Experimental Investigation on the Damage Characteristics for Light Armored Vehicle by Large Caliber Rifle Projectile

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Abstract. Large-caliber multi-function rifle projectile is one of the main weapons used by the army to attack light armored vehicles. The damage of the bullet to light armored targets is not only the direct killing effect of bullets hitting the target, but also the flames and fragments formed by the penetration process. In this paper, the impact effect of a large caliber multi-functional bullet on light armored vehicles with different firing distance is studied by experiments. By reducing the charge to simulate the shooting at different distances, rifle projectiles with different speed penetrate 10 mm armor plate, and the formation process of after-effect fragment and flame is captured by high-speed photography. The flying angle, flame length and flame time can be observed from the high-speed photographic image. Through data processing, the spatial range of the after-effect fragment and flame was obtained. The research results showed that there was a positive correlation between fragment speed and penetration velocity, the after-effect fragment dispersion and the flame length are not very sensitive to the distance, and the flame size at the distance of 100 m is up to about 50\% than 400 m, the flame action time at 400 m is 4.62 times that of 100 m, and the flame reached the brightest time at 400 m is 10.29 times that of 100 m.

1. Introduction
With the wide application and development of high-tech in the military field, the conflict between anti-armour weapons and armor protection technology has become more and more intense, while promoting each other, common development and alternating rise. With the constant development and change of the target, higher requirements are put forward for weapons and equipment. Among the light weapons, the 12.7 mm machine gun is the main supporting weapon for infantry units to fight against thin armored mobile targets, and occupies an irreplaceable position. After years of development, equipment performance has been continuously improved, which supports the development of a series of bullets with multiple capabilities, such as the killing, armor piercing, burning, explosion and after-effect killing. No matters which of the above is important, the ultimate goal is to penetrate armor protection and to kill the target.

The armor-piercing bullet is one of the main threats faced by light armored vehicles at present. The damage of this kind of projectile to light armored target is not only the direct killing effect caused by...
the impact of the projectile on the target, but also the injurious effect of after-effect fragments to the internal occupant. For bullets, the form of after-effect is mostly fragments and combustion. The current research on after-effect is more focused on the fragments, from the battlefield injury statistics[1]. The proportion of injury of fragments is significantly higher than that of the projectile.

In the research that has been carried out, Yan[2] used a fragile tungsten alloy core material for armor-piercing bullets to explore the killing ability of the after-effect fragments of bullet, in his research an after-effect test was carried out based on an armor-piercing bullet with tungsten alloy penetrator, 10 mm thick homogeneous steel plate and a typical polyethylene composite body armor. The mass distribution and the dispersion law of after-effect fragments and the penetration effects of after-effect fragments penetrating into body armor were analyzed in his research. Zheng Ningge[3] carried out a study on the after-effect test technology and evaluation method, aimed mainly at solving the imperfection problem of the after-effect evaluation standard for the armor-piercing projectile, and then the evaluation method for the armor-piercing projectile was established and improved. Guo Yingnan[4] found that the impact point of the 12.7 mm armor-piercing projectile on the ceramic composite armor was close to the edge of the ceramic target, and the projectile became oblique penetration. The ballistic limit of the target at different angles was obtained, and the parameters such as the mass, ballistic limit and failure mode of the projectile were simulated, and the offset angle of the target and the thickness of the equivalent Q235 steel target were predicted.

Although the predecessors have conducted a lot of research, the focus is on the penetration problem, the after-effect fragments are concentrated on the dispersion angle, and there is almost no research on the after-effect flame parameters on the combustion effect. In this paper, the 12.7 mm multi-functional bullet was selected as the penetrator, and the ballistic performance was tested. The scattered distribution law of the after-effect fragments and the after-effect flame distribution law are obtained, which can provide the basis for further quantity-effect analysis to the after-effect function.

2. Test conditions and methods
In this paper, the 12.7 mm multi-functional bullet was fired with a 12.7 mm speed-measuring ballistic gun. The core material is a fragile tungsten alloy. A large number of fragments with small mass can be formed after penetration. The bullet contain high-energy substances, which can form flames when hit target.

By adjusting the charge quantity to simulate the velocity at different distances, the velocity of the projectile hitting the target can be adjusted. The 10 mm/0 ° homogeneous steel plate is placed 100 m away from the muzzle, and the target I and target II were placed 60 cm and 80 cm behind the steel plate, respectively. Both the Target I and Target II were paper targets in fragment test. The high-speed camera is positioned on the side to capture the whole process of fragments and flame action in the ballistic penetration process. The penetration test data at a distance of 400 m were obtained by charge reduction test. Figure 1 shows the layout and field diagram of the test equipment.

![Figure 1. Sketch of ballistic impact experiment.](image)

3. Distribution law of after-effect fragments

3.1. Reasons for fragmentation
The after-effect fragments formed by armor-piercing bullets can be formed in two ways. First, the steel plate is blocked and destroyed in the process of interaction with the projectiles, and the core and other parts of the projectile are damaged. Second, when the fragile tungsten alloy core hits the target, the energy-containing material filled inside the core is squeezed to release energy reaction, so that the internal pressure is constantly rising, and then make the fragile tungsten alloy expanded and broken. Among them, the larger mass fragments are composed of steel plate plugged and core bottom fragmentation.

3.2. Shooting distance and fragmentation

During the test, a high-speed camera was utilized to record the fragmentation process after the projectile penetrated the steel plate. At the end of the penetration process, the after-effect fragments continue to fly away in the direction of ballistics and radial direction, and the speed of the radial direction is much lower than the speed of ballistic direction. The speed of the after-effect fragments along the ballistic direction is measured by the high-speed camera. High-speed photography can not only catch the after-effect fragment cloud flight process, but also the shock waves formed can be seen in the image. By comparing the after-effect fragments at shooting distance of 100 m and 400 m, it can be seen in Figure 2 that the after-effect fragments breaking speed formed at 100 m is higher than the shock wave speed, while the after-effect fragments speed formed at 400 m is lower than the shock wave speed. The relationship between the average speed of the after-effect fragment cloud, the shock wave speed and the shooting distance is shown in Figure 3.

![Figure 2. Shooting distance of 100 m and 400 m.](image)

Under the condition that the projectile can effectively penetrate the steel plate, the higher the armor-penetrating speed, the higher the speed of the after-effect fragment, but when the shooting distance is at the critical penetrating speed, the after-effect fragment also has a higher speed of motion, the instantaneous motion speed of the after-effect fragments cloud under the 100 m can reach about 440 m/s, and the 400 m about 270 m/s. At 400 m, the instantaneous speed of the after-effect fragments cloud is reduced by about 40% compared to 100 m.

![Figure 3. The relationship between the speed and the shooting distance.](image)

![Figure 4. The number of fragments.](image)
Since the after-effect fragments are irregular, the fragments will roll in flight. Through high-speed photography and observation of the rolling fragments, the fragments with a length greater than 5 mm are considered to be large-mass fragments. Statistics show that the average number of large-mass fragments at 100 m and 400 m is 6, that is, within the distance from 100 m to 400 m, the impact on the number of large-mass fragments is relatively small. The largest fragments are formed by the plug of steel plate with a diameter of approximately 12 mm. By comparing the recovered fragments with the high-speed photographic images, the fragments above 0.4 g are analyzed. Figure 4 shows the statistics of the number of fragments at 100 m and 400 m based on high-speed photography, of which the number of fragments only formed by fragments is eliminated by the steel plate plugged. From Figure 4, if only viewed from the number, the distance has less influence on fragments compared with the results of 100 m and 400 m.

Statistics are made on the penetration and distribution of target I and target II at 60 cm and 80 cm behind the steel plate, because only if the size of the fragment is greater than 2.5 mm can it be considered to cause effective damage to the target, so a large number of fragments of extremely small size and mass in after-effect fragments cloud can not effectively kill the target, so in the process of measuring, selecting the maximum size of the bullet hole is greater than 2.5 mm. Select the outer three bullet hole that meet the size requirements to form a triangle, make the outer circle of the triangle, record the radius of the circle, as dispersion circle radius of the fragment, and then get the flying angle between the two targets. Comparison of flying angles after penetrating the steel plate at 700 ms is shown in Figure 5, and comparison of flying angles of two targets is shown in Figure 6.

![Figure 5](image5.png)

**Figure 5.** The flying angle comparison at 700 ms.

Due to the different impact speeds, there is a difference in the after-effect fragment speed, at 100 m, in 700 ms the fragment cloud position is closer to Target I than 400 m, it can be judged from Figure 5 and Figure 6, that the discrete dispersion range of different shooting distance, encroaching on Target I before the after-effect fragment, of which 400 m due to the impact speed is low, the formation of the after-effect fragment speed is reduced, in the steel plate after 60 cm flying dispersion is greater than 100 m, but the difference between the flying angle is very small, that is, the fly-off of the after-effect fragment is not sensitive to distance.

![Figure 6](image6.png)

**Figure 6.** The comparison of flying angle.

![Figure 7](image7.png)

**Figure 7.** The scattered circle diameter of Target I and Target II.
There is no obvious difference in flying angle, but the scattering diameter of Target I and Target II are still distinguished by the obvious numerical values. Figure 7 shows the scattering circle diameter of Target I and Target II. It can be seen that the spread of fragments increases obviously from 0.6 m to 1.4 m behind the target, and the diameter of the spread circle from 1.4 m to 0.6 m is basically 3 times.

4. After-effect combustion analysis

4.1. Combustion characteristics

Most of the currently equipped armor-piercing incendiary bullets use metal incendiary agents as energetic materials. Among them, the active substances of aluminum and Teflon (Al+PTFE) are very stable at room temperature, and will react when hit, releasing a large amount of heat, which can ignite the oil tanks under certain conditions. On the basis of meeting the performance requirements such as power and firing intensity, the 12.7 mm multi-functional rifle projectile is to select a substable energy-containing composite material consisting of fluoride and metal fillers as an energy-containing material.

As the work has been carried out, the work containing the effect of energetic bullets, mainly for aircraft, tanks and other armored targets generally have fuel tanks, armor-piercing bullets into the target internal explosion, or with strong secondary fragments, explosion waves, shock waves and other damage to the armored engine, fuel, etc. The effect of the fire effect is less research on personnel. When combustion only occurs in the non-ammunition and fuel areas of armored vehicles, the effect of after-effect combustion on personnel is as follows: burning bare skin, burning air respiratory tract, burning oxygen consumption and generating harmful gas to interfere with personnel's combat.

Under the premise of the existing test results, the temperature and pressure distribution data of the flame are lacking, and the size of the flame produced by the after effect at different shooting distances is studied in this paper, which is the basis for further establishing the quantity-effect study of the effect of the after-effect flame on the human being.

4.2. Analysis of after-effect flame size

By processing the high-speed photographic image, the smoke in the after-effect flame is filtered to reduce the influence of the smoke in the image on the flame size measurement, and the image is compared with the smoke filtered image in the flame in Figure 8.

**Figure 8.** The compared with the smoke in the flame filtered and non-filtered. (a) comparison when the flame is longest; (b) comparison when the flame is at its brightest.
The duration of after-effect flame in the article. The maximum flame length ($L_{\text{max}}$), the maximum flame diameter ($D_{\text{mb}}$) and maximum flame brightness length ($L_{\text{mb}}$) are calculated, and the results are shown in Figure 9, and the comparison between the frame duration and the moment when the flame reached the brightest is shown in Figure 10.

![Figure 9](image-url)  
![Figure 10](image-url)  

**Figure 9.** The comparison of $L_{\text{max}}$, $D_{\text{mb}}$, $L_{\text{mb}}$.  
**Figure 10.** The comparison of brightest moment and duration.

Comparing the flame results at 100 m and 400 m in Figure 9 and Figure 10, it can be found that the active material burner made of aluminum and Teflon are particularly sensitive to the impact velocity. At 100 m, because of the high impact velocity, the combustion agent reaction is more intense than that at 400, that is, burnout time is earlier.

In terms of flame size, the maximum length of a flame at 100 m is 1.44 times that of 400 m, when the diameter is 1.23 times that of 400 m, and the maximum length of a flame is 1.54 times that of 400 m. The action time of flame at 400 m is 4.62 times of that of 100 m, and the brightest time at 400 m is 10.29 times of that of 100 m. Due to the low impact velocity at 400 m, which is about 0.8 times of that of 100 m, the flame action time is obviously higher than that at 100 m.

### 5. Conclusion and discussion

In this paper, an armor-piercing bullet with a fragile tungsten alloy core material was utilized to carry out the after-effect test of penetrating the steel plate, and the law of after-effect fragment flying and the distribution of after-effect flame were analyzed. The main conclusion is as follows:

In this paper, the rifle bullet with a fragile tungsten alloy armor-piercing cores is used, and the after-effect fragments are formed after armor-piercing projectile. From the fragment cloud speed, the velocity at 400 m decreases by approximately 40% than that at 100 m. The velocity of after-effect fragments formed at 100 m is higher than that of shock waves. The velocity of the after-effect fragments formed at 400 m is lower than that of shock waves.

For the after-effect fragment from 0.6 m to 1.4 m behind the steel plate after armor-piercing, the scattering of the after-effect fragments is not sensitive to the distance in numerical terms, but the diameter of the scattered circle at 1.4 m basically that of 0.6 m is 3 times.

From the size and time of the after-effect combustion flame, the burning is more intense at the distance of 100 m, from the size, the flame size at 100 m is up to about 50% than 400 m, the flame action time at 400 m is 4.62 times that of 100 m, and the flame reached the brightest time at 400 m is 10.29 times that of 100 m.

There are many forms of influencing after-effects. The article only discusses the distribution of after-effect fragments at 100 m and 400 m and the size and time of after-effect flames. It is still necessary to conduct further research on other issues, especially, the temperature distribution and pressure distribution of after-effect combustion.

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