Flight characteristics and mutual interference analysis of projectile launched in parallel

W F Zhu, N Zhao, J Qu and Y W Wang

Northwest Institute of Mechanical and Electrical Engineering, Xianyang, Shaanxi, China

E-mail: zc427611@163.com

Abstract. Using the knowledge of computational fluid dynamics, a 3D simulation model of a 16 tube gun was established, and the process of muzzle flow field from single formation to mutual interference, stability and attenuation was simulated by solving N-S equations. Through the simulation analysis, it can be seen that the muzzle flow field formed by each barrel will influence and superpose each other when the multi-barrel gun is launched, and the lateral force caused by the asymmetric muzzle blast wave is acted on the projectile, and the lateral force of the middle four projectiles is small, the other 12 projectiles is larger. The results can be used as a reference for structural design, firing accuracy prediction and muzzle parameters test of multi-barrel launching weapon system.

1. Introduction

Multi-barrel parallel launching is one of the effective methods to improve the firing frequency of weapon system. In the process of parallel launching, the muzzle flow fields formed by each barrel superimpose and interfere each other because of the close distance between the barrels, and form a more complex muzzle flow field. The muzzle flow field after mutual interference acting on the projectile is asymmetric, which will influence the lateral pressure distribution on the projectile and produce a lateral disturbance, thus affecting the firing accuracy of the weapon system. Therefore, it is of great significance to study the muzzle flow field of multi-tube short-range parallel launching by numerical simulation.

At present, the research on muzzle flow mainly focuses on the theoretical analysis, experimental study and numerical simulation of the physical phenomena and mechanism of muzzle flow. On the basis of the dynamic grid technique, Dai Shulan considered the influence of the moving projectile on the development of the flow field [1], Wang Bing simulated the motion process of the projectile by solving the axisymmetric equations [2], Jiang Xiaohai, Li Hongzhi simulated the initial flow field, the formation and development of the propellant gas flow field, the coupling and interaction process with the projectile by using moved grid and embedded grid method based on ALE equation and the second-order accurate Roe method [3,4].

In this paper, the muzzle flow mathematical-physical model of a 16-tube 30mm gun parallel firing is established, by using three-dimensional Navier-Stokes equations and the Roe difference method, the development process of muzzle flow field and the interaction between projectiles are obtained, which provides a reference for firing accuracy analysis of Gun.
2. Control Equations

2.1. Physical Model

Based on the theory of computational fluid dynamics, the control equations of the muzzle flow field are established. The k-e two-equation turbulence model is used to describe the effect of turbulence fluctuation, and the muzzle flow field is considered as a pure gas phase process without considering the secondary combustion. Three-dimensional, compressible, unsteady Navier-Stokes governing equations under Cartesian coordinate system as follows:

\[
\frac{\partial U}{\partial t} + \frac{\partial F}{\partial x} + \frac{\partial G}{\partial y} + \frac{\partial H}{\partial z} = \frac{1}{R_e} \left( \frac{\partial F_v}{\partial x} + \frac{\partial G_v}{\partial y} + \frac{\partial H_v}{\partial z} \right)
\]

In the formula, U is the conservation vector, F, G, H are the inviscid energy vectors, \( F_v, G_v, H_v \) are the viscosity flux vectors.

\[
U = \begin{bmatrix} \rho \\ \rho u \\ \rho v \\ \rho w \\ e \end{bmatrix}, \quad F = \begin{bmatrix} \rho u \\ \rho u^2 + p \\ \rho uv \\ \rho uw \\ (e + p) u \end{bmatrix}, \quad G = \begin{bmatrix} \rho v \\ \rho v^2 + p \\ \rho uv \\ \rho vw \\ (e + p) v \end{bmatrix}, \quad H = \begin{bmatrix} \rho w \\ \rho w^2 + p \\ \rho vw \\ pw \end{bmatrix}
\]

\[
F_v = \begin{bmatrix} 0 \\ \tau_{xx} \\ \tau_{xy} \\ \tau_{xz} \\ u \tau_{xx} + v \tau_{xy} + w \tau_{xz} + q_x \end{bmatrix}, \quad G_v = \begin{bmatrix} 0 \\ \tau_{xy} \\ \tau_{yy} \\ \tau_{yz} \\ u \tau_{xy} + v \tau_{yy} + w \tau_{yz} + q_y \end{bmatrix}
\]

\[
H_v = \begin{bmatrix} 0 \\ \tau_{xz} \\ \tau_{yz} \\ \tau_{zz} \\ u \tau_{xz} + v \tau_{yz} + w \tau_{zz} + q_z \end{bmatrix}
\]
\[
\begin{align*}
\tau_{xx} &= -\frac{2\mu}{3} \left[ \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} \right] + 2\mu \frac{\partial u}{\partial x} \\
\tau_{yy} &= -\frac{2\mu}{3} \left[ \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} \right] + 2\mu \frac{\partial v}{\partial y} \\
\tau_{zz} &= -\frac{2\mu}{3} \left[ \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} \right] + 2\mu \frac{\partial w}{\partial z} \\
\tau_{xy} &= \tau_{yx} = \mu \left[ \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right] \\
\tau_{xz} &= \tau_{zx} = \mu \left[ \frac{\partial u}{\partial z} + \frac{\partial w}{\partial x} \right] \\
\tau_{yz} &= \tau_{zy} = \mu \left[ \frac{\partial v}{\partial z} + \frac{\partial w}{\partial y} \right]
\end{align*}
\]

In the formula, \( \rho \), \( p \) are the density, pressure, \( u \), \( v \), \( w \) are the dynamic velocity of the fluid, \( e \) is the total energy for per unit volume, \( \mu \) is the viscosity coefficient.

3. Physical model

3.1. Geometric model

In this paper, the muzzle flow simulation model including the motion of projectile for a 16-tube 30 mm gun is established. In order to reduce the simulation time, take 1/4 model for modeling. The calculation area is 20m \( \times \) 5m \( \times \) 5m, the distance between the barrels is 0.15m, and the distribution of barrels is shown in figure 1.

4. Mesh generation

By using ANSYS ICEM, the 3D geometric model of the 16-tube 30mm gun is divided into two parts, one part is the outer domain of calculation, the other part is the inner computational domain of the barrels, which is the area of moving grid. The grid division of inner computing domain is shown in figure 2.
4.1. Boundary conditions
For the boundary conditions of muzzle flow simulation, there are solid wall boundary and pressure outlet boundary in the whole calculation area. The surface of the barrel and muzzle device is solid wall, and the projectile is the moving solid wall. The periphery of calculation area is pressure outlet boundary.

4.2. Numerical simulation results
The computational domain is discretized by AUSM scheme and finite-volume method according to the aerodynamic characteristics of projectile with high mach number and complex blast wave system. According to the given boundary conditions and initial conditions, the process of muzzle blast wave from single formation to mutual interference, stabilization and gradual attenuation is obtained by simulation, the influence of muzzle flow field on the motion state of projectiles and the interference of projectiles launched in parallel are obtained. The pressure contours at different time are shown in figure 3, and the forces acting on the projectile in different directions after exiting the muzzle are shown in figure 4-6.

When the projectiles are just out the muzzle to 0.25 ms, the propellant gas does not expand greatly, the muzzle flow field of each barrel has not superimposed each other, the projectiles only receive the axial force from propellant gas, accelerates forward flight, the side direction is not stressed basically. As the projectiles fly forward, the muzzle flow field of each barrel grows. When the expansion air between the barrels meets, a region of high pressure is formed, where the turbulence is more intense, the impact on the projectile is gradually increased, resulting in the force on both sides of the projectile is not uniform, and the projectile has a lateral acceleration from inner side to outer side. From 0.5 ms, under the influence of the air flow in the high pressure area between the barrels, the air flow in the bore of the outer side barrel is inclined to the outside side, and the mach disk deformation of the flow field in the bore of the outer side barrel can be clearly seen from the pressure cloud diagram. With the expansion of the middle high pressure area and the motion of the projectile, the propellant gas pressure between the two projectiles decreases after reaching the maximum value, and the lateral force caused by the middle high pressure area on the projectile decreases gradually. At the beginning of 2.2 ms, the projectiles began to break out of the blast wave, and the lateral force on the projectiles decreased continuously until 3 ms, when the projectiles were completely out of the range of the muzzle blast wave and no longer affected by the blast wave.

From the axial (X direction) force curve of the projectile in figure 4, it can be seen that because of the superposition of the muzzle flow fields, the region of the middle barrel is produced high pressure area, and the axial force of the Projectile 1 located in the middle is the largest; The Projectile 2 and the Projectile 3 located in the center of the outer side bear the next axial force, and the axial force is equal; The Projectile 4 located in the outermost side bear the least axial force. From the lateral (Y, Z direction) force curves of the projectiles in figures 5 and 6, it can be seen that affected by the interference of the superposed muzzle flow fields, in the Y and Z directions, Projectile 1 is subjected to both the outward force which generated by the inner side muzzle blast wave and the inward force which generated by the outer side muzzle blast wave. Because of the superimpose the inner side muzzle blast wave is greater than the outer side, the Projectile 1 is subjected to a
lateral force from the inside to the outside, the maximum lateral forces in the Y and Z directions are basically equal; Projectile 2 in the Z direction is only subjected to the outward force which generated by the inner side muzzle blast wave, the lateral force in the Z direction is larger than that in the Y direction; Projectile 3 in the Y direction is only subjected to the outward force which generated by the inner side muzzle blast wave, the lateral force in the Y direction is larger than that in the Z direction; Projectile 4 is both subjected to a outward force which generated by the inner side muzzle blast wave in the Y direction and Z direction, and recieve a asymmetry influence of muzzle flow field, the maximum lateral force in the Y direction and the Z direction are almost the same. The maximum lateral forces of the four projectiles in the Y and Z directions are shown in table 1.

| the maximum lateral force/N | Projectel 1 | Projectel 2 | Projectel 3 | Projectel 4 |
|---------------------------|------------|-------------|-------------|-------------|
| Y direction               | 68.9       | 188.8       | 191.2       | 120.0       |
| Z direction               | 67.1       | 56.7        | 56.9        | 120.5       |
Figure 3. The pressure contour at different time.

(e) 2.2ms  (f) 3.0ms  (g) 3.2ms  (i) 5ms

Figure 4. Force curves in X direction.

Figure 5. Force curves in Y direction.
5. Conclusion

When the 16-barrel 30 mm gun is launched in parallel, the effect of muzzle flow blast wave on the middle 4 projectiles is symmetric, the lateral force on the projectiles is small, and the effect on the other 12 projectiles is asymmetric, which will produce a large lateral disturbing force on the projectiles. The asymmetric flow field will produce a deflection to the projectiles, which will make it deviate from the trajectory and reduce the firing accuracy of the weapon. The simulation results in this paper can provide reference for the analysis of weapon firing accuracy, muzzle velocity and attitude test of multi-projectile.

References

[1] Dai Shulan, Xu Houqian, Sun Lei. 2007 *Journal of Ballistics* 19(3) 93-6
[2] Wang Bing, Xu Houqian. 2008 *Journal of Ballistics* 20(4) 84-7
[3] Jiang Xiaohai, Li Hongzhi. 2007 *Acta Armamentarii* 28(12) 1512-5
[4] Jiang Xiaohai, Fan Baochun, Li Hongzhi. 2008 *Applied Mathematics and Mechanics* 29(3) 316-24
[5] Zhang Xuewei, Li Qiang, Liu Bin. 2016 *Journal of gun launch & control* 37(2) 10-3
[6] You Guozhao, Xu Houqian, Yang Qiren. 2003 *Intermediate ballistic* Beijing: National defence industry press

![Figure 6. Force curves in Z direction.](image-url)