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THE DESIGN AND EXPERIMENTAL TESTS OF AERODYNAMIC SHAPES FOR AN EXTENDED-RANGE PROJECTILE

Prof. Zhongyuan Wang[1], Dr. Weiping Zhou[2], Prof. Shaosong Che[1]
Dr. Wenjun Yi[1] and Dr. Jinguang Shi[1]

[1]*Ballistic Research laboratory of China, Nanjing University of Science & Technology, P.O.Box, 210094,Nanjing, P.R.China*
[2] *Naval Academy of Armament, Beijing, P.R. China*

Gliding control is quite efficient technique to increase range for a projectile. The aerodynamic performance of this kind projectiles (such as the life/drag, flight stabilities and maneuverability, down-wash phenomenon, etc.) strongly affects the effect of gliding flight so that the aerodynamic design should be done first in research for this kind extended-range projectile. Based on aerodynamic calculations, some selected shapes or structures can be tested by wind tunnel and this is an efficient method to determine perfect aerodynamic structure for this kind projectiles. In this paper, the wind tunnel tests for some aerodynamic shapes of extended-range projectiles have been introduced and analysed. The results for these tests and analyses are helpful for us to select suitable aerodynamic structures of this kind projectiles.

INTRODUCTION

When the extended-range projectile flies pass through the apex of trajectory, the lift-canards on front projectile rotate that an equilibrium angle of attack and additional lift occur to slow down the descent of trajectory so that the range is increased. For the design of an extended-range projectile, based on some conditions and limits of the projectile, it is very important to design aerodynamic shapes with perfect aerodynamic performance so that the range could be increased with gliding flight. Due to this reason, the design of aerodynamic configuration is first thing we should do to design an extended-range projectile.

The extended-range projectiles discussed here are fired by gun. With some restrict of structure for projectiles, the duck-canards are usually used for the aerodynamic configuration. Perfect aerodynamic performance of this kind projectiles included, perfect stabilities for fin-stable projectiles during unguided flight, perfect maneuverability for canard-rotation during gliding flight, to increase the ratio of lift over drag and to trade off flight stability with maneuverability as well as reducing influence of down-wash for duck-canards. In these aerodynamic aspects, some of them are restricted or even conflict. It makes much difficulty to design aerodynamic configuration of an extended-range projectile.

The main process to design aerodynamic shapes for an extended-range projectile is that aerodynamic predictions of canards wings as well as their relative position are made firstly and wind tunnel tests about some suitable configurations are made secondly.

According to this process, the aerodynamic design of an extend-range projectile are introduced in this paper.

Method of Aerodynamic Simulation

Basic Control Equations

To predict aerodynamic coefficients for an extended-range projectile, the basic control equations of flow field are described as:

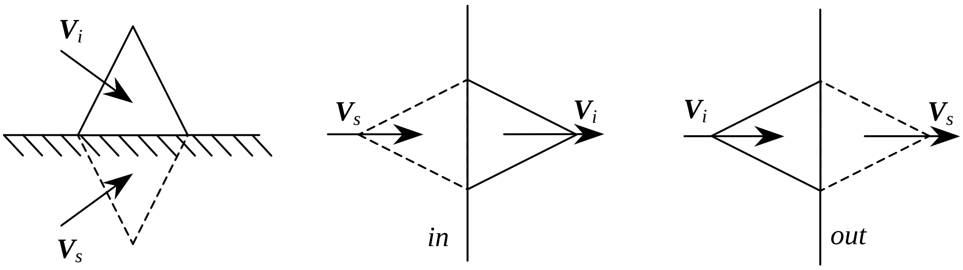
$$\frac{\partial \boldsymbol{U}}{\partial t}+\frac{\partial \boldsymbol{F}(\boldsymbol{U})}{\partial x}+\frac{\partial \boldsymbol{G}(\boldsymbol{U})}{\partial y}+\frac{\partial \boldsymbol{M}(\boldsymbol{U})}{\partial z}=0 \tag{1}$$

$$\boldsymbol{U}=\begin{bmatrix}\rho\\ \rho u\\ \rho v\\ \rho w\\ E\end{bmatrix},\quad \boldsymbol{F}(\boldsymbol{U})=\begin{bmatrix}\rho u\\ \rho u^2+p\\ \rho uv\\ \rho uw\\ (E+p)u\end{bmatrix},\quad \boldsymbol{G}(\boldsymbol{U})=\begin{bmatrix}\rho v\\ \rho vu\\ \rho v^2+p\\ \rho vw\\ (E+p)v\end{bmatrix},\quad \boldsymbol{M}(\boldsymbol{U})=\begin{bmatrix}\rho w\\ \rho wu\\ \rho wv\\ \rho w^2+p\\ (E+p)w\end{bmatrix}$$

Where, ρ—air density, u、v、w—three components of velocity, E—total energy, p—pressure.

Boundary Conditions

Supposing a invented control body of symmetry on boundary and taking a two dimensioned case, these triangles with dotted line are showed in figure 1.



(a) Solid surface of boundary (b) boundary with free in-flow (c) boundary with free out-flow

Fig.1 The relation of velocities on both sides of boundary

1) Condition with solid surface of boundary

Supposing flow moves in direction along tangent of solid surface, this movement can be considered as mirror reflection. The data in the center of invented triangle can be taken as:

$$\begin{cases} \rho_s = \rho_i \\ p_s = p_i \\ v_{s,n} = -v_{i,n} \\ v_{s,\tau} = v_{i,\tau} \end{cases}$$

2) Condition of boundary with free-in-flow

As shown in figure 1(b), there are relation as follows:

$$\begin{cases} \rho_i = \rho_s = \rho_\infty \\ p_i = p_s = p_\infty \\ v_i = v_s = v_\infty \end{cases}$$

Where, ρ_∞ 、 p_∞ and v_∞ are data of free stream.

3) Condition of boundary with free out-flow

As shown in figure 1(c), there are relation as follows:

$$\begin{cases} \rho_s = \rho_i \\ p_s = p_i \\ v_s = v_i \end{cases}$$

Numerical Method of CFD

We use a special method of finite volume as numerical simulation of the flow field for previous equations.

Since there are wings and lift-canards for an extended-range projectile, the computational grids are generated by a Forward-Surface method as non-structural grids. According to this technique, we develop code of aerodynamic computations which can provide interesting information about the flow field of an extended-range projectile.

Based on introduced methods, we can predict aerodynamic coefficients of extended-range projectiles with different structural configurations of lift-canards and wings. With these predictions, we can select some shapes with perfect aerodynamic performance and make wind tunnel tests for them.

THE WIND TUNNEL TESTS FOR DIFFERENT SHAPES OF EXTENDED-RANGE PROJECTILES

Models of Wind Tunnel Tests

Based on analyses of aerodynamic computations for extended-range projectiles, some geometrical models included two pairs of canards three pairs of wings and two pairs of canards/four pairs of wings are selected to do wind tunnel tests. These models can be adjusted with change of relative positions for canards and wings. Figure 2 to Figure 4 show the geometries of these models.

Fig.2 The geometry of model No.1 (with two pairs of canards/two pairs of wings)

Fig.3 The geometry of model No.2 (with two pairs of canards/three pairs of wings)

Fig.4 The geometry of model No.3 (with two pairs of canards/four pairs of wings)

Fig.5 A model in wind tunnel

Description of Wind Tunnel and Wind Tests

The wind tunnel experiment were conducted in a wind tunnel with test section 0.6 m×0.6 m. This is a subsonic/supersonic blow-down wind tunnel with a variable geometry nozzle. The angle of attack for test model can be varied continuously from －15° to ＋15° . Figure 5 shows a model in wind tunnel.

The test condition used for our tests are limited as follows:

free stream mach number: 0.8, 1.1, 1.8, 2.0

angle of attack: －2° , －1° , 0° , 2° , 4° , 6° , 8°

Results of Wind Tunnel Tests

Figure 6 to Figure 11 show the results of wind tunnel tests for test model No.2 and No.3.

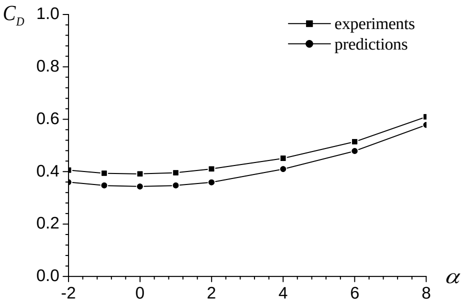


Fig.6 Axial force coefficients vs incidence(Model No.2, *M*=0.8)

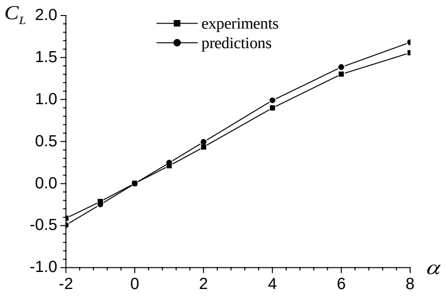


Fig.7 Normal force coefficient vs incidence (Model No.2, *M*=0.8)

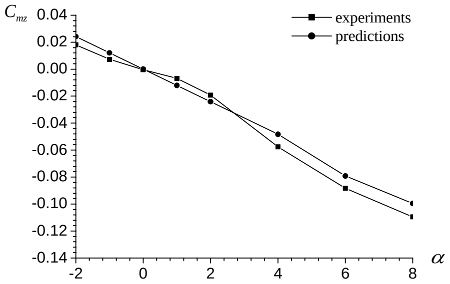


Fig.8 Pitching moment coefficients vs incidence (Model No.2, *M*=0.8)

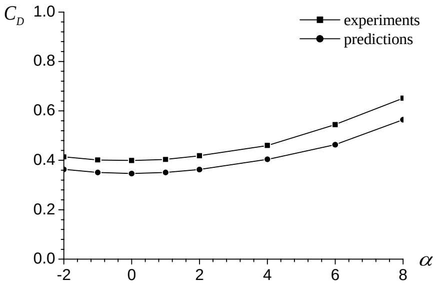


Fig.9 Axial force coefficient vs incidence (Model No.3, *M*=0.8)

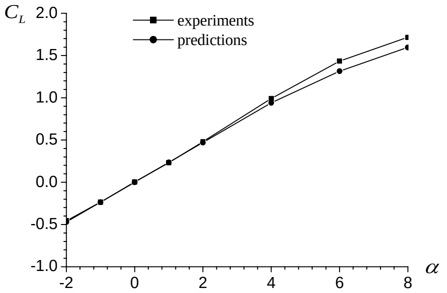


Fig.10 Normal force coefficient vs incidence (Model No.3, *M*=0.8)

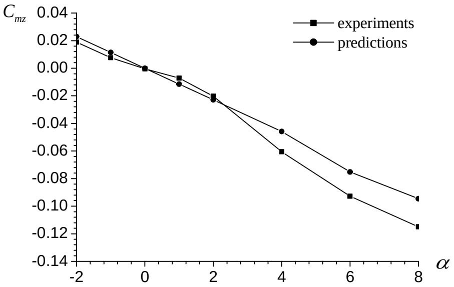


Fig.11 Pitching moment vs incidence (Model No.3, *M*=0.8)

Based on comparisons and analyses of wind tunnel tests for above different configurations we can see following results:

1) The predictions of CFD code introduced in this paper are agreement well with wind tunnel tests.

2) Those factors (shapes, pairs and relative position of lift-canards/wings) strongly effect down-wash phenomenon and flight stability. The results from perditions and experiments show that suitable lift-canards along with three pairs of wings have good performance of lift over drag and along with four pairs of wings (using “＋－＋” pattern) have less influence of down-wash.

3) In order to trade-off well the relation between enough lift supported by the wings four pairs of wings and reducing influence of down-wash to wings, four pairs of wings seem more suitable than three pairs (or two pairs) of wings.

CONCLUSIONS

Aerodynamic configuration strongly affects flight performance of an extended-range projectile so the design of aerodynamic shapes is first thing to do for the research of this kind projectiles.

Based on aerodynamic predictions and analyses, it is an efficient method to determine perfect configuration that some selected shapes or structures of models can be tested by wind tunnel. For a perfect aerodynamic structure, it usually trades-off the different characteristics of increasing lift over drag, reducing influence of down-wash and suitable flight stability, etc.

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