THE EFFECTS OF MUZZLE FLOWFIELD ON FIRING PRECISION IN A MULTI-BARREL GUN*

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The modern war requires continual improvement of the weapon shooting precision. Especially in multi-barrel weapons, there are so many factors affecting the shooting precision, such as the muzzle flowfield disturbance between different projectiles. Firstly a mathematical model of muzzle flowfield coupling with the interior ballistics process was established, and the simulation was conducted in a small caliber gun in which the finite volume method was used to solve the muzzle flow on the 2d unstructured grids. The numerical results are consistent with the experimental ones. Then, flowfields of two barrel gun was simulated, and the effects of barrel distance, firing delay between different projectiles on shooting precision were also discussed.

INTRODUCTION

In recent years, the modern war requires continuous improvement of the firing precision. Among a great deal of effects that affect the firing precision of gun, the disturbance of muzzle flowfield to projectile is an important factor. So it is important to make research on muzzle flowfield, and analyze the effects of muzzle blast wave on the firing precision of gun. It has vital significance to instruct experiment and improve the firing precision of gun. In the multi-barrel gun, the mutual interference of flowfield among the muzzles would affect not only the pressure of bottom of projectile, but also the lateral deviation; all this will have a large effect to shooting precision. Having a deep understanding to the form mechanism of muzzle complex wave system is very

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important. There are a lot of researches about muzzle flowfield on the numerical simulation hypotheses that neglecting the effects of initial flowfield and projectile moving. Although the question can be simplified by making such hypotheses, the result has a definite difference from the fact.

This paper calculates the muzzle flowfield coupling with the interior ballistic process. The calculation starts from the interior ballistic process. It is closer to the practical situation.

NUMERICAL SIMULATION OF INTERIOR BALLISTIC PROCESSES

Physical and Mathematical Models

The classical interior ballistic model is established and the equations about the combustion velocity, shape function, projectile velocity and energy can be found in reference [1].

The equation of projectile moving is:

$$sp_b - s(F_1 + F_2) = m\frac{dv}{dt} \tag{1}$$

where p_b is the pressure at the projectile base, F_1 is the pressure ahead of projectile and it can be gained from the calculation of the flowfield ahead the projectile by CFD, F_2 is the friction force.

Numerical Simulation Results and Experimental Verification

The program of interior ballistic numerical simulation is incorporated in the FLUENT Software. The paper takes a numerical simulation for the interior ballistic process of a small caliber gun by above equations. Where, propellant is 6/7, loading density is 0.828/cm^3, projectile travel is 1.50m.

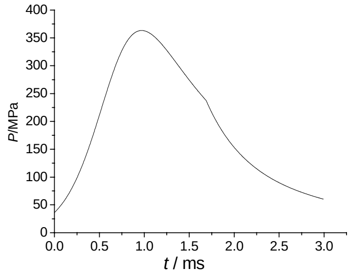


Figure 1. Breech pressure vs. time

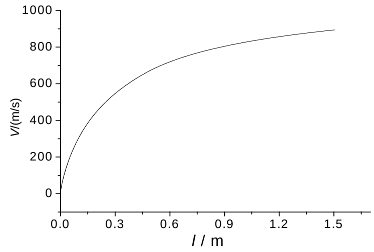


Figure 2. Projectile velocity vs. travel

The muzzle velocity and maximum pressure of this small caliber gun by experimenting is v_g =890 ± 15m/s and $p_t \leq$ 369.6Mpa respectively. The muzzle velocity and maximum pressure by numerical simulation is 893.98m/s and 368.4Mpa respectively. From the comparison between experiment and numerical simulation, the interior ballistic model including the pressure ahead the projectile is correct, and the method that coupling interior ballistic process with calculation of muzzle flowfield via pressure ahead the projectile is reliable.

It can be found that the change of pressure ahead projectile is the same as the change of projectile velocity, when t=2.8ms that foreside of projectile has exited muzzle, the pressure ahead projectile reduce rapidly for the distributed characteristic of initial muzzle flowfield, but the reciprocal effects between initial muzzle flowfield of double-barrel lead that the pressure ahead the projectile has a little increase.

NUMERICAL SIMULATION OF A DOUBLE-BARREL SMALL CALIBER GUN'S MUZZLE FLOWFIELD

The paper utilizes the FLUENT software to simulate the muzzle flowfield. FLUENT software that based on finite volume method main is employed for simulation and analysis of flow and heat transfer. It can deal with flow analysis, steady and unstable flow analysis, compressible and uncompressible flow model, laminar flow and hydraulic flow models, heat transfer and heat mixing analysis, chemical component mixing and reaction analysis, multi-phase flow analysis, solid and fluid coupling heat transfer analysis and porous medium analysis. Where, the hydraulic flow models include S-A model, $k-\varepsilon$ model, Reynolds stress model, LES model, standard wall function and double-layer wall model [2] [3].

Calculating Comparison

In order to validate the calculating results of FLUENT for muzzle flowfield, the calculating model of a 7.62mm gun is chosen. Where, barrel length is 530mm, barrel inner diameter is 7.62mm, charge weight is 1.625g. Choose Spalart-Allmaras hydraulic model and second order upwind scheme to simulate muzzle flowfield, make time-step as 0.000001s. After 1500 time-steps, the isoline of muzzle pressure can be gained.

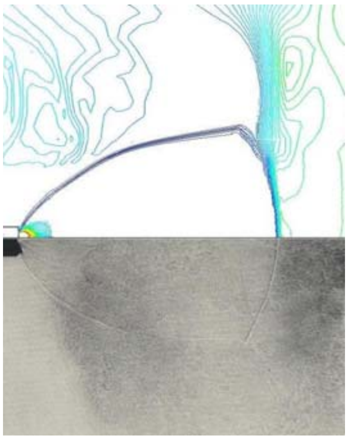


Figure 3. The calculation and experimental results of muzzle floefield of 7.62mm gun

Figure.3 shows the comparison of muzzle pressure between experimental and calculation result of a 7.62mm gun. It can be found that muzzle shockwave is ampullaceous, and is almost the same as experimental result. Thus, the method for numerical simulation of muzzle flowfield by FLUENT software is reliable.

Numerical Simulation of a Double-barrel Small Caliber Gun’s Muzzle Flowfield

Choose loading density is 0.828 g/cm^3, projectile travel is 1.5m, and barrels distance is 0.116m.

(1) Process of projectile moving in the barrel

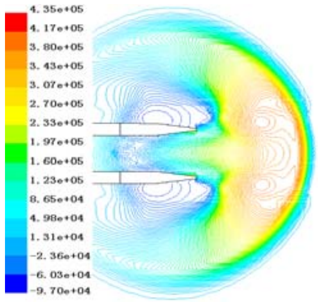


Figure 4. The pressure isoline

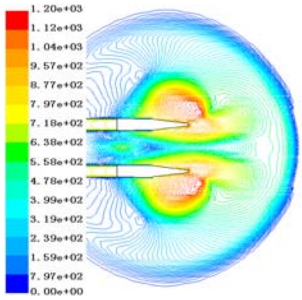
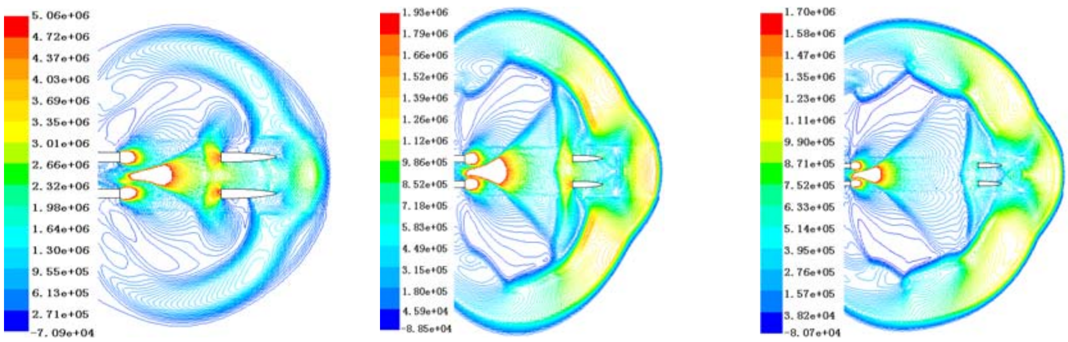


Figure 5. The velocity isoline

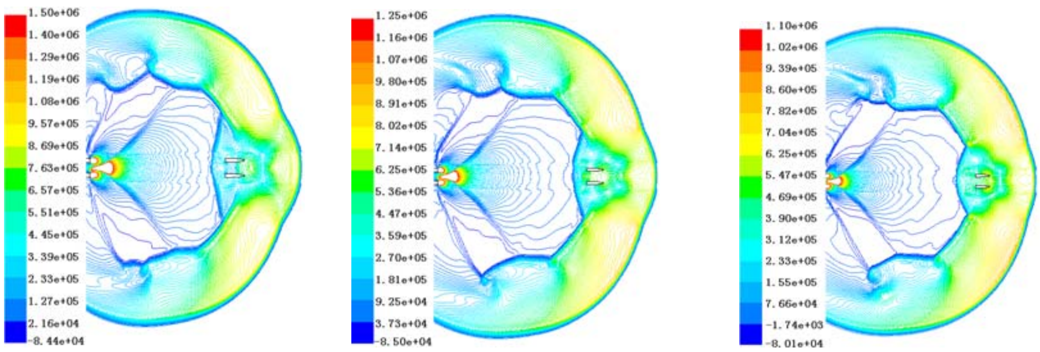
Figure 4 and Figure 5 is the isoline of pressure and velocity when projectile arriving at the muzzle respectively. It can be found that initial muzzle flowfield is made up of jet structure besieged with shockwave. For the inter-disturbance of initial flowfields between two barrels, a higher pressure and lower velocity area is formed between projectiles.

(2) Process of projectile exiting muzzle

In this process, the axial and lateral moving is controlled by the pressure difference among the pressures of ahead, rear and both sides of projectile. Calculate with relative pressure and the calculating time is begun from the projectile exiting muzzle.



t=0.3ms t=0.6ms t=0.9ms



t=1.2ms t=1.5ms t=1.8ms

Figure 6. Pressure isoline

Figure 6 show the form and development of double-barrel gun's muzzle flowfield. There exits a big muzzle pressure-ratio, and the projectile exiting muzzle resists the axial expansion of gas column. Thus the muzzle shockwave has a trend of lateral moving, the jet structure also displays the property of Big-Mach-Disc. From Figure 6, the muzzle shockwave forms at sides firstly, because of the direction of initial flowfield. When initial moment that projectile has exited muzzle, muzzle flowfield is surrounded by initial flowfield. As propellant gases venting into supersonic area of initial flowfield, it can't form forward muzzle shockwave before propellant gases' jet excesses the high speed area of initial flowfield. As for this calculation, the forward muzzle shockwave has formed completely until the time is 0.4ms. Because of the inter-disturbance of propellant gases between double-barrel, gases that laterally expanding into barrel added between two barrels. For the same radial velocity and contrary direction of propellant gases, there is only a high pressure area of axial velocity after mixing of propellant gases. This area is equal to a muzzle, and the high pressure propellant gases mixes in it, and then expands outside. This area is called core area in the next part. The supersonic core area's jet area of double-barrel can be separated into three parts. One is the jet area caused by mixture high pressure area, and it will be called centre area in the next part. Another two areas are the jet areas caused by the double-barrel propellant gases expanding towards outsides of barrel. This three jet areas are separated by four oblique shockwaves.

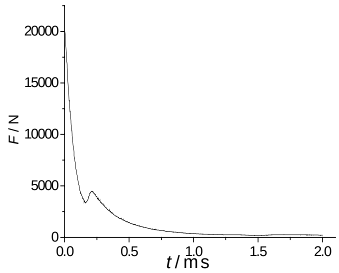


Figure 7. Base pressure vs. time when projectile exiting muzzle

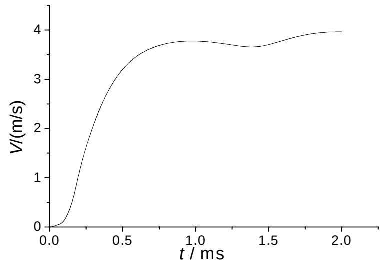


Figure 8. Lateral deviation velocity of projectile vs. time when exiting muzzle

Figure 7 show the distribution of base pressure of projectile after projectile exiting muzzle. It can be found that the bottom of projectile still has big pressure when projectile exiting muzzle for the high pressure of propellant gases in the barrel and the effecting of shockwave in the bottom of projectile from the figure 7. But as the quick expansion of propellant gases, pressure of bottom of the projectile is sharp falling in a short time when the projectile exiting muzzle. When it is 0.23ms, the high pressure gases formed by core area has a influence with the bottom of projectile, which makes the pressure of bottom of projectile rise a lot in a short time. It also can be found that the curve of projectile's velocity has some degree rising at that moment from figure 8. Because the core area expands outside very quickly, the bottom of projectile is locating the centre area of supersonic jet rapidly. But the velocity of projectile compared to the jet area is subsonic, the shockwave still exits at the bottom of projectile. When the projectile has past the Mach Disc, the shockwave of bottom of projectile disappears and varying trend of pressure is to be flat.

Figure 8 shows the distribution of lateral deviation velocity of projectile. For a high pressure area caused by two initial flowfields when the projectile just exits muzzle, there is a lateral deviation velocity after projectile exits muzzle, but the rising range of velocity is small. At 0.13ms, the core area affects the projectile, while the pressure between projectiles is rising, and then the lateral deviation velocity of projectile is also rising. With the movement of projectile and the expansion of core area, the pressure between projectiles and the increase of lateral deviation velocity is getting small. When it is 1ms, the deviation velocity achieves the maximum. After projectile past Mach Disc, because of the core influence of core area to projectile has disappeared and the Mach

Disc continues to expand, the velocity of gas between Mach Disc and bottom of projectile is larger than the velocity of projectile, and then there is a strait area between projectiles. When gases pass this strait area, the velocity is rising while the pressure is falling. Thus, after 1ms, the lateral deviation velocity of projectile has a little falling. For the influence of two barrels, there is a higher pressure area in the center line of two barrels. When it is 1.5ms, the pressure between projectiles has a little rising, and the lateral deviation velocity of projectile also has a little rising as the projectile entering this area. When it is 2ms, the deviation velocity of projectile is invariable.

CONCLUSIONS

This paper establishes a double-barrel small caliber gun's muzzle flowfield model. It can be found by the numerical simulation to this model that: (1)There is a large muzzle pressure ratio and projectile resistance in the beginning of shooting. While muzzle shockwave has a large trend to lateral movement, and the jet structure also displays the property of Big Mach Disc. (2)The muzzle flowfield is surrounded by the initial flowfield at the beginning of shooting. While gases jet can't form forward muzzle shockwave before it excesses the high velocity area of initial flowfield. (3)During the shooting of double-barrel gun, there is only a high pressure area of axial velocity after propellant gases expanding inside barrels. The jet area of supersonic core area is separated into three parts, which is divided by four oblique shockwave. (4)After projectile exiting muzzle, the pressure of bottom of projectile has a large rising in a small shooting time, and projectile produces a bigger lateral deviation velocity for the disturbance of propellants. The lateral deviation velocity has a large effect to shooting precision.

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