Analyses of Gliding Control for an Extended-Range Projectile

Prof. Zhongyuan Wang,
Prof. Houqian Xu, Dr. Jinguang Shi,
Dr. Wenjun Yi, Prof. Shaosong Chen

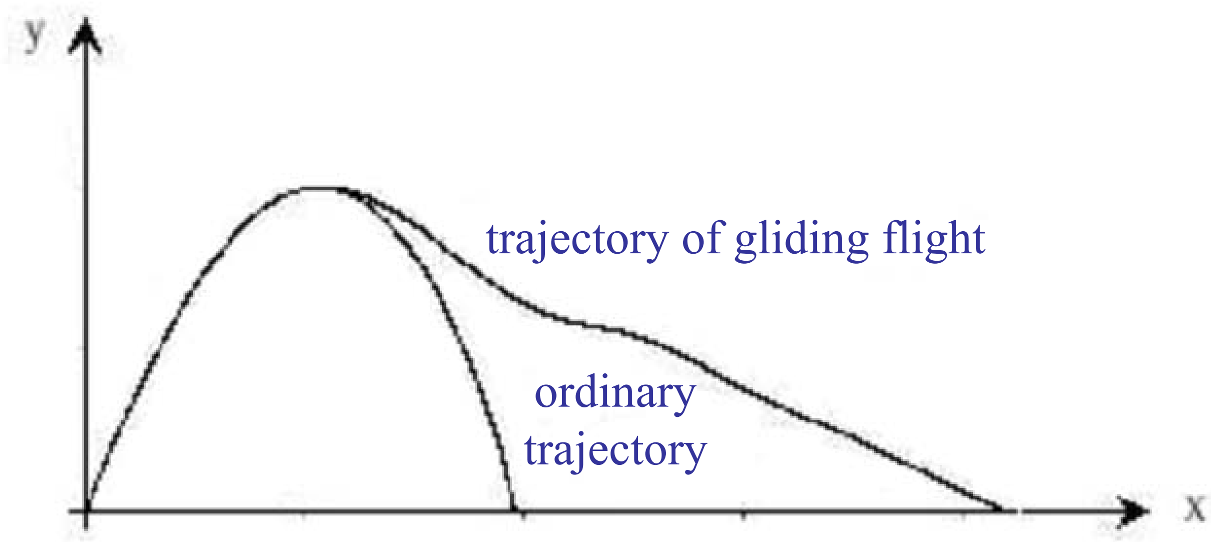
Ballistic Research Laboratory of China,
Nanjing University of Science & Technology ,
P.O.Box,210094,Nanjing,P.R.Chin

More Points

1. Introduction
2. Design of aerodynamic configuration for an extended-range projectile
3. Wind Tunnel Tests of extended-range projectiles
4. Analyses of favorite rotation of lift-canards during gliding flight

1. Introduction

Increasing range of a projectile with gliding flight is a quite efficient technique.



During gliding flight, the range and process of gliding control are strongly affected by following factors:

- Fine design of aerodynamic configuration
- To match well change for the rotation of lift-canards and the angle of attack

2. Design of aerodynamic configuration for an extended-range projectile

Aerodynamic Simulation and Code

The equations of CFD for a projectile can be described

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

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

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

CFD Technique

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

Fig.1 to Fig.3 are sketches of grids on surface of a projectile.

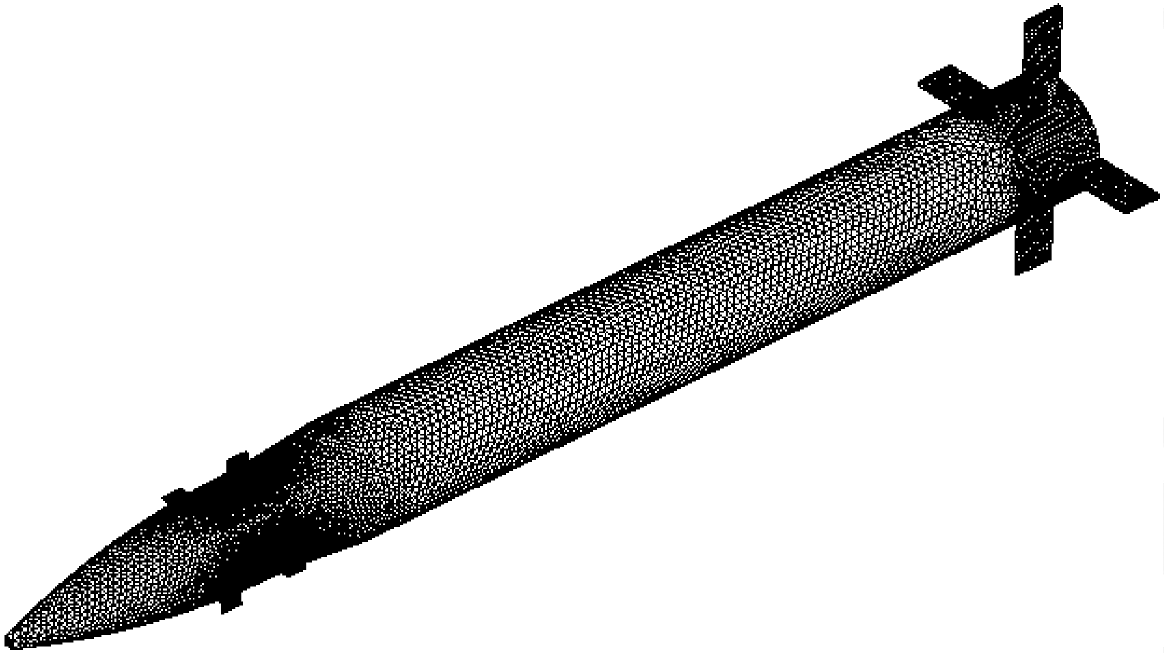


Fig .1 The sketch of grids on whole surface

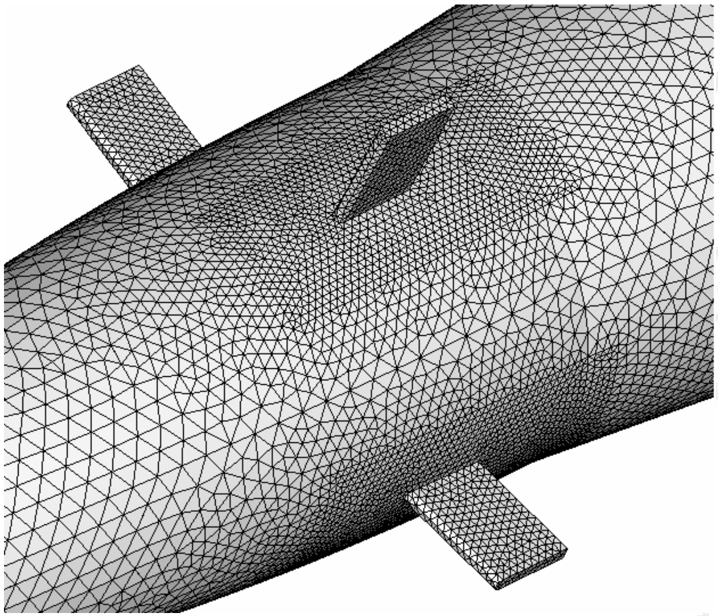


Fig .2 The sketch of grids on front projectile with lift-canards

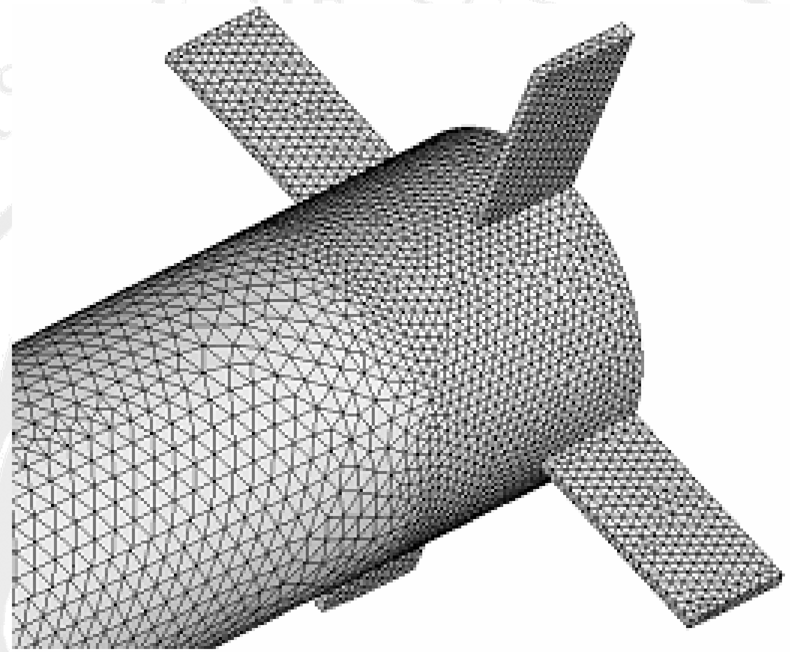


Fig .3 The sketch of grids on rear projectile with wings

Function of Code

Based on above basic equations and numerical simulation, we develop a code of aerodynamic computations .

Design of aerodynamic configuration

- Purpose of design
- Analyses of Aerodynamic Design

Fig.4 to Fig.7 are CFD numerical simulations for different lift-canards and wings.

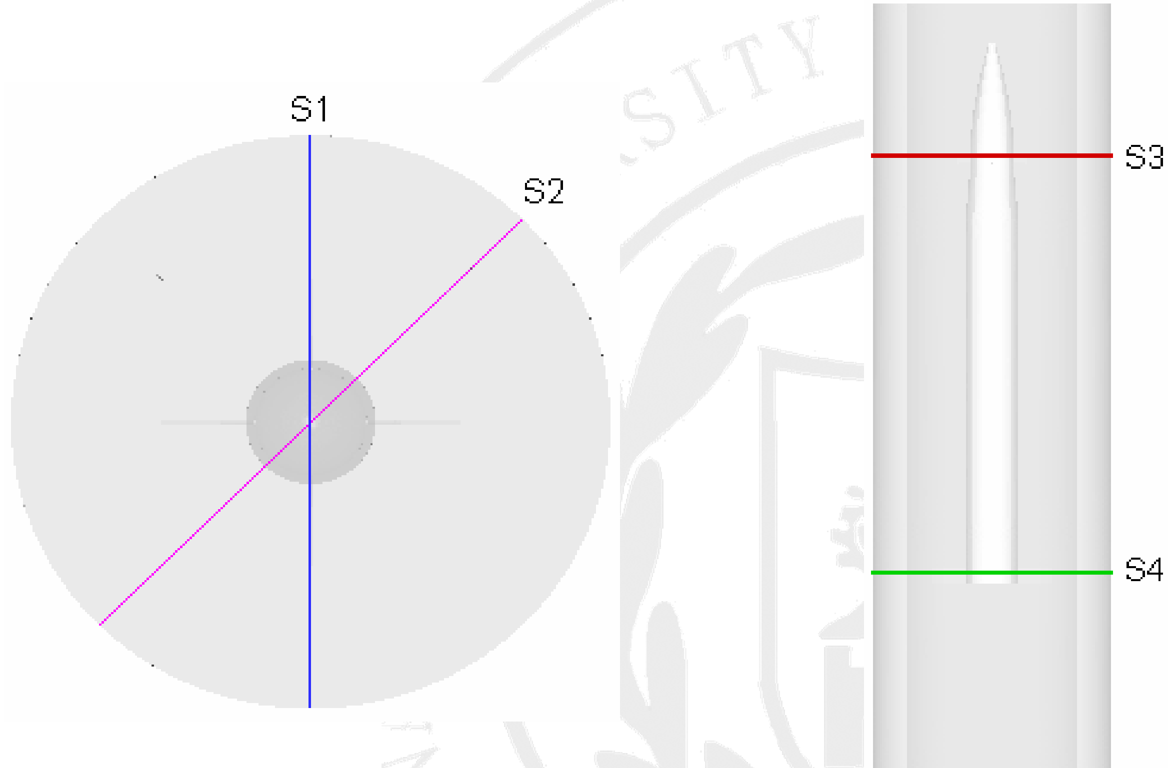
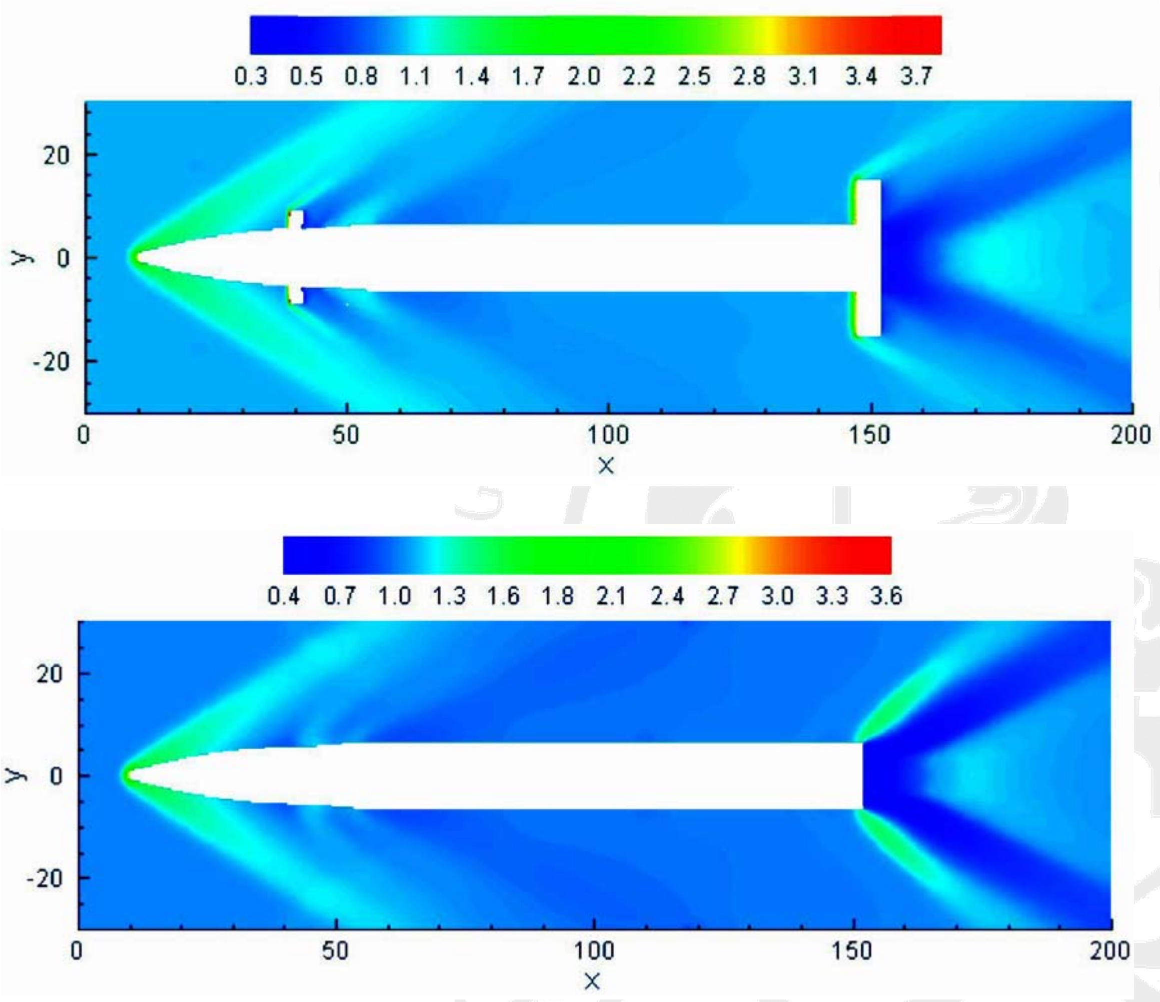


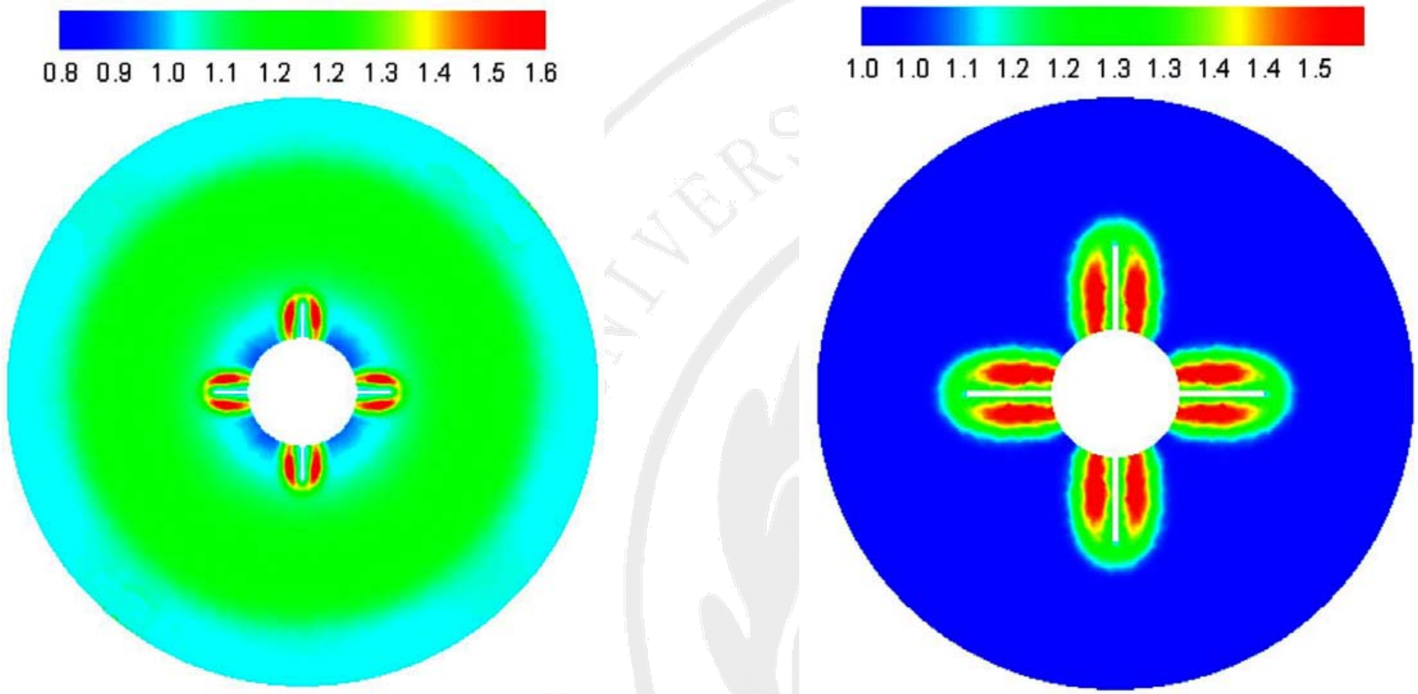
Fig .4 The sketch of different cross sections S1, S2, S3, S4 on a projectile



(a)

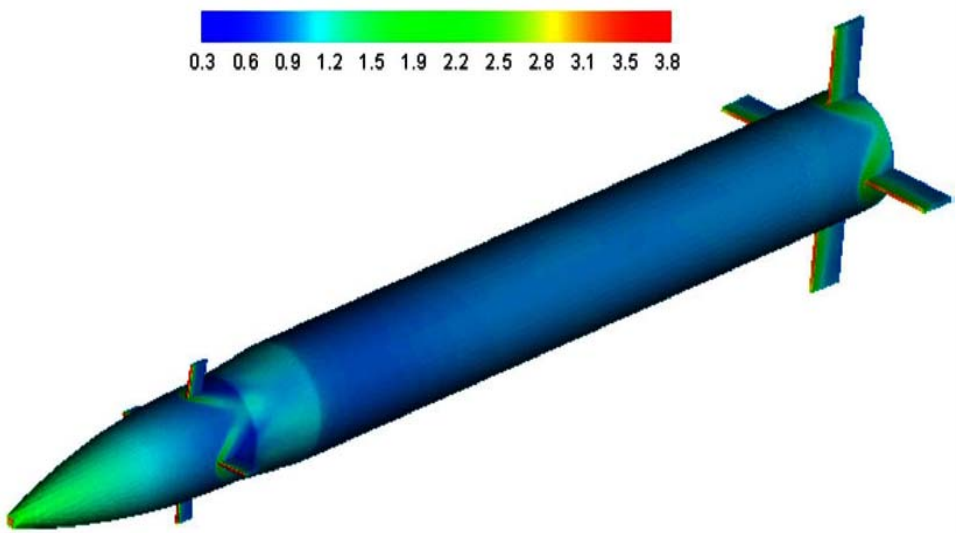
(b)

Fig .5 The pressure distribution on cross section S1, S2



(a) (b)

Fig .6 The pressure distribution on cross section S3, S4



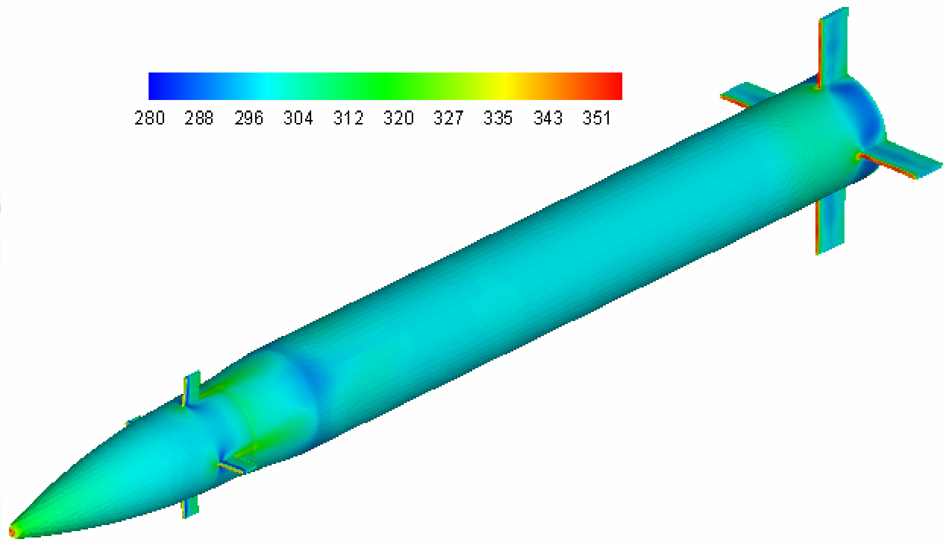


Fig .7 (a) The pressure distribution on whole surface of a projectile

Fig .7 (b) The temperature distribution on whole surface of a projectile

From numerical results we know that these factors (including shapes, pairs and position) of lift-canards and wings strongly affect aerodynamic characteristics. So for any extended-range projectile, the aerodynamic design with CFD code should be done first in order to get good relation between flight stability and maneuverability.

3. Wind tunnel tests of extended-range projectiles

3.1 Models of wind tunnel tests

Some geometrical models with different shapes or pairs of lift-canards and wings are selected for wind tunnel tests.

Fig.8 to Fig.11 show the geometries of some these models.

Fig.8 The geometry of model No.1
(with one pair of lift-canards and three pairs of wings)

Fig.9 The geometry of model No.2
(with two pairs of lift-canards and three pairs of wings)

Fig.10 The geometry of model No.3
(with two pairs of lift-canards and two pairs of wings)

Fig.11 The geometry of model No.4
(with two pairs of lift-canards and four pairs of wings)

3.2 Description of Wind Tunnel

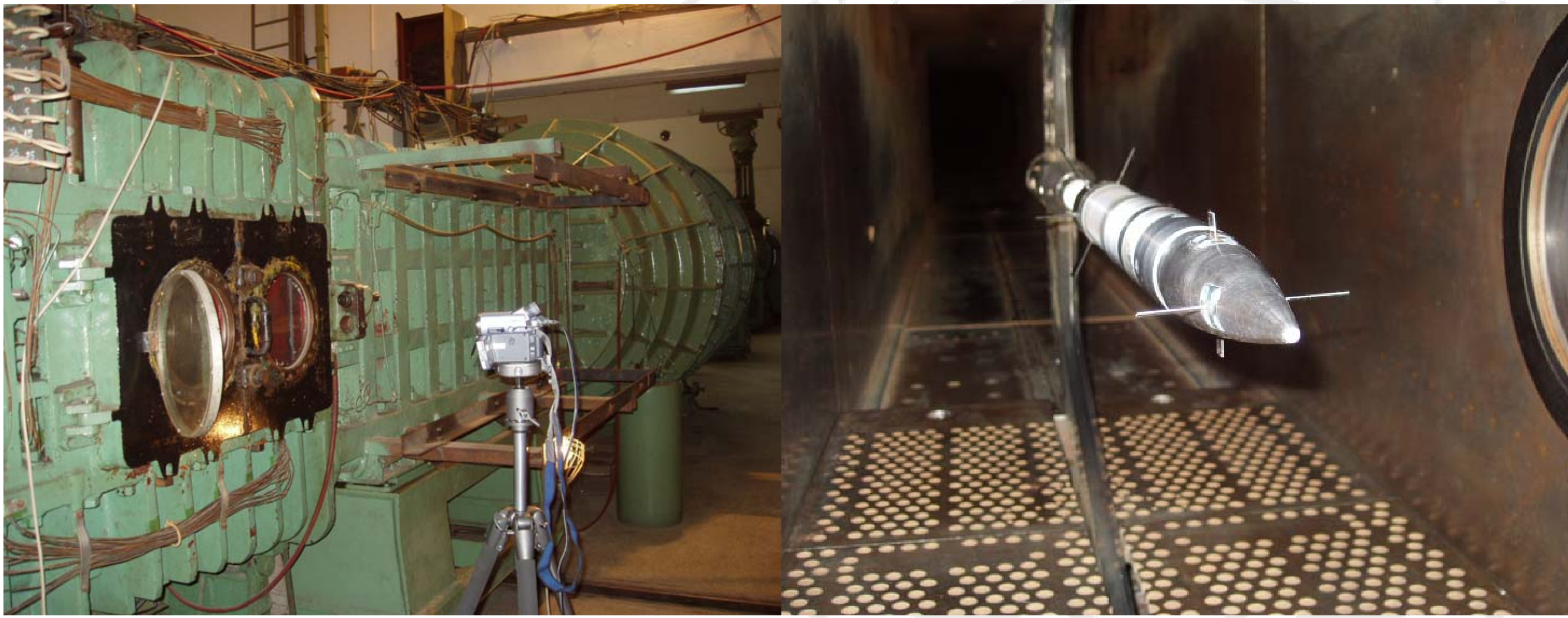


Fig.12 A blow-down wind tunnel

3.3 Results of Wind Tunnel

Fig.13 to Fig.18 show some results of wind tunnel tests.

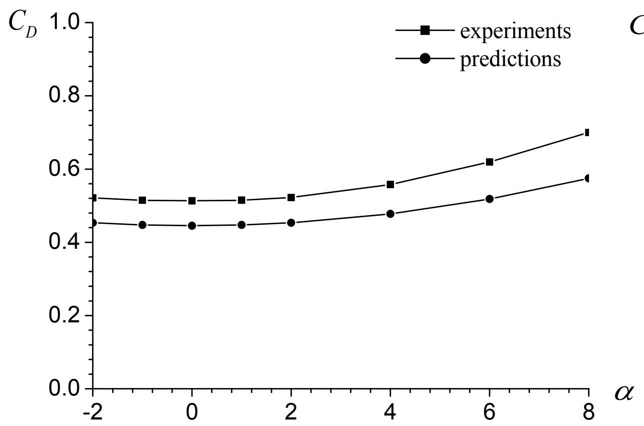


Fig.13 Axial force coefficient vs incidence (Model No.1, M=1.79)

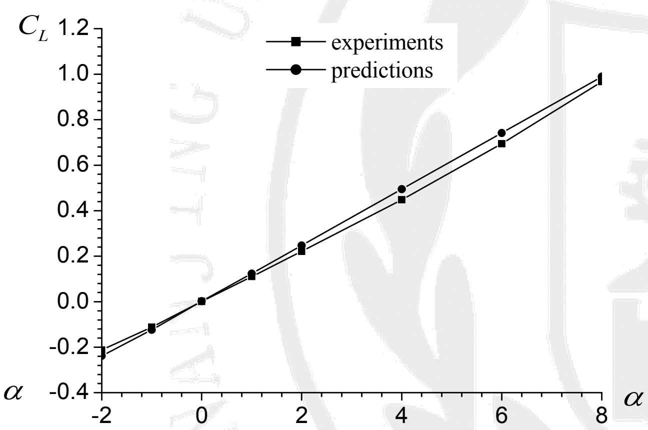


Fig.14 Normal force coefficient vs incidence (Model No.1, M=1.79)

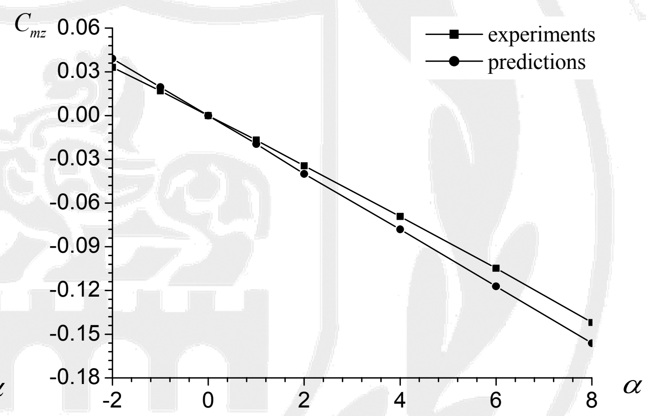


Fig.15 Pitching moment coefficient vs incidence (Model No.1, M=1.79)

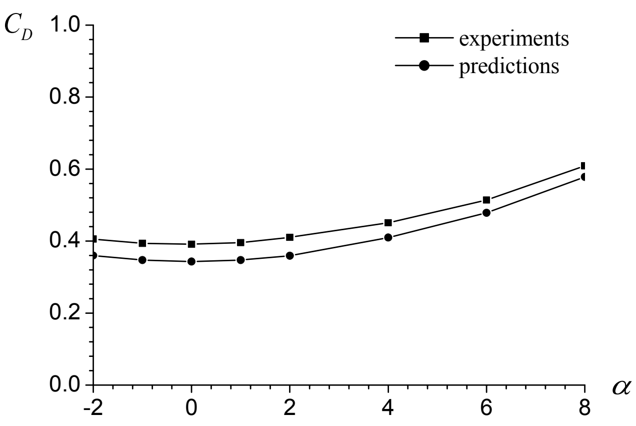


Fig.16 Axial force coefficient vs incidence (Model No.2, M=0.8)

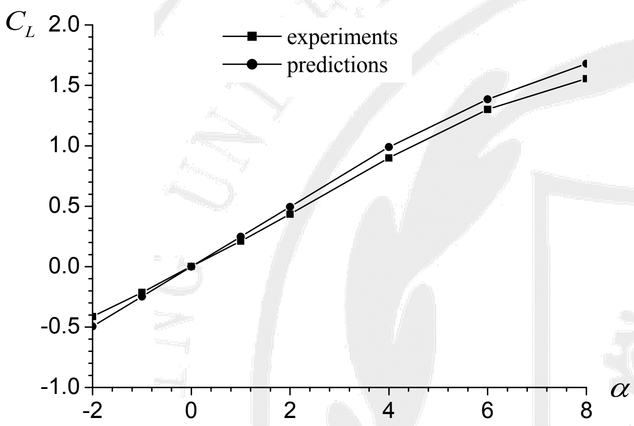


Fig.17 Normal force coefficient vs incidence (Model No.2, M=0.8)

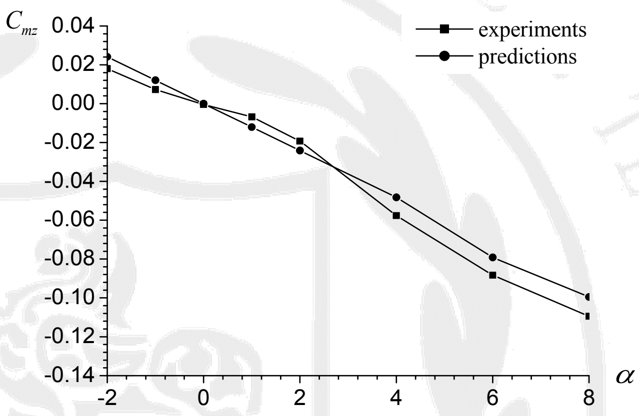


Fig.18 Pitching moment coefficient vs incidence (Model No.2, M=0.8)

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

- The predictions of CFD code are agreement well with wind tunnel tests.
- Those factors strongly affect flight stability, maneuverability and down-wash phenomenon.
- To design aerodynamic configuration for an extended-range projectile combined the predictions with CFD code and wind tunnel tests should be used.

4. Analyses of favorite rotation of lift-canards during gliding flight

During gliding flight the angle of attack is changed by control of lift-canards. If the rotating angle of canards is too large, it will cause some problems such as flight stability or increasing drag fast and it is not suitable for gliding flight. If the rotating angle of canards is too small, it will cause other problems such as small angle of attack and it is not efficient to increase range with gliding flight.

At any time during gliding flight, there is an equilibrium relation between rotation of canards and angle of attack:

$$\alpha(t)=\left(\frac{C'_y x_1}{C'_{y\alpha} x_2}-1\right)\delta^*(t)$$

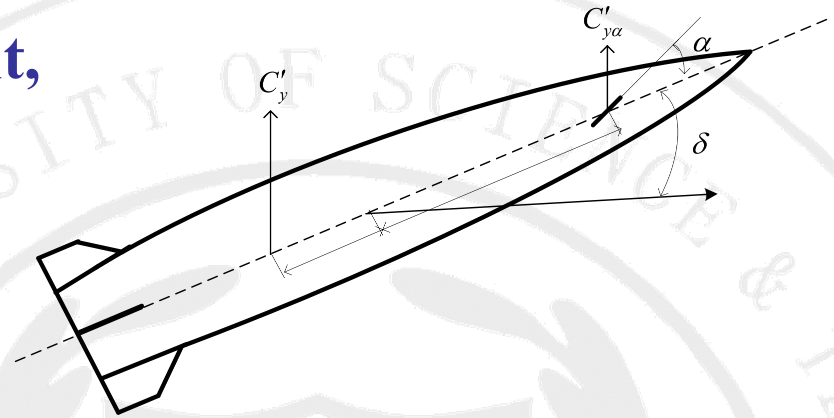


Fig.19 Angle of attack vs angle of rotating canards

$\alpha(t)$ —angle of rotating canards,

$\delta^*(t)$ —instantaneous balance angle of attack.

Of cause different $\alpha(t)$ causes different $\delta^*(t)$ and range of gliding flight.

To analyses the effect of rotating canards to range of gliding flight. We can use a 6D model of trajectory and some optimum method to find the favorite angle of rotating canards.

Sequence Quadric Programming (SQP)

Sequence Quadric Programming is a special method in optimum theory. We can use it to make optimization of the farthest range with different angles of rotating canards.

Main Idea or Process

To find a favorite angle of rotating canards, we can use following methods:

- CFD code and other empirical method to predict aerodynamic coefficients.
- 6D model of trajectory to calculate the range of gliding flight.
- SQP method to find the result of optimization for angle of rotating canards with the farthest range.

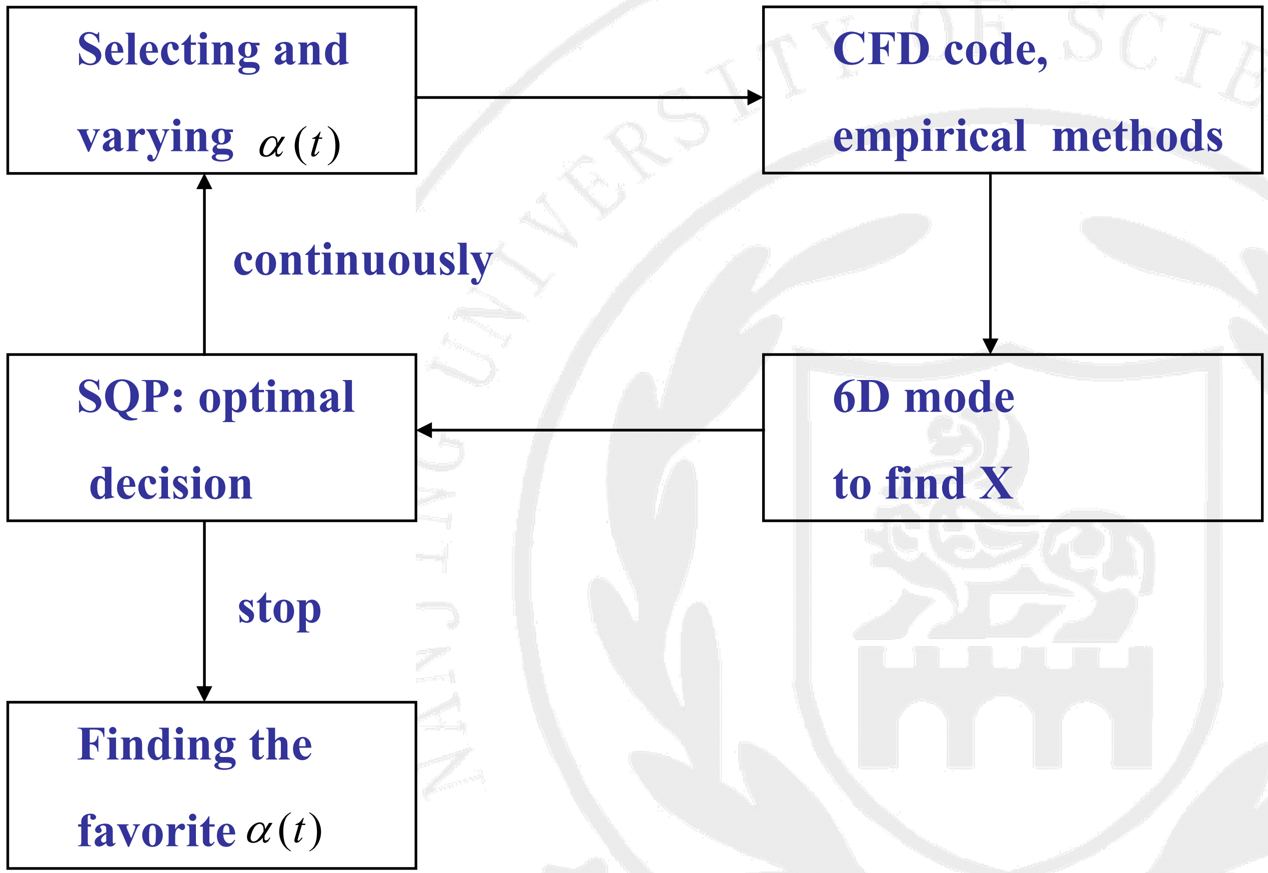


Fig.20 General process to find favorite $\alpha(t)$

For a special extended range projectile, the favorite angle of rotating canards and corresponding angle of attack have been calculated in Fig.21 and Fig.22

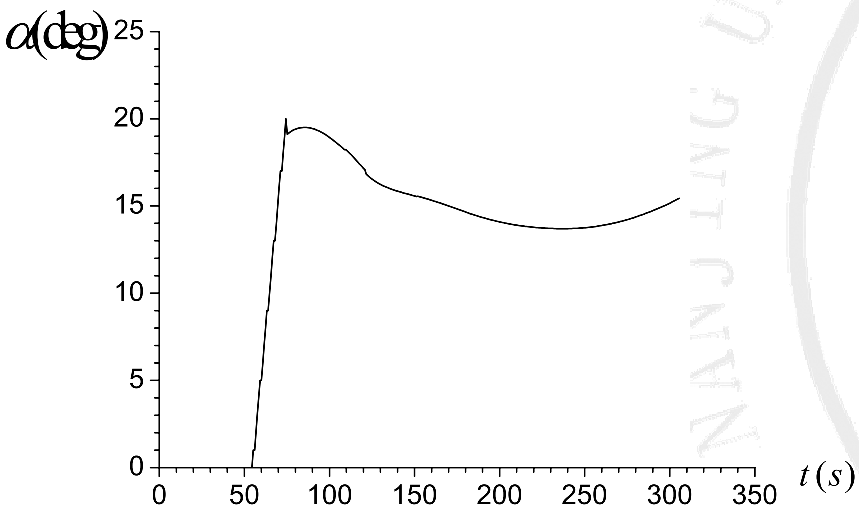


Fig.21 the curve of favorite angle of rotating canards

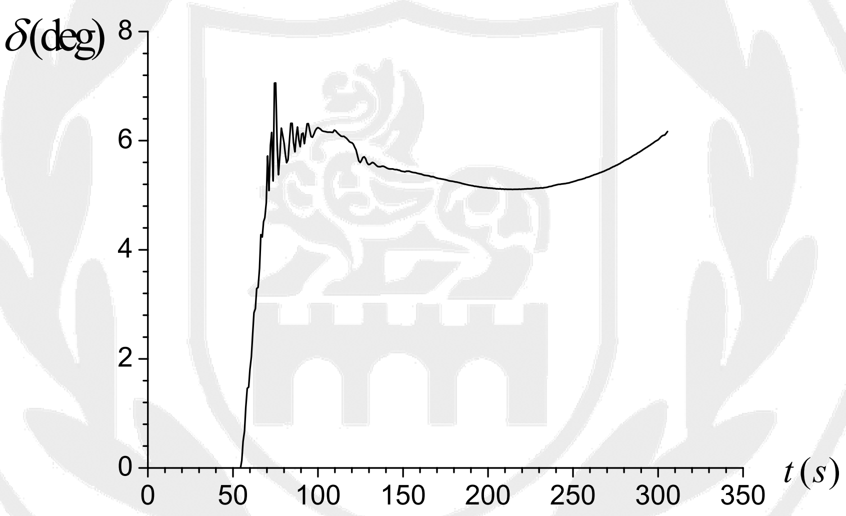


Fig.22 the curve of corresponding angle of attack

Conclusions

- For an extended-range projectile, the CFD code introduced here can be used.
- The results from predictions and experiments show that the factors strongly affect aerodynamic characteristics.
- Based on the 6D model of trajectory and SQP method, the favorite angle of rotating canards can be found.