2015 The 5th International Workshop on Computer Science and Engineering
doi: 10.18178/wcse.2015.04.073

Research on Correction Ability for Simple Guided Artillery Rocket's Fixed Canard Rudder

Aitian Yan, Changsheng Zhou, Jinsheng Xu, and Jian Li
School of Mechanical Engineering, Nanjing University of Science and Technology, Nanjing, 210094, China

Keywords: fixed canard rudder, single glow, rolling control, correction force, ballistic correction

Abstract. According to the application requirements of adopting fixed canard rudder technology to medium and small guidance rocket, a kind of single channel rolling control strategy suitable for fixed canard rudder was proposed. The working principle of fixed canard rudder was mainly analyzed. The equations of cycle average control force and moment were deduced. The 6DOF external ballistic model of the fixed canard rudder was established. The numerical simulation of the Wing lift was carried out with the Fluent, and the simulation & research of the correction ability was carried out combining the 6DOF external ballistic equation. According to this, the correcting ability of the fixed canard rudder was emulated and calculated, the result shows that the correcting ability is enough by using the rudder, and it's one of the feasible low cost and the miniaturized rudder technology.

Introduction

Due to the rotation of the nose cone of fixed canard rudder that Guided Artillery Rocket mainly uses the multichannel canard rudder or micro pulse rocket to correct the trajectory. The hardware control system of multichannel canard rudder is relatively complex, its installation space is large and high costs[1]. Using micro pulse rocket trajectory correction, although has the characteristics of fast response, due to the limitation of pulse number of rockets, can only be a moment or a few moment modification effect[2]. In recent years, some researchers carry out conventional ammunition fixed canard rudder technology, which is similar to US PGK technology and has a great potential in the low cost of conventional ammunition guidance improving market. The structure is like "cross rudder fixed-wing", one pair is rotating rudder, the other pair is steering rudder, through an alternator and variable resistance loader to control the rudder speed. Compared to multi-channel canard rudder, fixed canard rudder is greatly simplified, fullfill the goal of low costs, reflecting the software instead of hardware functions mainstream development thinking. This technique has been successfully applied to 155mm shells and 120mm mortars, shows tremendous potential market in improvement of conventional ammunition low cost guidance[3]. Therefore establish fixed canard rudder dynamic model and research its correction ability is of great importance for simple guidance missile control system design[4].

In this paper, in view of the small and medium caliber simple guided rockets with low cost, miniaturization and the application of the fixed canard rudder, a pair of rudder was studied and its working principle was analyzed. Six degrees of freedom external ballistic model was established, the dynamic model of fixed canard rudder and correction ability was studied.

The working principle of fixed canard rudder

Fig.1 shows the layout of rolling control fixed canard rudder system, which uses the linear type rudder-face. A pair of rudders are installed at the position of 90° and 270° in the warhead section, and the rudders have 5° tilt in the same direction in order to produce lift force, which brings a torque relative to the centroid of the whole missile that causes the change of attack angle and flight path[5]. A high speed permanent brushless DC motor is used to control the rotation of rudder system that relative to the projectile[6].

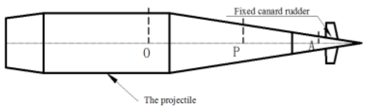

Fig.1 Fixed canard rudder system

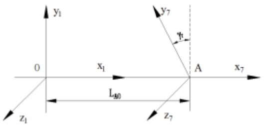

Fig.2 Single channel rolling control

Due to the rotation of the nose cone of fixed canard rudder that relative to the projectile, there must be a certain angle γ_r between the rudder control surface and the projectile axis coordinate $ox_1y_1z_1$, so a new rudder nose cone coordinate $Ax_7y_7z_7$ is established. The origin of the new coordinate is at the position of the instantaneous centroid of rudder nose cone, axis Ax_7 coincides with longitudinal axis of the projectile, and positive direction is towards the warhead. Axis Ay_7 is located in longitudinal symmetry plane of the rudder nose cone and is vertical to axis Ax_7, the positive direction is upward. Axis Az_7 is vertical to plane Ax_7y_7 and it constitutes a right-handed coordinate. The rudder nose cone coordinate is also a moving coordinate, as shown in Fig.2. In the projectile axis coordinate, any fixed position is defined as the zero point of projectile’s rolling angle. Assuming that the projectile’s rolling angle is γ, the rudder nose cone’s rolling angle is $\dot{\gamma}$, the rudder nose cone’s rolling speed is $\dot{\gamma}_r$. Different from general rudder system, when the command of system’s rolling angle keeps invariant, which means the rolling angle of rudder nose cone relative to the projectile axis coordinate remains stable as γ_r, actually the rudder nose cone then roll reversely at the speed of projectile’s rolling speed, so the rolling angle’s stability relative to projectile axis coordinate can be realized. Because of the stability of rudder nose cone’s rolling angle, the coupling between the channels can be effectively reduced, which is beneficial to realize the high maneuvering control for projectile[7].

Control force and torque equation of fixed canard rudder

Single channel control mode with high efficiency, design of control system is simple, volume of control unit is small, locate in the front of projectile and easy to design, etc, and it was widely paied attention in the guided munition control system[8].

Fixed canard rudder fixed in the nose cone part of the projectile, only rotate at a certain speed around the projectile vertical axis, can generate control force by single channel rolling control mode on the pitch and yaw plane to control the motion of the projectile[9]. For rocket with low-speed rotation can control the rolling of the warhead cone to point to the correct direction, produce cycle average control force on the pitch and yaw direction to make two-dimensional rocket trajectory correction. A spin structure was used at the tail of projectile, rolling under the reverse rolling rotational moment caused by downwash, thereby overcoming the canard downwash[10]. Due to the control force Fc caused by fixed canard rudder is a constant. Assuming projectile rotate taking w_0 for positive half-circle and w_1 for negative half-circle, control diagram as shown in Fig.3, cycle average operating force[11] is:

$$F_{cy} = \frac{1}{T}[\int_0^{t_1} F_c \sin\left(\omega_0 t\right) dt + \int_0^{t_2} F_c \sin(\pi + \omega_1 \mathrm{t}) \mathrm{dt}] \tag{1}$$

$$F_{cz} = \frac{1}{T}[\int_0^{t_1} F_c \cos\left(\omega_0 t\right) dt + \int_0^{t_2} F_c \cos(\pi + \omega_1 \mathrm{t}) \mathrm{dt}] \tag{2}$$

Where $T = t_1 + t_2$, $\omega_1 = k\omega_0$, k is proportional coefficient.

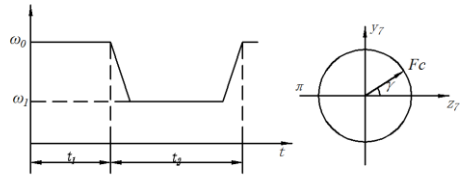

Fig.3 Single channel rolling control

By derivation, cycle average force F_{cy} of the operating force Fc along A_{y7} axis is maximum, $F_{cy}=\frac{k-1}{k+1}\frac{2F_c}{\pi}$, while cycle average force F_{cz} along Az7 axis is zero. When the initial phase control signal is zero, then the cycle average control force on the warhead cone is:

$$F(\delta)=F_{cy}+F_{cz} \tag{3}$$

That is $F(\delta)=F_{cy}=\frac{k-1}{k+1}\frac{2F_c}{\pi}$, known as long as by switching the speed of the actuator, ratio k can be changed, cycle average control force can be adjusted. If the initial phase of the control signal advance an angle φ, cycle average control force $F(\delta)$ project on the warhead cone coordinate z_7A_{y7} direction respectively are:

$$F_{y7}=F(\delta)\cos(\varphi) \tag{4}$$

$$F_{z7}=F(\delta)\sin(\varphi) \tag{5}$$

(4)(5)divided by $F(\delta)$,let be

$$k_y=\frac{F_{y7}}{F(\delta)}=\cos(\varphi) \tag{6}$$

$$k_z=\frac{F_{z7}}{F(\delta)}=\sin(\varphi) \tag{7}$$

Where k_y k_z are pitch and yaw command instruction coefficient and drift coefficient respectively.by changing the k_y k_z, direction of the control force can be adjusted. Then

$$F_{y7}=k_y\frac{k-1}{k+1}\frac{2F_c}{\pi} \tag{8}$$

$$F_{z7}=k_z\frac{k-1}{k+1}\frac{2F_c}{\pi} \tag{9}$$

Meanwhile control moment of F_{y7} F_{z7} relative to the axis A_{z7} A_{y7} can be gained:

$$M_{y7}=k_z\frac{k-1}{k+1}\frac{2F_c}{\pi}L_{AO} \tag{10}$$

$$M_{z7}=k_y\frac{k-1}{k+1}\frac{2F_c}{\pi}L_{AO} \tag{11}$$

Where L_{AO} is distance from centroid of fixed canard rudder to centroid of projectile.

Research on correction force of fixed canard rudder

Six degrees of freedom external ballistic equation of canard rolling control.

By analyzing the force and torque generated when conventional rockets in flight, adding the force and moment generated when fixed canard rudder is rolling control, using Newton's second law and the momentum theorem, centroid motion equation of rocket trajectory coordinate system and around center motion dynamic equation in the first elastic axis coordinate. Combine centroid translational motion equation and around centroid dynamic equation, six degrees of freedom external ballistic equation under[11] control force of rocket can be got as follows:

$$\frac{dv}{dt}=\frac{1}{m}(F_{x2}+F_{cx2}) \tag{12}$$

$$\frac{d\theta}{dt}=\frac{1}{mv\cos\psi_2}(F_{y2}+F_{cy2}) \tag{13}$$

$$\frac{d\psi_2}{dt}=\frac{1}{mv}(F_{z2}+F_{cz2}) \tag{14}$$

$$\frac{d\omega_z}{dt}=\frac{1}{C}(M_z+M_{cz}) \tag{15}$$

$$\frac{d\omega_\eta}{dt}=\frac{1}{A}(M_\eta+M_{c\eta})-\frac{C}{A}\omega_z\omega_\zeta+\omega_\zeta^2\tan\varphi_2 \tag{16}$$

$$\frac{d\omega_\zeta}{dt}=\frac{1}{A}(M_\zeta+M_{c\zeta})+\frac{C}{A}\omega_\zeta\omega_\eta-\omega_\eta\omega_\zeta\tan\varphi_2 \tag{17}$$

$$\frac{d\varphi_a}{dt}=\frac{\omega_\zeta}{\cos\varphi_2} \tag{18}$$

$$\frac{d\varphi_2}{dt}=-\omega_\eta \tag{19}$$

$$\frac{d\gamma}{dt} = \omega_{\delta} - \omega_{\zeta} \tan\varphi_2 \qquad (20) \qquad \frac{dx}{dt} = v\cos\psi_2\cos\theta \qquad (21)$$

$$\frac{dy}{dt} = v\cos\psi_2\sin\theta \qquad (22) \qquad \frac{dz}{dt} = v\sin\psi_2 \qquad (23)$$

Rudder correction ability at work.

When the rudder switch speed in the direction of pitch, it suffer lift and pitch moment,through (8) to (11), lift and pitch moment can be got:

$$F_y = \cos(\varphi)\frac{k-1}{k+1}\frac{\rho V^2}{\pi}S\{[(\frac{S_1}{S}C_{yy}^{'}) + C_y^{'}]\delta_1 + (\frac{S_1}{S}C_{zz}^{'})\alpha\} \qquad (24)$$

$$M_z = \cos(\varphi)\frac{k-1}{k+1}\frac{\rho V^2}{\pi}lS\{[(\frac{S_1}{S}m_{zz}^{'}) + m_z^{'}]\delta_1 + (\frac{S_1}{S}m_{zz}^{'})\alpha\} \qquad (25)$$

According to meaning of $m_z^{'}$, $m_z^{'} = C_y^{'}\frac{L_{OP}}{L}$, $m_{zz}^{'} = C_{yy}^{'}\frac{L_{OG}}{L}$, Where S_1 is surface area of rudder, S is cross-sectional area of the projectile. C_y is lift coefficient, $C_y^{'}$ is derivative of lift coefficient, m_z is static moment coefficient, $m_z^{'}$ is derivative of static moment coefficient, m_{zz} is equatorial damping torque coefficient, $m_{zz}^{'}$ is derivative to $l\omega_1/v$ of equatorial damping torque coefficient.

Simulation research on the correcting ability of fixed canard rudder

Simulation analysis on the aerodynamic characteristics of fixed canard rudder

Fig.4 shows the structure of fixed canard rudder, which consists of rudder nose cone, a pair of linear type rudder-face that fixed on the rudder nose cone, guidance fuze device, connection head of nose cone, high speed bearing, bond, support frame, high speed permanent brushless DC motor, sleeve, motor motion controller, thermal battery and rear cover. The two rudder wings are installed at the position of 90° and 270° on the circumference of rudder nose cone, and have 5° tilt in the same direction. The area of a single rudder wing is 0.0056m^2, the span is 159mm.

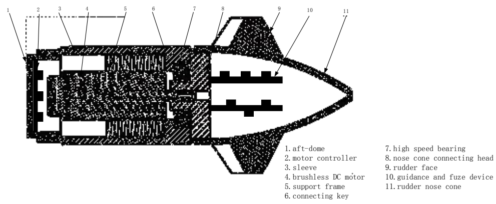

Fig. 4. 3D Structure of the fixed canard rudder

To get the aerodynamic that the correcting ability simulation of fixed canard rudder demands, according to designed model of fixed canard rudder, the Fluent is used on numerical simulation of the aerodynamic of its vanes. The lift F_c of rudder wings is calculated under different height and wing declination. The numerical simulation results of the lift F_c td was used for the research of subsequent simulation.

Simulation research on the correcting ability of rudder.

According to six-freedom rigid ballistic equation (12) to (23), a certain control force F_c and its corresponding torque are given at any angle in the plane Ay_Az_A of rudder, the simulation research on the two-dimension trajectory correcting ability of fixed canard rudder. The simulation results are shown in Tab.1.

Table 1: Trajectory simulation parameter table

Initial condition		Trajectory parameters obtained from simulation	
Initial speed	50m/s	Flight time	106.23s
Initial firing angle	53°	Range	30253m
Initial rotation speed	40rad/s	Launching height	13672m
Initial rotation angle	2.65°	Trajectory vertex time	47s

Thrust	27734N	Maximum speed	1028m/s
Thrusting time	2.55s	Impact point speed	349m/s

Fig.5 shows the law of impact points on the effects of lateral correcting force of fixed canard rudder. As shown in the figure, the projectile’s correcting ability is proportional to the correcting force of rudder. According to some actual projectile whose firing accuracy CEP is about 450m, (E_x=1/170, E_z=1/100), it can be inferred that the correcting value of fixed canard rudder is larger than the dispersion of projectile, which proves that it’s feasible to adopt the correcting scheme of fixed canard rudder. Two groups of symmetric trajectory control azimuths (γ_r =π/2, 3π/2) are selected from the simulation conditions, and then the variation curves of each trajectory data can be drawn as Fig.6 to Fig.10. It can be seen from the figures that the changing rules of attack angle and lateral velocity are presenting a symmetric variation trend.

It can be observed from Fig.6 and Fig.7 that the variation of lateral velocity is corresponding to that of lateral range. The one-sided lateral distance correction of trajectory impact point can be 1100m, which is mainly covering the dispersion area of non-control impact point. It can be seen from Fig.8 to Fig.10 that the differences between each data with or without control under the effect of rudder correcting ability are significant. The high and low attack angle, lateral attack angle and complex attack angle all show a large amplitude of mutation, which leads to the change of the lift and resistance of projectile and make the lateral velocity increase by about 28m s^{-1} (Fig.7). The complex attack angle is affected by both high and low attack angle and lateral attack angle, it will be soon reaching the peak value 4.4° at the beginning and then decrease continuously until it converges to a smaller value

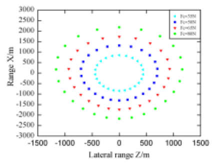

Fig.5. Law between lateral correction force of the fixed canard and impact point

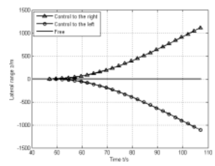

Fig.6. Variation Curves of lateral range

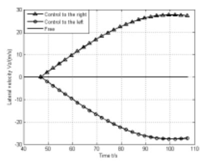

Fig.7. Variation curves of lateral velocity

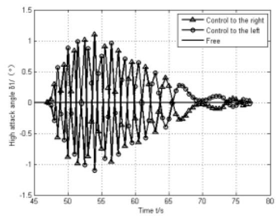

Fig.8. Variation Curves of high attack angle

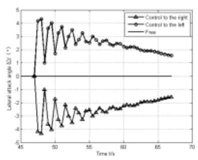

Fig.9. Variation Curves of lateral attack angle

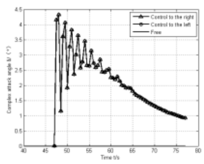

Fig.10. Variation Curves of complex attack angle

Conclusions

Correction ability of fixed canard rudder ballistic was analyzed, the result shows: (1) The correction value of fixed canard rudder is greater than the dispersion of projectile, prove that fixed canard rudder steering correction is feasible. Trajectory impact basicly cover the dispersion area of no control impact, transverse trajectory correction can be completed effectively. (2)Curves of high low and lateral attack angle converges to the minimum decreasing, indicating that the projectile has good flight stability under steering correction force.

Acknowledgements

This work was supported by the Nanjing University of Science and Technology Research Funding(NO: ZDJH02).

References

[1] Shi Jinguang, Wang Zhongyuan. A Study on Correctional Force for Simple Control[J]. Journal of Ballistics, 2006, 18(2):14-17.

[2] Wang Junquan, Wang Xiaoming, Li Wenbin. The Principle and Dynamics Analysis of a Four-shaft-linked Actuator [J]. Acta Armamentarii, 2006, 27(1): 54-57.

[3] Li Yan, Wang Zhongyuan. Electromechanical Actuator Controller Based on Discrete Sliding Mode Variable Structure[J]. Journal of Nanjing University of Science and Technology. 2009, 33(1): 96-99.

[4] Ji Xiuling, Wang Haipeng. CFD Prediction of Longitudinal Aerodynamics for a Spinning Projectile with Fixed Canard[J]. Transactions of Beijing Institute of Technology, 2011, 31(3): 265-268.

[5] Wang Jianghua, Gu Liangxian, Gong Chunlin. Dynamic Modeling of Deflectable Nose Missiles[J]. Acta Aeronautica et Astronautica Sinica, 2010, 31(4):831-835.

[6] Cui Yebing, Ju Yutao. Feasiblity of high bandwidth four rudder wings electromechanical actuator[J]. Electric Machines And Control. 2012, 16(12):87-93.

[7] Cui Yebing, Ju Yutao. Research on Dual Mode Control for Electric Servo Mechanism of Thrust Vector Control[J]. Journal of Solid Rocket Technology, 2012, 35(5):688-693.

[8] Lu Hao, Li Yunhua. Design Theory of Thrust Vector Control Servo Mechanism for a Type of Spacecraft[J]. Journal of Beijing University of Aeronautics and Astronautics. 2010, 36(12):1417-1421.

[9] Dong Chaoyang, Wang Feng, Gao Xiaoying. Missile Reaction-jet /Aerodynamic Compound Control System Design Based on Adaptive Sliding Mode Control and Fuzzy Logic[J]. Acta Aeronautica et Astronautica Sinica. 2008, 29(1):165-169.

[10] Xia Changliang, Fang Hongwei. Permanent-Magnet Brushless DC Motor and Its Control[J]. Transactions of China Electrotechnical Society, 2012, 27(3), 25-30.

[11] Meng Xiuyun. Principle of missile guidance and control system[M]. Beijing Institute of Press, 2003.