Research on ballistic and aerodynamic characteristic of uncontrolled trajectory correction device

Wei Zhou1,a, Jian Zhang1,b*, Cean Guo1, Shuang Zhao1, Wenke Xu2

1School of Equipment Engineering, Shenyang Ligong University, Shenyang 110159, Liaoning, China.
2Liaoshen Industries Group Co., Ltd, Shenyang 110045, Liaoning, China.
=aemail: zhouwei@sylu.edu.cn, b*email: wilchou724@163.com

Abstract. This paper studies the 125mm tank high explosive projectile equipped with two-dimensional correction device. To investigate the aerodynamic characteristic of two-dimension trajectory correction device before starting the correction device for ballistic control, a mathematical model of the fixed-canard rotation was established and the simulation calculations were performed, which uses a ballistic correction procedure to calculate the possible ballistic deviation caused by the rotational speed. The results show that the trajectory distribution is less than 1m, in the speed interval, and determines the best time to reduce the correction device and control the trajectory according to the change of polar restraining moment.

1. Introduction
At present, it is mostly are local Asymmetric Wars. The hitting accuracy of ammunition makes great demands In this battlefield environment. This paper studies the 125mm tank high explosive projectile equipped with two-dimensional correction device, focusing on the aerodynamic characteristics of uncontrolled ballistic correction device, so as to ensure the ballistic stability before the action of correction device.

The two-dimensional trajectory correction projectile consists mainly of the trajectory correction device and the two parts of the projectile body, as shown in Figure 1, its main function is to control the projectile flight pitch and yaw through the correction device's 4 canards to achieve the goal of accurate hit.

Figure 1 Brief diagram of the two-dimension trajectory correction projectile

Before starting the trajectory correction device, the four canards wings of the correction device maintain a stable high-speed rotational motion, and the high-speed circular motion in the very short period of time can offset the deflection torque generated by the same direction rudder, as shown in Figure 2.
Figure 2  Rotational moment of the differential rudder

It is known from the force analysis of the figure, the canard rotation is mainly given the differential rudder, which is an important mechanism to maintain the flight stability of the correction device in the uncontrolled state after launch, and the rotational speed will affect the initial trajectory accuracy of the correction projectile. Therefore, the influence relationship between the differential rudder speed and the trajectory deviation must be analyzed to ensure the trajectory consistency before the start of the trajectory correction mechanism.

2.  The rotation movement of the correction device

2.1.  computational model

It is known from the Figure 4, The correction device has an spin velocity \( \dot{\gamma}_{xd} \). Each differential rudder offers \( F_{xd} \) steering the external force, generating torque \( F_{xd} \cdot L_{R} \), so the total torque \( M_{xd} \) of the guide (1).

\[
M_{xd} = F_{xd} \cdot L_{R} = \frac{\rho v^2}{2} S_{xd} L_{sd} m_{sd} \varepsilon_{d}
\]  

(1)

In which \( \varepsilon_{d} \) is the canard deflection angle, \( S_{xd} \) is the characteristic area of the correction device, \( L_{sd} \) is the torque length, and \( m_{xd} \) is the roll moment coefficient. During rotation there is a torque \( M_{xr} \) action around the correction device that prevents it from spinning is shown in type (2).

\[
M_{xr} = m_{xd} \rho v S_{xd} L_{sd} \varepsilon_{d} \dot{\gamma}_{xd}
\]  

(2)

In which the \( m_{xd} \) correction device polar restraining moment coefficient. Therefore, the rotation equation (4.3) of the correction device around the shaft is seen.

\[
J_{xd} \frac{d^2 \gamma_{xd}}{dt^2} = J_{xd} \frac{d\dot{\gamma}_{xd}}{dt} = M_{xd} - M_{xr}
\]  

(3)

In which \( J_{xd} \) is the polar inertia moment of the trajectory correction device, the formula (1) and the formula (2) are brought into the formula (3) and the simple formula is transformed:

\[
\frac{d\dot{\gamma}_{xd}}{dt} + \frac{m_{xd} \rho v S_{xd} L_{sd}^2 \varepsilon_{d}}{2J_{xd}} \dot{\gamma}_{xd} = \frac{\rho v^2}{2J_{xd}} S_{xd} L_{sd} m_{xd} \varepsilon_{d}
\]  

(4)

The balanced speed formula is available when the rotational acceleration is zero:

\[
\dot{\gamma}_{xdmax} = \frac{m_{xd} \varepsilon_{d}}{2m_{xd} L_{sd}} \nu \varepsilon_{d}
\]  

(5)

In which \( \dot{\gamma}_{xdmax} \) is the balance rotational speed, namely, the canard at a certain moment the speed of the speed will eventually return to this balance rotational speed, in engineering calculations, it is possible to \( \dot{\gamma}_{xdmax} \) as the actual speed \( \dot{\gamma}_{xdmax} \).
2.2. Analysis of the effects of rotational speed and speed. Before installing the correction device, the speed and rotational speed relationship under the small shot angle of the 125m blast grenade is shown in Figure 3.

![Figure 3](image1.png)

Figure 3 The relationship between grenade speed and speed of 125mm high explosive shell

Because the independent rotating correction device on the projectile is studied, the damping torque of the correction device is less than the damping torque of the projectile body, so the relationship between the speed of the correction device and the speed of the projectile needs to be analyzed. As can be seen from formula (5), under the condition that the canard deflection angle and torque length are fixed, the balance rotational speed is proportional to the speed and the polar restraining moment coefficient, and the moment coefficient of the correction device can be calculated at different speeds, so the relationship between the balance rotational speed and the polar restraining moment coefficient of the correction device can be calculated as shown in Figure 4.

![Figure 4](image2.png)

Figure 4 The relationship between balance rotational speed and polar restraining moment coefficient of the correction device

2.3. Influence between rotational speed and trajectory accuracy. According to the steady-state rotating speed, the periodic movement frequency of the device can be corrected, the effect of the same direction rudder steering lift can be analyzed at this frequency. As the polar restraining moment coefficient increases with the rotating speed and decreases with the rotating speed, it can be seen that the smaller the balance rotational speed, the greater the amount of projectile deviation from the trajectory. Therefore, the minimum balance rotational speed before the action of the correction device is taken as the value to analyze the dispersion of the unit time projectile on the vertical side of the velocity vector. Assuming that the correction projectile is not subject to other forces during this period and that both the rotating speed and the projectile speed are unchanged, as shown in Figure 5, the correction projectile is the trajectory produced by the correction projectile perpendicular to the velocity vector plane, which is the trajectory deviation caused by the correction device with the same direction rudder correction force at the same level as rotation frequency.
Figure 5 Movement trajectory of the projectile in the vertical plane of the velocity vector

According to the calculation results diagram, the lift caused by the same direction rudder causes the projectile to make periodic circular motion in the vertical plane of the velocity, and the lift size caused by the same direction rudder determines the trajectory radius of the circular motion. In the figure, the correction projectile is scattered at about 1 m in the vertical plane of the velocity vector, and this error is relatively small in the high-speed flight of Mach 1 to 2.5 of the projectile, which can be considered to meet the stable flight requirements of the projectile under the uncontrolled state.

3. fluid simulation calculation analysis

3.1. Geometrical model. Considering the uncertainty of the flow direction of the surrounding air flow field, the tetrahedron adaptive grid can well calculate the free flow. The correction device air flow field divides 1.78 million quadrilateral grid, and the correction projectile air flow field divides 2.68 million quadrilateral grid, showing the air flow field geometry model as shown in Figure 6 and the grid model.

Using the transient problem solution with the density basis, the turbulence model is the SST model, and the velocity inlet, outer wall and outlet are all the pressure far-field boundary conditions. Dynamic pneumatic simulation calculation of Mach 1, 1.5, 2 and 2.5 respectively, where the velocity before the trajectory vertex is about Mach number 1 and the muzzle velocity of Mach number 2.5.

3.2. Analysis of the dynamic aerodynamic characteristic of the correction device. The maximum gas flow is also the most complex. Figure 7 shows the speed of 1120 n/min, 2.5 Mach number, at the speed of 0.005 seconds, listing the surface pressure changes of the correction device every 0.005 seconds.
Figure 7 the surface pressure distribution of the correction device at the 2.5 mach number

According to the figure, the maximum pressure area of the correction device is the top, at $7.67 \times 10^5$ Pa. There is an annular regional pressure between the top of the correction device and the front edge of the canard, which indicates that after the ultrasonic flight is compressed because the front air is compressed and the shock, the complex pressure gradient forms between the shock behind and the external surface of the correction device, with zero and negative pressure, showing the negative pressure value on the back plane of the canard and increases the inverted side force of the canard.

In the number of Mach 2.5, Mach 2, Mach 1.5, Mach 1, respectively, the upper and lower surfaces of one of the duck rudders were selected for pressure analysis. The distribution of the pressure at different Mach numbers is shown in Figure 8. The air at the front edge of the rudder rises rapidly by the compression pressure. Therefore, in the shock zone, the gas expansion at 0.003m away from the edge so that the pressure gradually decreases until 0.02m at the rear edge of the canard.

Figure 8 The pressure distribution on the upper and lower surface of the canard

4. Correction device speed test during uncontrolled
To verify the influence of the rotational speed of the correction device on projectile distribution, the test used the initial velocity of the slide ballistic gun 10-degree, full charge, constant temperature $15^\circ C$ and 840m/s, measuring the relative speed curve of the canard and projectile body through the recovered black box as shown in Figure 9.

In the speed of the maximum speed as a reference for the normalization processing. The first half fluctuates greatly from the figure, the relative rotation of the projectile and the correction device after the outlet 1s reaches the maximum value, the relative speed at the trajectory rise section 9s, and the curve tends to reach a stable flight balance speed after 11 seconds.
The lowest relative speed value occurs at 9s, it is due to the formula (3) guidance the relationship between roll moment $M_{xd}$ and polar restraining moment $M_{xr}$. When $M_{xd} > M_{xr}$, $d\dot{y}_{sd}/dt > 0$, the speed $\dot{y}_{sd}$ increases, and the increase of speed $\dot{y}_{sd}$ inevitably causes the value of the polar restraining moment $M_{xr}$ to increase until $M_{xd} < M_{xr}$. Similarly, when $M_{xd} < M_{xr}$, $d\dot{y}_{sd}/dt < 0$, the speed $\dot{y}_{sd}$ decreases, and the decrease of speed $\dot{y}_{sd}$ inevitably causes the value of the extremely inhibitory moment $d$ to decrease until $M_{xd} > M_{xr}$. Since the selection of the uncontrolled time is between the vertices of the trajectory and the projectile did not reach the vertex when the relative speed is 9s and the relative speed pair is low, the minimum energy of the motor.

5. Conclusion
1. The dispersion of the correction projectile at the minimum equilibrium speed is studied, calculating the motion trajectory of the correction projectile in the vertical plane of the velocity vector, finding that the maximum dispersion radius does not exceed 1m, and obtaining the conclusion that the correction projectile can maintain the trajectory stability when uncontrolled.
2. The aerodynamic characteristics of the correction device are calculated by the sliding mesh technique. The relative speed curve of the correction device and the projectile body is analyzed according to the dynamic test results. It confirm the existence and the best time of the pneumatic correction device to control the trajectory.

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