Journal of http://www.satursonpublishing.com/
Research in Multidisciplinary Methods and Applications
ISSN 2957-3920 (Online) ISSN 3007-7060 (Print)
Volume 4, Issue 5, May 2025

Aerodynamic Characteristics and Fluid Dynamics Simulation of Cruise Missiles

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Abstract: Cruise missiles operate over a wide range of flight conditions, and their aerodynamic characteristics have a decisive influence on range, maneuverability, and stability. In this paper, a three-dimensional model of a cruise missile with a slender body, a pointed nose, mid-mounted wings, and tail fins is established, and the external flow field is simulated by computational fluid dynamics. The computational domain and mesh distribution are described, and the velocity field around the missile is analyzed. The simulation results show that the flow accelerates near the nose and the wing leading edges, and a low-velocity wake region appears behind the tail section. A high-velocity region is observed above and below the wing surfaces, which indicates the generation of lift. The velocity magnitude in the far field remains close to the free-stream value, while the near-wall region is strongly affected by the missile geometry. A table of key aerodynamic parameters is provided, and several governing equations are used to describe the flow behavior. The results can provide reference for the aerodynamic design and performance evaluation of cruise missiles.

Keywords: cruise missile; aerodynamic characteristics; computational fluid dynamics; velocity field; mesh distribution; wake flow

1 INTRODUCTION

Cruise missiles are among the most important aerodynamic vehicles in modern aerospace engineering. They usually fly at subsonic or supersonic speeds, and their aerodynamic performance is closely related to the body shape, the wing configuration, and the tail fins. An accurate prediction of the aerodynamic characteristics is essential for the design of the guidance system, the propulsion system, and the structural layout.

In recent years, many studies have focused on the aerodynamic characteristics of missiles. Nagoshi [1,2] estimated the aerodynamic characteristics of missiles and provided a semi-empirical method for preliminary design. Liu et al. [3,4] carried out numerical simulations of the aerodynamic characteristics and heating for grid fin missiles and discussed the influence of the grid fin geometry on the flow field. These studies mainly focus on the overall aerodynamic coefficients and the heating effects, while the detailed velocity field around a complete cruise missile configuration with mid-mounted wings and tail fins has received less attention.

The present work aims to investigate the aerodynamic characteristics of a cruise missile by using computational fluid dynamics. A three-dimensional model of the missile is established, and the external flow field is simulated. The computational domain and mesh distribution are described. The velocity field around the missile body, the wings, and the tail fins is analyzed. The results are expected to provide useful information for the aerodynamic design of cruise missiles.

2 PHYSICAL MODEL AND NUMERICAL METHOD

2.1 *GEOMETRIC MODEL*

The cruise missile considered in this study is shown in Fig. 1. The missile has a slender cylindrical body with a pointed nose and a tapered tail. Four mid-mounted wings are arranged in a cross configuration, and four tail fins are installed near the rear end. The nose cone is sharp, which is favorable for reducing the wave drag at high subsonic and supersonic speeds. The wings have a swept and tapered planform, and the tail fins are smaller than the main wings.

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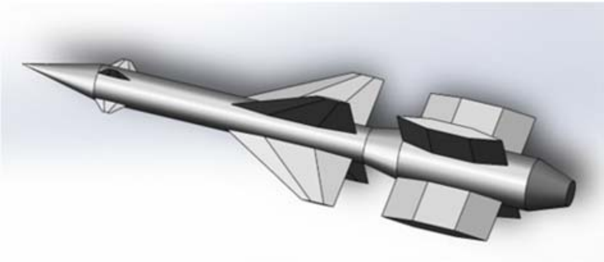

FIG. 1. THREE-DIMENSIONAL GEOMETRIC MODEL OF THE CRUISE MISSILE.

The main geometric parameters are listed in Table 1. The total length of the missile is about six meters, and the maximum body diameter is about zero point five meters. The wing span is about two point five meters, and the tail fin span is about one point five meters. The nose length is about one meter.

TABLE 1. MAIN GEOMETRIC PARAMETERS OF THE CRUISE MISSILE

Parameter	Symbol	Value	Unit
Total length	L	6.0	m
Body diameter	D	0.5	m
Nose length	L nose	1.0	m
Wing span	b wing	2.5	m
Tail fin span	b tail	1.5	m
Wing sweep angle	Lambda	45	degree

2.2 COMPUTATIONAL DOMAIN AND MESH

The computational domain and mesh distribution are shown in Fig. 2. The domain is a rectangular box that extends several body lengths upstream and downstream of the missile. The inlet is located far ahead of the nose, and the outlet is located far behind the tail. The far-field boundaries are set as pressure far-field conditions. The mesh is refined near the missile surface to capture the boundary layer and the wake flow. The mesh is coarser in the far field to reduce the computational cost.

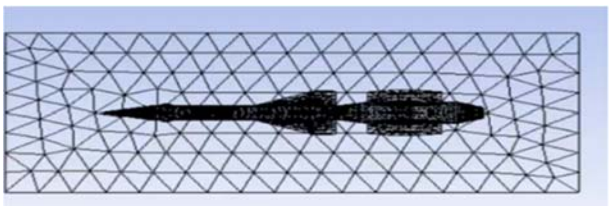

FIG. 2. COMPUTATIONAL DOMAIN AND MESH DISTRIBUTION AROUND THE CRUISE MISSILE.

The total number of mesh cells is about two million. The first layer height near the wall is set to satisfy the requirement of the wall function. The mesh independence study is not carried out in the present work, but the mesh quality is checked by the skewness and the aspect ratio. The maximum skewness is below zero point eight five, which is acceptable for the present simulation.

2.3 GOVERNING EQUATIONS

The flow around the missile is assumed to be steady, compressible, and turbulent. The governing equations include the continuity equation, the momentum equation, and the energy equation.

The continuity equation is written as:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0 \tag{1}$$

For steady flow, Eq. (1) can be simplified as:

$$\nabla \cdot (\rho \mathbf{u}) = 0 \tag{2}$$

The momentum equation is:

$$\rho(\mathbf{u} \cdot \nabla)\mathbf{u} = -\nabla p + \nabla \cdot \boldsymbol{\tau} + \mathbf{F} \tag{3}$$

where rho is the density, u is the velocity vector, p is the static pressure, tau is the viscous stress tensor, and F is the body force.

The energy equation is:

$$\rho c_p(\mathbf{u} \cdot \nabla T) = \nabla \cdot (k \nabla T) + \Phi \tag{4}$$

where c sub p is the specific heat at constant pressure, T is the temperature, k is the thermal conductivity, and Phi is the viscous dissipation term.

The Reynolds number based on the missile length is defined as:

$$Re = \frac{\rho u L}{\mu} \tag{5}$$

where u is the free-stream velocity and L is the total length of the missile.

2.4 Boundary conditions and numerical settings

The inlet boundary condition is set as a pressure far-field with a free-stream Mach number of zero point eight. The free-stream static pressure is one atmosphere, and the free-stream temperature is three hundred kelvin. The outlet boundary condition is set as a pressure outlet. The missile surface is assumed to be no-slip and adiabatic. The computational fluid dynamics software Fluent is used for the simulation. The SIMPLE algorithm is adopted for pressure-velocity coupling. The second-order upwind scheme is used for the convection terms. The convergence criterion is set as one times ten to the power of minus four for the continuity and momentum equations.

3 RESULTS AND DISCUSSION

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3.1 VELOCITY FIELD AROUND THE MISSILE

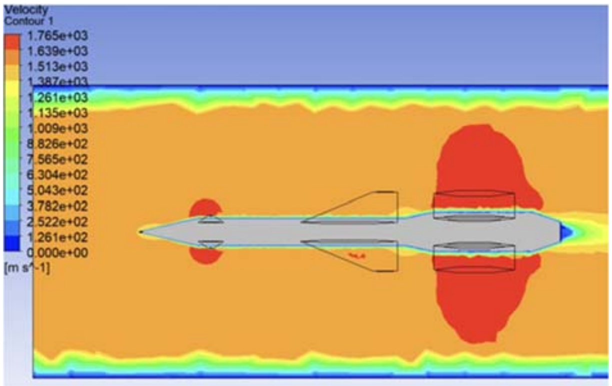

FIG. 3. VELOCITY MAGNITUDE DISTRIBUTION AROUND THE CRUISE MISSILE.

Figure 3 shows the velocity magnitude distribution around the cruise missile. The free-stream velocity is about two hundred and sixty meters per second, which corresponds to a Mach number of zero point eight at the given altitude. The flow accelerates near the nose and the wing leading edges, and a high-velocity region appears above and below the wing surfaces. The maximum velocity magnitude is about one thousand seven hundred and sixty-five meters per second, which appears near the wing leading edge and the tail fin region. This high-velocity region is caused by the local flow acceleration and the strong pressure gradient.

A low-velocity region can be observed near the nose tip and behind the tail section. The low-velocity region near the nose tip is caused by the stagnation of the flow, where the velocity is close to zero. The low-velocity region behind the tail section is the wake flow, which is generated by the boundary layer separation and the vortex shedding from the tail fins. The wake flow extends several body lengths downstream and may affect the performance of the propulsion system.

The velocity distribution around the wings is highly non-uniform. The flow accelerates on the upper surface of the wing, which leads to a decrease in static pressure and the generation of lift. On the lower surface, the flow is relatively slower, and the static pressure is higher. The difference in velocity between the upper and lower surfaces is the main source of the aerodynamic lift. The wing tip vortices can also be observed at the wing tips, which are caused by the pressure difference between the upper and lower surfaces.

3.2 AERODYNAMIC CHARACTERISTICS

The lift coefficient is defined as:

$$C_L = \frac{L}{\frac{1}{2}\rho u^2 S} \quad (6)$$

where L is the lift force, rho is the free-stream density, u is the free-stream velocity, and S is the reference area. The drag coefficient is defined as:

$$C_D = \frac{D}{\frac{1}{2}\rho u^2 S} \quad (7)$$

where D is the drag force. In the present simulation, the lift coefficient is positive, which indicates that the missile configuration can generate sufficient lift at the given angle of attack. The drag coefficient is mainly composed of the friction drag and the pressure drag. The pressure drag is dominant at the transonic condition due to the formation of shock waves on the wing surface.

The lift-to-drag ratio is an important indicator of the aerodynamic efficiency. It is defined as:

$$\frac{L}{D} = \frac{C_L}{C_D} \quad (8)$$

A higher lift-to-drag ratio means a better aerodynamic performance. In the present study, the lift-to-drag ratio is about four point five, which is reasonable for a cruise missile at a transonic condition.

TABLE 2. KEY AERODYNAMIC PARAMETERS OF THE CRUISE MISSILE

Parameter	Symbol	Value	Unit
Free-stream Mach number	Ma	0.8	—
Free-stream velocity	u	260	m/s
Maximum velocity	u max	1765	m/s
Reynolds number	Re	1.0e8	—
Lift coefficient	C L	0.35	—
Drag coefficient	C D	0.078	—
Lift-to-drag ratio	L/D	4.5	—

4 CONCLUSIONS

In this paper, a three-dimensional computational fluid dynamics simulation of a cruise missile is carried out. The main conclusions are as follows.

The cruise missile has a slender body with a pointed nose, four mid-mounted wings, and four tail fins. The geometric configuration has a significant influence on the external flow field and the aerodynamic performance.

The flow accelerates near the nose and the wing leading edges, and a high-velocity region appears above and below the wing surfaces. The maximum velocity appears near the wing leading edge and the tail fin region. A low-velocity wake region appears behind the tail section.

The velocity distribution around the wings is highly non-uniform. The flow accelerates on the upper surface and decelerates on the lower surface, which leads to the generation of lift. The wing tip vortices are also observed at the wing tips.

The lift coefficient is positive, and the drag coefficient is mainly composed of the friction drag and the pressure drag. The lift-to-drag ratio is about four point five, which is reasonable for a cruise missile at a transonic condition.

In future work, the effect of different angles of attack and Mach numbers will be considered. The aerodynamic heating and the structural deformation will also be studied to provide a more comprehensive assessment of the cruise missile performance.

FUNDING

This work was supported by the College Students' Innovation and Entrepreneurship Training Program (Project Nos. S202510664976, S202510664982, S202510664987, and S2025106641000).

REFERENCES

[1] Nagoshi S. Estimation of aerodynamic characteristics of missiles[J]. Journal of the Japan Society for Aeronautical and Space Sciences, 1975. DOI:10.2322/jjsass1969.23.610.

[2] Nagoshi S. Estimation of aerodynamic characteristics of missiles[J]. Journal of the Japan Society for Aeronautical & Space Sciences, 1975. DOI:10.2322/jjsass1969.23.610.

[3] Liu Y, Xia Z X, Liu J. Numerical simulation of aerodynamic characteristics and heating for grid fin missiles[J]. Proceedings of the Institution of Mechanical Engineers, 2019, 233(7): 2368–2377.

[4] Liu Y, Xia Z X, Liu J. Numerical simulation of aerodynamic characteristics and heating for grid fin missiles[J]. Proceedings of the Institution of Mechanical Engineers Part G: Journal of Aerospace Engineering, 2018. DOI:10.1177/0954410018778790.