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Influence of yawing force frequency on angular motion and ballistic characteristics of a dual-spin projectile

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Abstract

A roll-decoupled course correction fuze with canards can improve the hit accuracy of conventional unguided ammunitions. The fuze increases accuracy by reducing the effect of angular and translational motion produced by the cyclical yawing forces applied on the projectile. In order to investigate the influence of yawing forces on angular motion, a theoretical solution of the total yaw angle function with the cyclical yawing forces is deduced utilizing the 7 degrees of freedom (7-DOF) model designed for this calculation. Furthermore, a detailed simulation is carried out to determine the influence rules of yawing force on angular motion. The calculated results illustrate that, when the rotational speed of the forward part is close to the initial turning rate, the total yaw angle increases and the flight range decreases sharply. Moreover, a yawing force at an appropriate frequency is able to correct the gun azimuth and elevation perturbation to some extent.

Keywords: Course correction fuze; Dual-spin projectile; Rotate speed

1. Introduction

Compared to the conventional munitions, the design of dual-spin projectile with canards is becoming increasingly popular. The increase in popularity of dual-spin projectile is attributed to its increased accuracy and cost effectiveness. Costello et al. [1] established a 7-DOF dynamic model to investigate the dynamic properties of a dual-spin projectile with canards, and the model was used to solve for angle of attack, swerving dynamics and stability factors. Grignon et al. [2] discussed the relationship between gyroscopic stability and the moment of inertia through numerical simulations. The stability and design of the trajectory control autopilot for 155 mm dual-spin projectiles with different types of canards were modeled and analyzed in references [3–6]. Liu et al. [7] studied the swerving orientation of a spin-stabilized projectile with fixed canards. Nevertheless, of all the works on the dynamic properties of dual-spin projectiles stated previously, none has discussed the impact of spin rate on the forward section of trajectory and its effect on the trajectory. When the forward body of projectile is rolling, a cyclical yawing force is applied on the projectile, which impacts the angular and translational motions. To analyze the influence of frequency of the cyclical force on angular and translational motions during flight of projectile and get an appropriate frequency, the response of the projectile under a cyclical force is studied in this paper.

2. Dynamic model

The mathematical model describing the motion of dual-spin projectile consists of four rotational and three translational degrees of freedom.

2.1. Reference frames

The basic reference frames, such as inertial reference frame (IRF) $OX_NY_NZ_N$, non-rolling body reference frame (NRRF) $O\xi\eta\zeta$, and velocity reference frame (VRF) $OX_2Y_2Z_2$, are defined to establish a dynamic model. The definition of the frames, angles and their relationship are shown in Figs. 1–3. The schematic plot of the dual-spin projectile is shown in Fig. 4.

2.2. Mathematical model

2.2.1. Equations of motion

To determine the angular motion, the differential equations of θ_a, ψ_2 and φ_a, φ_2 are set out in VRF and NRRF respectively.

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Nomenclature

δ_1, δ_2	angle of attack, angle of sideslip
φ_a, φ_2	pitch, yaw angle of projectile
θ_a, ψ_2	pitch, yaw angle of velocity
l_{CG}	distance between the point of mass and the point of the cyclical force
$\gamma_A, \gamma_F, p_A, p_F$	roll angle and the rotate speed of the aft and forward parts
I_{xA}, I_{xF}	axial moment of inertia of the aft and forward parts
I_y	transverse moment of inertia
b_y	lift aerodynamic coefficient $\times \rho S/(2m)$
b_x	drag aerodynamic coefficient $\times \rho S/(2m)$
k_{zz}	roll damping moment aerodynamic coefficient $\times \rho S d^2/(2I_y)$
k_z	overturning moment aerodynamic coefficient $\times \rho S d/(2I_y)$

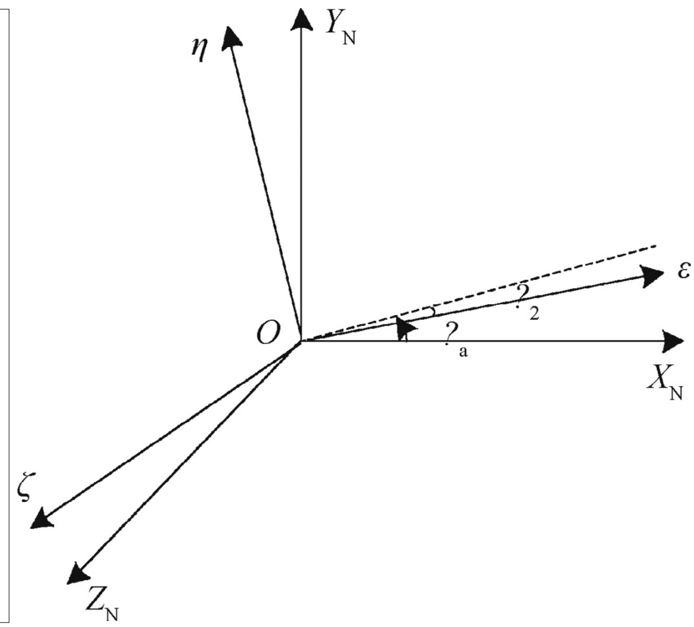

Fig. 2. Inertial reference frame and non-rolling reference frame.

$$\begin{bmatrix} \dot{v} \\ \dot{\theta}_a \\ \dot{\psi}_2 \end{bmatrix} = \begin{bmatrix} F_{x2}/m \\ F_{y2}/mv\cos\psi_2 \\ F_{z2}/m \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \end{bmatrix} = \begin{bmatrix} v\cos\psi_2\cos\theta_a \\ v\cos\psi_2\sin\theta_a \\ v\sin\psi_2 \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} \dot{\gamma}_A \\ \dot{\gamma}_F \\ \dot{\varphi}_a \\ \dot{\varphi}_2 \end{bmatrix} = \begin{bmatrix} p_A - r\tan\varphi_2 \\ p_F - r\tan\varphi_2 \\ r/\cos\varphi_2 \\ -q \end{bmatrix} \tag{3}$$

$$\begin{bmatrix} \dot{p}_A \\ \dot{p}_F \\ \dot{q} \\ \dot{r} \end{bmatrix} = \begin{bmatrix} M_{A\varepsilon}/I_{xA} + 2qrI_{yA}/I_{xA} \\ M_{F\varepsilon}/I_{xF} + 2qrI_{yF}/I_{xF} \\ M_\eta/I_y + r^2\tan\varphi_2 - r(p_A I_{xA} + p_F I_{xF})/I_y \\ M_\zeta/I_y - rq\tan\varphi_2 + q(p_A I_{xA} + p_F I_{xF})/I_y \end{bmatrix} \tag{4}$$

where $I_y = I_{yA} + I_{yF}$, $M_\eta = M_{A\eta} + M_{F\eta}$, $M_\zeta = M_{A\zeta} + M_{F\zeta}$.

The torque and moment of inertia in Eq. (4) correspond to the center of total mass. The subscripts of those symbols used above show the function area and the vector direction.

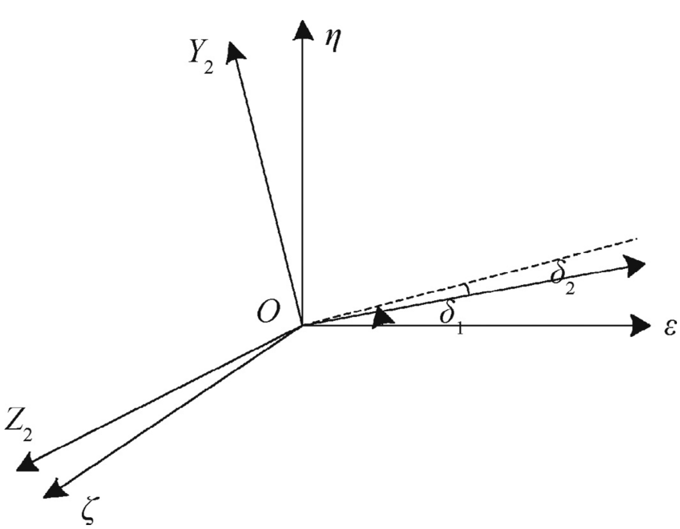

Fig. 1. Non-rolling reference frame and velocity reference frame.

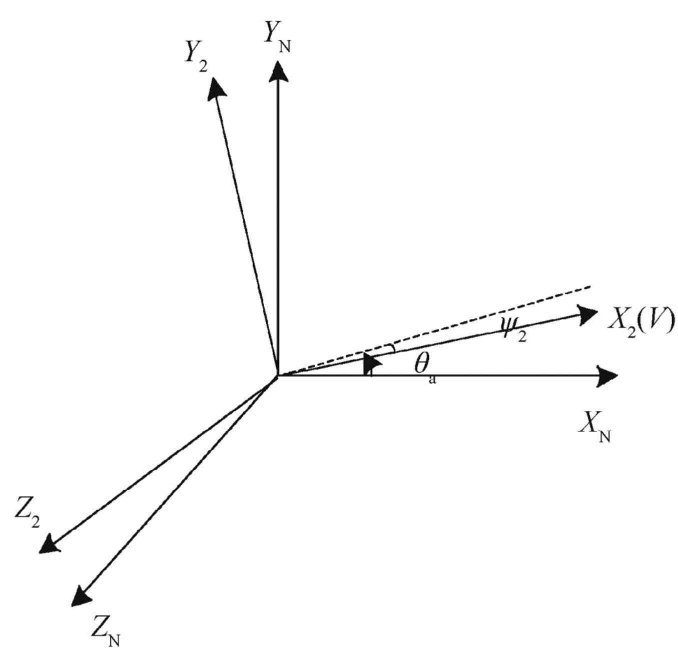

Fig. 3. Inertial reference frame and velocity reference frame.