Experimental study on the influence of boundary conditions on firing accuracy of anti-materiel rifle

Peng Li¹ and Peng Dong

Army Engineering University, 97 Heping West Road, Shijiazhuang, Hebei, China

¹E-mail: rifle_li@hotmail.com

Abstract. As a high precision individual weapon, the shooting accuracy of anti-materiel rifle is the most concerned index of designers. When the anti-materiel rifle shoots, it uses the lying position to support the shoulder way. Therefore, the ground and shooter conditions constitute the boundary conditions of shooting. In order to study the influence of boundary conditions on shooting accuracy of anti-materiel rifle, a series of experiments were carried out. The experimental results showed that the ground conditions have a significant effect on the shooting accuracy of anti-materiel rifles, while the shooter’s weight has little effect.

1. Introduction

Anti-materiel rifle, or large caliber sniper rifle, usually has caliber exceeds 12.7 mm. Its main purpose is to destroy high value targets of 1-2 km in battlefield like commanders, light armored vehicles, radar, oilcans, aerodrome equipments, and so on. As an individual weapon, it usually shoots in a prone position. The rifle rack is supported on the ground. The butt of the rifle is against the shooter’s shoulder. The ground condition and shooter constitute the boundary conditions of shooting. As a sniper rifle, firing accuracy is the most important technical index of the anti-materiel rifle. In order to improve the shooting accuracy, the boundary conditions were studied experimentally in this paper.

2. Mathematical model of firing accuracy

To show the influence of structure parameters on firing accuracy and get firing accuracy index, mathematical model of firing accuracy of anti-materiel rifle was established firstly.

2.1. Basic hypotheses

To establish mathematical model of firing accuracy conveniently, several hypotheses were declared as follows [1]:

(1) Distributions of outline and mass of rifle and bullet are symmetrical. The angle of bullet axis and velocity vector is 0. According this hypothesis, air resistance vector is superposed with bullet axis. And air resistance track through center of bullet mass. The bullet can be studied as a particle.

(2) Influence of Coriolis force and change of acceleration with latitude are ignored.

(3) Curvature of earth and change of acceleration of gravity with altitude are ignored.

The shoot range of large caliber sniper rifle is much shorter than canon. And its trajectory is very flat. Therefore, these hypotheses do not affect analysis of firing accuracy.

Wind should be considered in firing accuracy model. Wind speed is defined parallel to the ground. And the vertical vector of wind is ignored. So wind could be decomposed to lengthways wind and...
transverse wind. Lengthways wind is expressed as $w_z$ and defined parallel to the firing plane. Transverse wind is expressed as $w_z$ and defined vertical to $w_x$.

According to these hypotheses, coupled equations of bullet movement were established [2].

$$\begin{align*}
\frac{dv_x}{dt} &= -cH(y)G(v_x,c)(v_x - w_x) \\
\frac{dv_y}{dt} &= -cH(y)G(v_y,c)v_y - g \\
\frac{dv_z}{dt} &= -cH(y)G(v_z,c)(v_z - w_z) \\
\frac{dx}{dt} &= v_x \\
\frac{dy}{dt} &= v_y \\
\frac{dz}{dt} &= v_z \\
\frac{dp}{dt} &= -\rho g v_y
\end{align*}$$

(1)

Where,

$v_x$, $v_y$, $v_z$ - components of bullet velocity according to $x$, $y$ and $z$ axis.

$v_x$ - velocity of bullet relatives to air.

$x$, $y$, $z$ - coordinate axes of bullet.

$c$ - ballistic coefficient.

$H(y)$ - air density function.

$G(v_x,c)$ - resistance function.

$p$ - Atmospheric pressure.

Once ballistic parameters $c$, $v_0$, $\theta_0$ and wind velocity $w_x$, $w_z$ were confirmed, the trajectory of bullet was confirmed, too.

2.2. Simulation model of firing accuracy

Figure 1 shows the simulation model of firing accuracy of anti-materiel rifle established in Simulink of Matlab based on the mathematical model.

![Figure 1. Simulation model of firing accuracy in Simulink.](image)
Used the model of firing accuracy upper, firing of anti-materiel rifle at shoot range of 200 m was simulated. Figure 2 shows results of firing accuracy simulation.

![Figure 2. Impact points distribution of 200 m.](image)

2.3. Firing accuracy index of anti-materiel rifle
When measuring the shooting accuracy of small arms, the radius of half scatter circle and the radius of all scatter circle are often used. The former is referred to as $R_{50}$. And the latter is called $R_{100}$. $R_{50}$ is the radius of the circle centered on the average impact point, including 50% of the impact points. $R_{100}$ is the radius of the circle including 100% of the impact points. $R_{50}$ application is more common in practice.

Based on statistical knowledge, the calculation methods of $R_{50}$ and $R_{100}$ are as follows [3]:

$$R_{50} = \sqrt{2\ln 2\sigma}$$

$$R_{100} \approx 3R_{50}$$

Where $\sigma$ is mean square error of impact point coordinates. Obviously, the smaller the $R_{50}$ or $R_{100}$, the higher the shooting accuracy of the anti-materiel rifle.

3. Experimental analysis of the influence of boundary conditions on firing accuracy
There are many factors affecting the shooting accuracy of anti-materiel rifles, including vibration, shooter and gun mounting conditions. The influence of weapon vibration can be analyzed by establishing finite element model. The vibration response of the anti-materiel rifle is related to the boundary conditions. Therefore, its accuracy is sensitive to the conditions of gun mounting. The gun mounting on different ground media is a major factor affecting the firing accuracy of anti-materiel rifles.

In order to study the influence of different gun mounting schemes on the accuracy of anti-materiel rifles, five typical ground surfaces were selected for experimental study. The different ground surfaces and their mechanical properties are shown in the Table 1.
Table 1. Typical ground surfaces and their mechanical properties.

| Ground surfaces   | Sandy land | Grass land | Clay land | Gravel land | Concrete ground |
|-------------------|------------|------------|-----------|-------------|-----------------|
| Density (g/cm³)   | 1.47       | 1.77       | 1.86      | 2.1         | 2.3             |
| Elastic modulus (MPa) | 0.45       | 1.03       | 3.5       | 15          | $2.1 \times 10^4$ |

In the experiment, the shooting distance is 200 meters. The shooting experiment was divided into two groups with 50 shots in each group. Shooting by the same shooter can eliminate the influence of shooter difference. The experimental results of shooting accuracy are shown in the Table 2.

Table 2. Experimental results of firing accuracy on different ground surfaces.

| Ground surfaces   | Radius of scatter circle (mm) | Average value |
|-------------------|-------------------------------|---------------|
|                   | Group 1 | Group 2 |                  |                  |
|                   | $R_{50}$ | $R_{100}$ | $R_{50}$ | $R_{100}$ | $R_{50}$ | $R_{100}$ |
| Sandy land        | 8.96    | 25.76    | 6.96     | 16.56      | 7.96    | 21.16     |
| Grass land        | 6.4     | 20.48    | 5.6      | 12.4       | 6.0     | 16.44     |
| Clay land         | 6.32    | 14.16    | 5.2      | 12.72      | 5.76    | 13.44     |
| Gravel land       | 6.24    | 19.84    | 6.4      | 16.88      | 6.32    | 18.36     |
| Concrete ground   | 17.52   | 73.2     | 18.96    | 78.08      | 18.24   | 75.64     |

The line chart of the experimental results is shown in Figure 3.

![Figure 3](image-url)

Figure 3. Experimental results of firing accuracy on different ground surfaces.

Experimental results show that the shooting accuracy is the best when the anti-materiel rifle is set on the clay ground. Then there is grass land, gravel land and sandy land. When the rifle is set on the concrete ground, the shooting accuracy is the worst.

Anti-materiel rifles are used in the way of lying shoulder fire. The huge recoil force produced in the moment of rifle shooting is directly borne by the shooter’s shoulder. The weight of the shooter will have a certain influence on the inherent dynamic characteristics and dynamic response characteristics of the rifle. Therefore, the weight of the shooter may also affect the accuracy of the anti-materiel rifle.

In order to study the influence of shooter’s weight on the firing accuracy of anti-materiel rifle, a skilled shooter was selected for shooting experiment. In the experiment, the shooting distance is 200 meters. The shooting experiment was divided into two groups with 30 shots in each group. The
shooter changed his weight by wearing sandbags. The experimental results of shooting accuracy are shown in the Table 3.

**Table 3.** Experimental results of firing accuracy of shooters with different weights.

| Weights of the shooter (kg) | Group 1 | Group 2 | Group 3 | Average value |
|-----------------------------|---------|---------|---------|---------------|
|                             | R_{50} | R_{100} | R_{50} | R_{100}       | R_{50} | R_{100} | R_{50} | R_{100} |
| 50                          | 4.79   | 15.07   | 6.29   | 14.68         | 7.43   | 15.42   | 6.17   | 15.06   |
| 55                          | 6.72   | 17.66   | 5.21   | 15.15         | 6.32   | 13.59   | 6.08   | 15.47   |
| 60                          | 7.63   | 12.48   | 6.88   | 19.53         | 5.24   | 13.75   | 6.58   | 15.25   |
| 65                          | 6.48   | 15.72   | 4.85   | 11.30         | 7.37   | 16.97   | 6.23   | 14.66   |
| 70                          | 7.03   | 14.63   | 4.93   | 17.06         | 4.28   | 15.81   | 5.41   | 15.83   |
| 75                          | 6.72   | 11.38   | 5.19   | 15.45         | 5.89   | 16.83   | 5.93   | 14.55   |
| 80                          | 5.69   | 13.13   | 5.05   | 13.87         | 5.75   | 15.34   | 5.49   | 14.11   |

The line chart of the experimental results is shown in Figure 4.

![Figure 4. Experimental results of firing accuracy of shooters with different weights.](image)

From the experimental results, it can be seen that the change of shooter’s weight has little effect on the firing accuracy of anti-materiel rifle. This shows that the anti-materiel rifle has good compatibility with shooters. The change of shooter’s weight doesn’t affect the shooting accuracy as much as the change of ground surfaces.

4. Conclusions

It can be seen from the above analyses that the change of physical and mechanical properties of ground has a certain influence on the vibration frequency and muzzle response of the anti-materiel rifle. The ground condition is the key factor affecting the firing accuracy, because it has a direct impact on the vibration shape of the anti-materiel rifle. Therefore, in order to ensure the shooting accuracy, the anti-materiel rifle should not be set up on the ground which is too soft or too hard. Although the recoil of anti-materiel rifle is much greater than that of ordinary rifle, the weight of shooter has no significant effect on shooting accuracy. A well-trained shooter can shoot accurately with an anti-materiel rifle, no matter how light or heavy he is.
References

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