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Investigation on the flow control of micro-vanes on a supersonic spinning projectile

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Abstract

Studies have shown that micro-wedge vortex generators (MVG) can effectively control the flow separation of supersonic boundary layer. In order to improve the flight stability of spinning projectile, the original standard 155 mm projectile was taken as an example, and the micro-vanes were mounted at the projectile shoulder to investigate the separation control on the aerodynamic characteristics of projectile. Numerical simulations were performed with the use of DES method for the flow fields of projectiles with and without micro-vanes, and the characteristics of the boundary layer structures and aerodynamic data were compared and discussed. Numerical results show that the micro-vanes can be used to inhibit separation of fluid on projectile surface, and improve the flight stability and firing dispersion of projectile.

Keywords: Spinning projectile; Micro-vane; Stability; Aerodynamic characteristics; Fluid control

1. Introduction

Precision strike is a general trend in modern warfare, and many countries in the world improve the flight stability and firing dispersion of projectile mainly through the development of guided munitions and transformation of conventional ammunition [1]. Supersonic spinning projectiles are greatly influenced by boundary layer separation in the process of flight [1,2]. The flight stability of a projectile is one of the basic requirements of the projectile design [3], which it means that its angle of attack between the axis of the projectile and velocity vector should be within a certain limit, and gradually decay [4–6].

Micro-vanes are found to be able to suppress the separation of supersonic flow. In this paper, in order to further improve the flight stability of the standard 155 mm projectile [7], the micro-vanes were mounted at the projectile shoulder according to the Task Force findings [8–10], so that the fluid separation in the boundary layer of projectile can be suppressed, and the projectile has a stronger anti-interference ability during flight for improving its flight stability and firing accuracy. The supersonic flow structure around micro-vanes and the control mechanism of boundary layer separation were discussed in detail in Refs. [8–10].

Numerical simulations were performed with the use of DES method for the flow fields of 155 mm standard projectiles for two cases with and without micro-vanes. The modifications of the boundary layer structures and aerodynamic data for two cases were compared and discussed. Numerical results show that the micro-vanes can be used to inhibit the fluid separation of projectile surface, improve the projectile lift and pitching moment, and eliminate the shaking of lift and pitching moment, as a result of improving the flight stability and firing dispersion, which can provide guidance for the improvement of supersonic projectiles.

2. Investigation approach

The fluid field of supersonic spinning projectile was simulated based on DES simulation method. Realizable $k-\varepsilon$ turbulence model is used for the near wall region, and the large eddy simulation (LES) is used for external flow field, in which the spatial discrete are discretized using the finite volume method, the convection term is approached with the second order AUSM format, and a central difference scheme is used for the viscosity term.

The transport equations of turbulent kinetic energy and dissipation in realizable $k-\varepsilon$ turbulence model are

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$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho k u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_K+G_b-\rho\varepsilon-Y_M \tag{1}$$

$$\frac{\partial(\rho \varepsilon)}{\partial t}+\frac{\partial(\rho \varepsilon u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right]+\rho C_1 E\varepsilon -\rho C_2\frac{\varepsilon^2}{k+\sqrt{v\varepsilon}}+C_{1\varepsilon}\frac{\varepsilon}{k}C_{3\varepsilon}G_b \tag{2}$$

The control equations of LES model can be obtained by filtering Navier–Stokes equations in wave number space or irrational space. The filtration process is to remove the small vortexes which are shorter than filter width or a given unreasonable width. The resulting control equations of maelstrom are

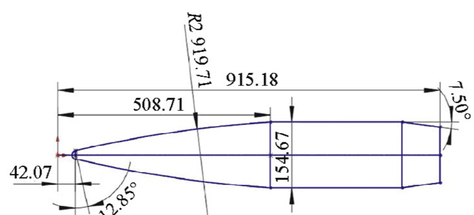
$$\frac{\partial\rho}{\partial t}+u\frac{\partial\rho\bar{u}_i}{\partial x_i}=0 \tag{3}$$

$$\frac{\partial}{\partial t}(\rho\bar{u}_i)+\frac{\partial}{\partial x_j}\left(\rho\overline{u_i u_j}\right)=\frac{\partial}{\partial x_j}\left(u\frac{\partial\bar{u}_i}{\partial x_j}\right)-\frac{\partial\bar{p}}{\partial x_j}-\frac{\partial\tau_{ij}}{\partial x_j} \tag{4}$$

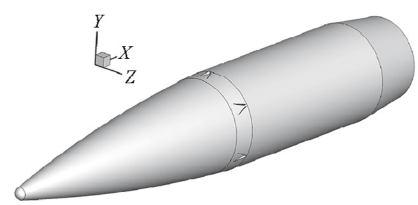
where τ_{ij} is defined as subgrid stress, $\tau_{ij}=\rho\overline{u_i u_j}-\rho\bar{u}_i\bar{u}_j$.

A sliding mesh needs to be used in order to simulate the flight state of spinning projectile. Sliding grid technology requires an external fixed area and inner motion area round the projectile, with a pair of interfaces being between two areas, and the points of the interface grid do not need to overlap; they only need to do numerical interpolation on the slip boundary to ensure the flux conservation between two regions, and the deformation of grid cell in motion, do not occur. Therefore the sliding grid technology occupies less memory of computer, calculates fast and has high precision.

155 mm M549 projectile, as shown in Fig. 1(a), was used as an example in the present paper. The micro-vanes were mounted at the projectile shoulder to form a new physical model, as shown in Fig. 1(b). Fig. 2 shows the computational

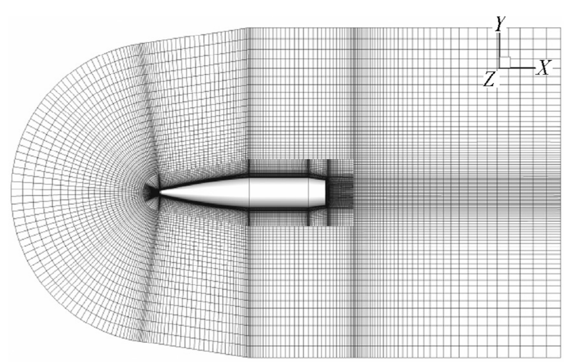


(a) Without vanes

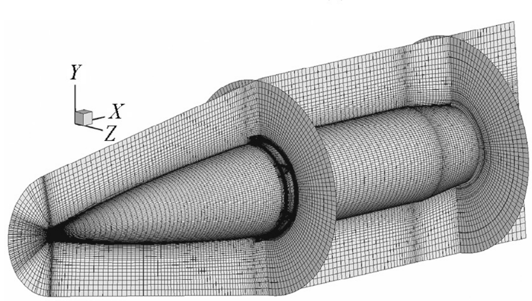


(b) With vanes

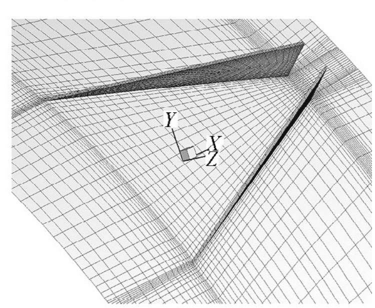
Fig. 1. M549 projectile [7].



(a) Grid distribution of symmetric surface



(b) Sliding grid near projectile



(c) Grid near vane

Fig. 2. Grid around the projectile.