Analysis and Research on the Impact of Bullet Head Eccentricity on Air Resistance

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Abstract. Through numerical simulation, the transverse resistance of the head eccentric bullet at 0.29 Ma, 0.58 Ma, 0.97 Ma and the eccentricity angle of 0° ~5° in the air was studied. When the bullet head deflects and flies at a certain speed, the tip of the bullet produces agitation to the air. This paper tries to find out the angle of minimum resistance by using the simulation software ANSYS when the eccentricity angle of the bullet head is between 0° and 5° degrees, and optimize the shape of the existing bullet. In this paper, three kinds of velocity are simulated. The simulation results show that the resistance of the head eccentric bullet in flight can become smaller. There is always a corresponding head eccentric angle at different speeds to minimize the flight resistance. As a result, the bullet can fly faster and farther.

1. Introduction
Bullets and missiles in modern weapons are the main means of hitting targets. Flying speed has a large effect on the lethality of the ammunition, and the speed of ammunition is related to flight resistance. The research on the aerodynamics of normal-shaped ammunition has been relatively mature, and people have begun to pay attention to the improvement of weapon performance of eccentric ammunition. With regard to the research on ammunition of head deflection, a series of theoretical analysis and experimental studies of aerodynamic characteristics have been conducted at domestic and foreign. Hole experiments did by Landers³ have proved the feasibility of head-deflecting ammunition flying under supersonic conditions. Wang Fei [2] studied the aerodynamic characteristics of the head deflection projectile and the results showed that when the head deflection angle reached 4.5°, the range increased by 77%. Ming Li, Rui Zhu [3] ~[4] and others studied the aerodynamic characteristics of the deflection head missile during flight, explored the resistance of the missile head at different deflection angles, and the position of the center of gravity. Further, Fanghai Wei [5] conducted a preliminary discussion on the trajectory correction technology for controlling the deflection angle of the arrowhead on the basis of the theory that the deflection angle of the arrowhead section generates additional control force. Tingxin Gao [6] of Shanghai Eighth Academy of Hospitals made a thorough research on the aerodynamic characteristics of the two control methods of yaw control and rudder wing. Mifsud [7] studied the tail-stabilized projectile with a deflectable head. The results show that the head deflection of 8° can double the lift coefficient at an attack angle of 1°.

Previous research mainly focused on the aerodynamic characteristics of head deflection missiles, but for missiles, there is no rotation of the missile itself, and bullets have high-speed rotation during flight, and domestic research on eccentric bullets is rare, so the research on eccentric bullets in the head is a new innovation and attempt.
This paper uses ANSYS software to carry out numerical simulation calculations, and studies the force in the air of the eccentric bullet (or cannonball, the same below) that rotates at high speed under the condition of subsonic speed. This article attempts to explore the corresponding flight speed that minimizes the flight resistance Head deflection angle to optimize the shape of existing bullets. In future applications, bullets with corresponding angles for different firing speeds of guns will be manufactured to maximize flight distance and lethality, providing a new way for the manufacture of new weapons.

2. Building a computational model

2.1. Building a geometric model
According to the general 7.62 mm bullet, it is simplified to the geometric model shown in Figure 1. The ratio of the long diameter (radius) is 6:5. In order to avoid the instability caused by the position of the center of gravity being too far away, the bullet tail is extended and increased. The mass of the tail of the bullet forces the center of mass to approach the axis of the bullet infinitely, reducing the instability caused by the center of mass deviation from the axis. In order to simulate the more detailed simulation results, the air model is set to a cylinder with a length of 60mm and a bottom radius of 50mm, with the standard atmosphere as the medium.

![Figure 1. Schematic diagram of the geometric model](image)

2.2. Meshing the Geometric Model
According to the bullet's own structure and accuracy, the mesh around the connection between the bullet and the bullet is carefully divided. Figure 2 shows the mesh division results of the bullet surface.

![Figure 2. Bullet surface mesh](image)  ![Figure 3. Surface mesh of air fluid](image)

By adjusting the grid at the fine connection point, the grid of the larger structure in the bullet is simplified to improve the calculation efficiency. There are total of 272,270 meshes, with less than 0.03% of inferior meshes. Figure 3 is a schematic diagram of fluid area meshes, with a total of 108070 meshes.
3. Calculation condition setting

In order to obtain the simulation results more accurately, the commercial fluid mechanics software ANSYS is used to do the aerodynamic simulation research.

The Renault time-averaged simulation method has high calculation efficiency, and the accuracy of the solution can basically meet the actual needs of engineering. It is the most widely used turbulence numerical simulation method in the field of fluid machinery\(^5\). The turbulence model used in this paper is the Spalart-Allmaras model. This model is more economical for large-scale grid computing, but it has poor simulation of 3D flow, free shear flow, and strong separation flow. It is mainly used in aerodynamic research and is suitable for less complex flows, such as wings and fuselages, Missiles, hulls, etc.

Spalart-Allmaras model transport equation is:

\[
\frac{\partial}{\partial t} (\rho \nu) + \frac{\partial}{\partial x_i} (\rho \nu_i u_i) = G_v - Y_v + S_v + \frac{1}{\sigma} \left[ \frac{\partial}{\partial x_j} \left( \mu + \rho \nu \frac{\partial \nu}{\partial x_j} \right) \right] + C_{\nu 2} \rho \left( \frac{\partial \nu}{\partial x_j} \right)^2
\]  

(1)

In this formula, \( \tilde{\nu} \): Turbulent kinematic viscosity, \( G_v \): Turbulent viscosity increase term, \( Y_v \): Turbulent viscosity decrease term, \( \nu \): Molecular kinematic viscosity, \( S_v \): User-defined source term

Determined by the following formula:

\[
G_v = C_{b1} \rho \tilde{S} \tilde{v}
\]  

(2)

\[
\tilde{S} = S + \frac{\nu}{\kappa^2 d^2} f_{v2}, \quad f_{v2} = 1 - \frac{\chi}{1 + \lambda^2 v}, \quad S = (2\Omega_1 \Omega_2)^{1/2}
\]

\( C_{b1} \) and \( k \) are constants, \( d \) is the distance from the wall, and \( \Omega_1 \) is the laminar rotation tensor

The model for turbulence disappearance is

\[
Y_v = C_{w1} \rho f_w \left( \frac{\nu}{d} \right)^2
\]

\[
f_w = g \left[ \frac{1 + C_{w3}^6}{B^6 + C_{w3}^6} \right]^{1/6}
\]

\[
g = r + C_{w2} (r^6 - r)
\]

\[
r \equiv \frac{\nu}{S \kappa^2 d^2}
\]

(3)

The model constant is \( C_{b1} \), \( C_{b2} \), \( \sigma \), \( C_{v1} \), \( C_{w1} \), \( C_{w2} \), \( C_{w3} \)

Due to the deflection angle of the bullet's head, the pressure on both sides is unequal at each instant of the bullet's flight and rotation, resulting in asymmetrical flow fields in the left and right areas of the bullet, and normal axial forces (lateral forces). The rifle of the gun needs to be modified from the principle of gyro stability. The bullet obtains a large angular velocity from the rifling of the barrel. After the bullet is ejected from the barrel, it rotates at high speed around its own axis to overcome the turning moment. Gyro stability is mainly determined by the gyro stability factor and the upper limit of entanglement.

The so-called gyro stability, the bullet obtains a large angular velocity from the rifling of the barrel. After the bullet is ejected from the barrel, it rotates at high speed about its own axis, thereby
overturning the overturning moment$^{[11]}$. Gyro stability is mainly determined by the gyro stability factor and the upper limit of entanglement.

The gyro stability factor marks the size of the gyro stability. Only when the gyro stability factor $S_g > 1$ is used, the spinner has gyro stability.

The upper limit of the entanglement of the rifle is the formula (4) derived from the gyro stability conditions.

$$\eta = \frac{\pi}{2} K \frac{\sqrt{J_x \mu C_m g}}{J_y 1000 \frac{h}{d} k_{mc0}}$$

In the formula:
- $J_x$: the moment of inertia of the bullet pole,
- $J_y$: the moment of inertia of the bullet,
- $\mu$: the mass distribution coefficient of the projectile,
- $C_m$: the mass coefficient of the projectile,
- $h$: the distance from the center of mass of the projectile to the center of air resistance,
- $d$: the maximum diameter of the projectile,
- $K$: the flip moment characteristic number

So the final calculation conditions are: the incoming Mach number is 0.29, 0.58, 0.97. The deflection angles of the bullet head are 0°, 1°, 2°, 3°, 4°, and 5°, respectively. The bullet flies at a speed of 500r/s.

4. Analysis of calculation results

Through ANSYS calculation, the drag coefficients and the pressure center positions of different warhead deflection angles during flight are obtained at different flight speeds. Because the calculated Mach numbers are all lower than Mach 1, the shock resistance coefficient does not appear. It is often expressed as $(C_d, C_x, C_w)$. It is a dimensionless quantity in fluid mechanics. It is used to indicate that an object is in a fluid (such as water or air) in resistance. The drag coefficient appears in the drag equation. A smaller drag coefficient indicates that the object is less subject to wind or fluid resistance$^{[12]}$.

$$C_x = X / q_s$$

In the formula:
- $C_x$: resistance coefficient,
- $X$: resistance (resistance is the same as the direction of the incoming flow speed, which is positive backward),
- $q$: dynamic pressure, $q = \rho \ast v \ast v / 2, \rho$ is air density, $v$ is Velocity of air flow relative to the object,
- $s$: reference area (the reference area used in this article is the area of the ellipsoid of the bullet head).

From Figure 4, it can be seen that in the case of subsonic speed, the head deflection angle has an influence on the x-axis force. When the bullet travels at a speed of 100 m/s, and the bullet's head deflection angle is 1°, the x-axis resistance coefficient decreases by 3% compared to 0°. When the bullet flight speed is 200m/s, the drag reduction effect is the best when the head deflection angle is 3°, which is 2% lower. When the bomb flying speed is 330m/s, the drag reduction effect is the best when the deflection angle of the head is 2°, which decreases by 8%.

![Figure 4. Effect of the deflection angle of the bullet head on the x-axis drag coefficient.](image-url)
As shown in Table 1, the specific values of the x-axis resistance coefficient under different deflection angles.

| Flight Speed | 0° | 1° | 2° | 3° | 4° | 5° |
|--------------|----|----|----|----|----|----|
| 100 M/S      | 0.5| 0.49| 0.52| 0.54| 0.63| 0.65|
| 200 M/S      | 0.53| 0.56| 0.62| 0.52| 0.69| 0.72|
| 330 M/S      | 0.57| 0.63| 0.45| 0.56| 0.78| 0.9 |

The factors that affect the stability of the bullet's flight are the relative position of the pressure center and the center of gravity. The pressure center, referred to as the pressure center, is the point where the force system is combined to a special point, and the sum of the moment is 0. Figure 5 shows the displacement of the pressure center position under different deflection angles of the bullet head. It can be seen that the pressure center position has always moved forward relative to the initial position with the increase of the deflection angle of the bullet head. Select the resultant moment in the ANSYS cloud diagram and limit the displayed value range to get Figure 5, which is 3° from the missile head deflection in reference [1]. The same applies to the following cases. At the same time, the larger the deflection angle at the same speed is, the greater the forward movement distance is.

![Figure 5](image_url)

Figure 5. Deviation of pressure center position at 1° and 5°

The forward movement of the pressure center will inevitably lead to the instability of the bullet. Obviously, the area of the circle in Fig. 5 is the approximate position of the pressure center. Further limit the range of the displayed value, you can get a more accurate position of the pressure center.
Figure 6. Effect of the deflection angle of the bullet head on the displacement of the x-axis pressure center.

Figure 7. Effect of the deflection angle of the bullet head on the z-axis pressure center position shift.

Figure 6 shows the x-axis offset distance of the center of pressure of the bullet at different angles under the condition that the declination of the head increases. It is not difficult to see that with the increase of the angle, the position of the center of pressure is single tail at three speeds. It can be seen from Figure 7 that under the condition, the head deflection angle increases, the z-axis offset distance of the press center at different angles is not difficult to see. As the angle increases, the offset of the press center position increases at three speeds.

5. Conclusion

In this paper, a numerical simulation is performed on a rotating bullet model with a deflection angle, and the aerodynamic characteristics of the bullet model with a deflection angle are preliminary explored. At a deflection angle of 0° to 5°, 100m/s, 200m/s, at the speed of 330m/s, the obstacles of the bullets and the deviation of the pressure center are as follows:

1) This article simulates the obstruction of the bullet at three speeds respectively. The simulation results show that when the flight speed is 100 m/s, the bullet's x-axis resistance decreases by 3% when the eccentric angle is 1° relative to 0°. When the bullet flight speed is 200m/s, the drag reduction effect is the best when the head deflection angle is 3°, which is 2% lower. When the bomb flying speed is 330m/s, the drag reduction effect is the best when the deflection angle of the head is 2°, which decreases by 8%.

2) With the increase of the deflection angle of the bullet's head, the center of gravity of the bullet will continue to move forward, and excessive forward movement will cause flight instability.

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