Research on small caliber weapons firing ranges security enhancement considering the projectile-obstacle impact

N-D Zvîncu¹, C-E Moldoveanu¹, A-D Mandache-Dodoiu¹, F-M Dîrloman² and I Vedinaș¹
¹Military Technical Academy “Ferdinand I”, Faculty of Integrated Weapons Systems, Engineering and Mechatronics, Blvd. George Coșbuc, No. 39-49, 050141, Bucharest, Romania
²Military Technical Academy “Ferdinand I”, Doctoral School “Defense and Security Systems Engineering”, Blvd. George Coșbuc, No. 39-49, 050141, Bucharest, Romania

E-mail: daniel.zvincu@mta.ro

Abstract. Weapons systems are used to gain a tactical, strategic, material or mental advantage over an adversary or enemy target. The modern weapons systems are designed to be technologically complex but practical for operator usage. The firing phenomenon consists of a multitude of mechanical and thermodynamic processes with the result being the movement of the projectile towards a chosen target. The projectile movement from the weapon to the point of impact defines its trajectory.

Firing ranges are locations where military personnel is operating certain weapons systems in order to achieve specific results and certain levels of readiness. Due to increasing urbanisation of the areas adjacent to firing ranges, monitoring the projectile trajectory becomes mandatory in order to be able to provide a secure climate for both military personnel and civilians.

It is the purpose of the author to provide the numerical simulation tool (a MATLAB application) which is useful for tracking the projectile trajectory from the muzzle of the weapon to the impacted obstacle. By computing the useful information obtained with the internal and external ballistics, the theoretical trajectory of a projectile can be calculated. In order to get the most accurate values, preliminary knowledge is needed. So by using appropriate tools and software, a projectile's trajectory can be calculated if the correct values are provided (mass, diameter, initial angle, initial speed). The tool created has different weapons-ammunition specifications and initial conditions parameters loaded that can be combined with the existing drag laws known in ballistics (Siacci law, 1930 law or 1943 law) to describe the projectile movement in atmosphere.

As obstacles are defined, similar to the ones existing in a firing range, the tool can assess where the impact occurred and is able to display necessary values (impact points coordinates, velocities, impact angles, etc) while also creating 3D and 2D visualisations on the integrated graphic area. This way, the tool can be used to create impact assessments for specific weapons systems and decisions can be made to enhance the security of the firing range and the firing safety.

Three different firing range configurations are considered for comparison when using certain small caliber weapons used by NATO countries.

1. Introduction

The research is conducted on the determination of weapon aiming angles considering the bullet trajectory in the firing range. These determinations are part of the author's work concerning the evaluation of firing range ballistic protection, when firing, in different conditions, small caliber weapons systems.
weapons [1, 2] as approaches concerning risks when firing small calibre weapons in ranges were mostly considering the lead exposure for military personnel, toxicity levels and environmental risks [3, 4].

Initial research was concerned on determining the projectile initial velocity, mass and the cross sectional area. This was realised using Photron high speed camera for slow motion analysis, precision weighing equipment and measuring systems.

Having the experimental values determined for the weapons systems tested, next the computational program can be developed.

For comparison purposes, results will presented for two weapons, the AKM assaul riffle chambered for 7.62 x 39 mm ammunitions, respectively the Brügger & Thomet APR 308 sniper rifle, using 7.62 x 51 mm NATO ammunition [5]. The goal of the author is to create a numerical tool based on experimental approaches and numerical simulation to evaluate risks of projectile-obstacle impact and ricochet phenomenon.

2. Experimental determinations
The experimental determinations are conducted to measure some of the initial parameters needed for the bullet trajectory calculus. In order to obtain the bullet trajectory we use the following initial conditions for each weapon system:
- the initial speed, \( v_0 \) [m/s];
- the initial angle, \( \theta_0 \) [°];
- the initial position, \((x_0, y_0, z_0)\);
- the mass, \( m \) [g];
- the bullet diameter, \( d \) [mm].

Therefore, for the projectile initial velocity at the barrel of the weapon, the following experimental testing scheme shown in figure 1 was used:

![Figure 1. Experimental determinations setup.](image)

For accuracy, the weapon system is fixed on the mounting device. The high speed camera is recording the projectile movement on a specific known distance from the weapon barrel. Having the motion time, the velocity is obtained.

Considering the results of the experimental firings, the following values were attributed:

| Weapon system               | AKM assaul riffle | Brügger & Thomet APR 308 |
|-----------------------------|-------------------|--------------------------|
| Bullet velocity \((v)\) [m/s] | 980               | 833                      |
| Projectile shape index \((i)\) | 1.1575            | 1.048                    |
3. Projectile trajectory numerical simulation

In order to compute the trajectory of the bullet, the different forces and phenomena occurring during the flight need to be assessed. The most effective way to do that is to express all the forces applied to the bullet and to establish the equations of the movement \[6, 7, 8\]. Some hypotheses are taken into account: the bullet is studied for a short-range; the Coriolis force is neglected etc. \[9, 10\]. The following forces are considered to be applied to the system: weight \((G)\) – equation (1), drag \((R_x)\) – equation (2):

\[
G = mg \\
R_x = \frac{\rho(y) \cdot v^2}{2} \cdot S \cdot C_x(M)
\]

with:
- \(\rho\), density of the air [kg/cube m];
- \(v\), bullet velocity [m/s];
- \(S\), cross sectional area [m²];
- \(C_x(M)\), drag coefficient.

Next we can establish the equations needed to study the bullet movement. We use the fundamental principle of dynamics \[9\]. Were obtained the equation (3):

\[
\begin{align*}
\frac{dv}{dt} &= -g \cdot \sin \theta - \frac{\rho \cdot v^2}{2 \cdot m} \cdot S \cdot i \cdot C_x(M) \\
\frac{d\theta}{dt} &= -\frac{g \cdot \cos \theta}{v} \\
\frac{dx}{dt} &= v \cdot \cos \theta \\
\frac{dy}{dt} &= v \cdot \sin \theta
\end{align*}
\]

where:

\[
M(v, a) = \frac{v}{a}
\]

\[
a = \sqrt{\gamma \cdot R \cdot T(y)}
\]

\[
\begin{align*}
\gamma &= 1.4 \\
R &= 286.9 \left[ \frac{J}{kg \cdot K} \right]
\end{align*}
\]

- \(M\) being the Mach number obtained by dividing the bullet velocity at the local speed of sound;
- \(\gamma\) is the adiabatic coefficient of air;
- \(R\) is the characteristic constant of air as a mixture of gases;
- \(i\) is the projectile shape index.

Drag coefficient is given for the 1943 law, in the following table 1 given in \[11\]:

| Table 1. Drag coefficient values for mach number variation. |
|-----------------------------------------------------------|
| Mach number  | 0   | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| C_{1943}(M)  | 0.1573 | 0.1573 | 0.1573 | 0.1573 | 0.1573 | 0.1573 | 0.1573 | 0.1573 | 0.1594 | 0.1854 |
| Mach number  | 1   | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 1.9 |
| C_{1943}(M)  | 0.3254 | 0.3776 | 0.3840 | 0.3793 | 0.3707 | 0.3609 | 0.3509 | 0.3414 | 0.3322 | 0.3238 |
Using the the equation (3) to (6) presented above, a computational program having the aim to calculate the single or multiple trajectories was set up. The impact points of the trajectories are obtained by taking in account the obstacles defined.

Three different firing range configurations were considered as below, in figure 2:

![Firing range models considered](image-url)

**Figure 2.** Firing range models considered.
For these configurations, the numerical calculations were realised, using increments of 0.1 for both vertical and horizontal angles of inclination of the weapon’s aiming direction ($\theta_{0V}$, $\theta_{0H}$).

The interface for the trajectory calculus and the graph area generated afterwards, can be visualised in figure 3, respectively figure 4.

![MATLAB program interface](image)

**Figure 3.** MATLAB program interface.

![Graph area of the interface](image)

**Figure 4.** Graph area of the interface (XZ plot, XY plot, 3D plot).

The program has different settings allowing to compare bullet trajectories both numerical and visual. The command window also displays the numerical values of the impact point, for better comparison.

4. **Numerical Simulation Results**

The values obtained are graphically presented next, indicating two situations:
- values of -1 for the cases when the trajectory is hazardous, extending past the firing range area;
values of 1 for the cases of trajectories that are capitated in the firing range.

Results obtained from the ballistic protection perspective, when simulating firings with AKM rifle in the first firing range configuration.

Results obtained from the ballistic protection perspective, when simulating firings with Brügger & Thomet APR 308 sniper rifle in the first firing range configuration.

Results obtained from the ballistic protection perspective, when simulating firings with AKM rifle in the second firing range configuration.

Results obtained from the ballistic protection perspective, when simulating firings with Brügger & Thomet APR 308 sniper rifle in the first firing range configuration.
Results obtained from the ballistic protection perspective, when simulating firings with AKM rifle in the second firing range configuration

Results obtained from the ballistic protection perspective, when simulating firings with Brügger & Thomet APR 308 sniper rifle in the first firing range configuration

5. Conclusions
The third configuration of the firing range offers the best ballistic protection of the firing range and the adjacent area, for changes in the horizontal and vertical firing angles, respectively.

The first two configurations have multiple values less than 7° of the vertical firing angle for which the projectile trajectory exceeds the firing range area.

By adding an additional ballistic panel at a distance of 25 meters from the firing alignment, the vertical angle for which ballistic protection of the third firing range configuration is ensured can be doubled.

6. References
[1] N-D Zvincu et al 2019 Acoustic pressure and flame generation determinations in case of mechanical and gas-dynamic processes for small caliber weapons IOP Conf. Ser.: Mater. Sci. Eng. 591 012073.
[2] Zvincu N.-D., Haller L., Nistoran G.-D., and Vedinaş I 2017 Determinations of some Firing Effects of Small Caliber Weapons MTA Review XXVIII(2) 75-99.
[3] Štěpánek L., Nakládalová M., Klementa V., Ferenčíková V. 2020 Acute lead poisoning in an indoor firing range Medycyna Pracy 71(3), 375-379, https://doi.org/10.13075/ mp.5893.00930.
[4] Bückler P., Lloyd Pope A. 1996 Modelling Environmental Risk for Firing Ranges, Environmentally Responsible Defence, Publisher: Australian Defence Studies Centre.
[5] https://modernfirearms.net/en/sniper-rifles/standart-caliber-rifles/switzerland-standart-caliber-rifles/bt-apr-308-eng/, accessed date: 17 of september 2020.
[6] Goga D A 2007 Safety and performance features of small caliber weapon systems Analysis and Simulation of Semiconductor Devices Scientific Universe Publishing House (in Romanian) Bucharest.
[7] Carluci D., Jacobson S. 2018 Ballistics, Theory and design of guns and ammunitions CRC Press.
[8] Cîrmaci-Matei M.V. 2010 Small arms – Analysis. Testing. Functioning Military Technical Academy Printing House, Bucharest.
[9] Marinescu I. and Verboncu S. -1973 Mechanisms of automatic weapons Military Publishing House, Bucharest (in Romanian).
[10] Robert L. McCoy 1999 Modern Exterior Ballistics Schiffer Publishing Ltd.
[11] Khaikov, V. 2017 Review of mathematical formulas for the air resistance law of the 1943 year Part 1. Electronic Information Systems 4(15) 74-90.