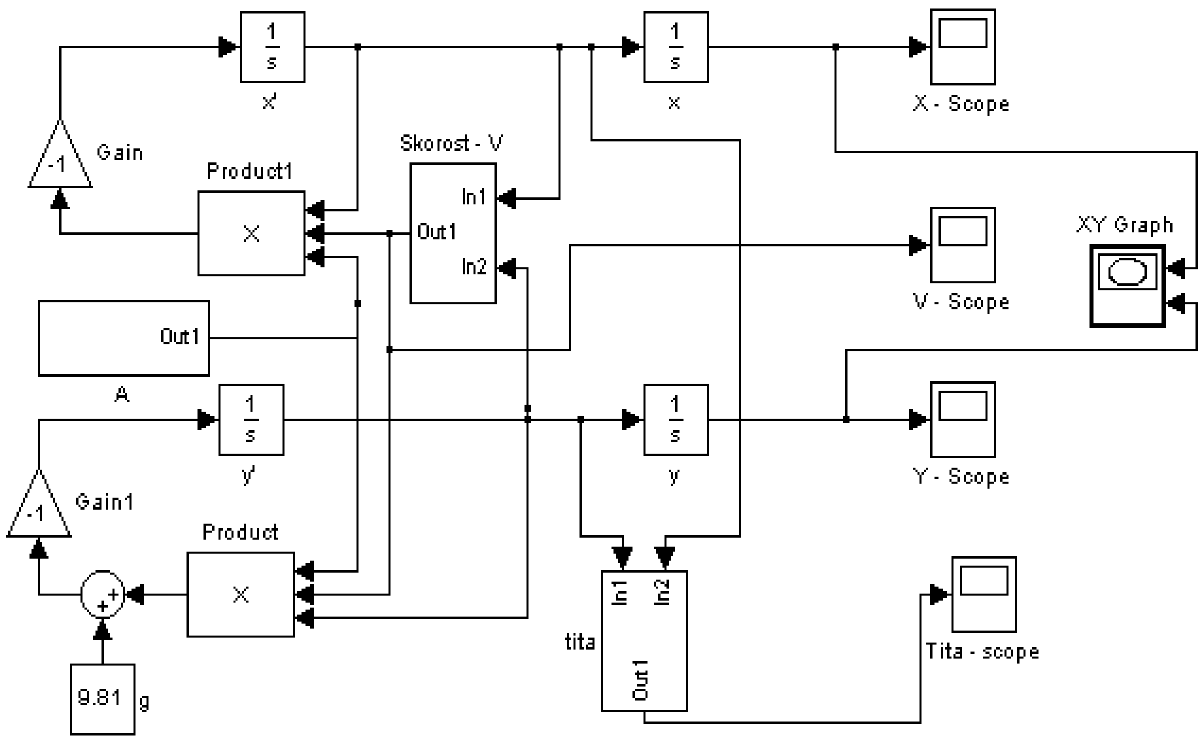

Figure 1: Sheet of the simulation model of a program MATLAB – SIMULINK to solve the main problem of the external ballistics.

Figure 1 shows a sheet for the numerical solution of a system of second order ordinary differential equations. The equations are written in the form of an equality with respect to the senior derivative (acceleration) as shown in the system of equations (1).

The solution is performed as the signals for the acceleration components obtained - multiplied in advance in signal amplification blocks (referred to in the sheet as „– 1”) with „- 1”, are submitted to integration blocks (designated as „*1*/s”). The output of these blocks receives a signal for the speed components. These components are fed to a speed calculation unit (denoted by the sheet as „Skorost - V”. In addition, these signals are submitted for reintegration into integration blocks („$\frac{1}{s}$”), where components for displacements along the two axes are obtained – x and y.

To calculate the angle that the body concludes, signals from the speed component blocks are sent to a block designated as „Tita” where the current angle value is calculated θ.

Axis displacements, speed signals, angle changes θ and the trajectory are submitted to the blocks respectively „X- Scope”, „Y – Scope”, „V – Scope”, „Tita Scope” and „XY – Graph”.

With the developed MATLAB – SIMULINK model, numerical and graphical simulations were performed to determine the basic parameters of the flight path for the 60 mm, 82 mm and 120 mm mortar round. The results are shown in Tables 1, 2 and 3.

Table 1 The results from the calculations of the basic parameters of the flight trajectory for the 60mm mortar round

Initial launch velocity of the mortar round V_0 [m/s]	Mortar elevation angle θ [deg]	Maximum flight distance *Xmax* [m]	Maximum flight altitude *Ymax* [m]	Flight time t [s]	Speed of the mortar round upon reaching the earth's surface V_C [m/s]	Angle when reaching the earth's surface θ_C [deg]
25	45	63,7	15,9	3,6	25	45
25	65	48,8	26,1	4,6	25	65
25	85	11,0	31,6	5,0	25	85
30	45	91,7	22,9	4,3	30	45
30	65	70,3	37,7	5,6	30	65
30	85	15,9	45,5	6,1	30	85
35	45	124,8	31,2	5,1	35	34
35	65	95,7	51,3	6,5	35	65
35	85	21,7	62	7,1	35	85
40	45	163,0	40,8	5,7	40	45
40	65	125,0	67,0	7,4	40	65
40	85	28,3	80,9	8,2	40	85

Table 2 The results from the calculations of the basic parameters of the flight trajectory for the 82mm mortar round

Initial launch velocity of the mortar round V_0 [m/s]	Mortar elevation angle θ [deg]	Maximum flight distance *Xmax* [m]	Maximum flight altitude *Ymax* [m]	Flight time *t* [s]	Speed of the mortar round upon reaching the earth's surface V_C [m/s]	Angle when reaching the earth's surface θ_C [deg]
25	45	63.0	16	3.60	25	45
25	65	48.5	26	4.60	25	65
25	85	11.0	32	5.10	25	85
30	45	91	23	4.30	30	45
30	65	69.5	37.5	5.55	30	65
30	85	15.8	46	6.10	30	85
35	45	124	31	5.00	35	45
35	65	94.5	51	6.45	35	65
35	85	21.5	61.5	7.10	35	85
40	45	160.5	40	5.80	40	45
40	65	123	66.5	7.40	40	65
40	85	28	80.5	8.10	40	85

Table 3 The results from the calculations of the basic parameters of the flight trajectory for the 120mm mortar round

Initial launch velocity of the mortar round V_0 [m/s]	Mortar elevation angle θ [deg]	Maximum flight distance *Xmax* [m]	Maximum flight altitude *Ymax* [m]	Flight time *t* [s]	Speed of the mortar round upon reaching the earth's surface V_C [m/s]	Angle when reaching the earth's surface θ_C [deg]
25	45	63.5	16	3.60	25	45
25	65	48.5	26,2	4.60	25	65
25	85	11.0	31.0	5.10	25	85
30	45	91	23	4.30	30	45
30	65	70.0	37.5	5.55	30	65
30	85	15.8	45.5	6.10	30	85
35	45	124	31	5.05	35	45
35	65	95	51.5	6.45	35	65
35	85	21.5	61.5	7.10	35	85
40	45	160.5	40	5.80	40	45
40	65	123	66.5	7.40	40	65
40	85	28	80.5	8.10	40	85

Based on the obtained results presented in Tables 1, 2 and 3, the following conclusions can be made when firing on short distances with mortars:

- the velocity at which the mortar round hits the ground is approximately the same as the velocity when it was fired.
- the angle at which the mortar impacts the ground is equal to the launch angle;
- it is practically unnecessary to consider crosswind when developing short range shooting tables;
- for training – practice firing at a range of up to 100 m the necessary initial velocity for the round must be around 32÷33 [m/s];
- on short distance firing the initial velocity and firing angle have a major influence, but not the mass and the force of front resistance, so that the trajectories for different types of mortars at low starting velocities will be practically the same;
- in solving the problem of flight stability, a practical solution should be sought by shifting the center of gravity towards the top of the mortar.

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