Analysis of aerodynamic characteristics of missile with different sweep angle under supersonic condition

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Abstract. The increasing complexity of the modern battlefield requires that the aircraft can achieve multi-mission and low energy operation. In this paper, the dynamic characteristics of the missile are analyzed by building a 3D model of the missile and CFD simulation, in order to study the dynamic characteristics of the missile at different swept back angles. The lift force and drag force of the missile under different sweeps are studied, and the influence of the variable sweep angle on the aerodynamic characteristics of the whole body is revealed.

1. Introduction

As the future battlefield and combat mode change, high performance tactical indicators bring challenges to the overall missile design. As an important development direction of the new-generation aircraft, the deformable aircraft can change its structure on a large scale according to the flight environment and task demand to obtain the best aerodynamic layout and manoeuvrability. The deformable wing technology has re-emerged as a research hotspot at home and abroad.[1].

Nowadays, many countries have extended the deformable wing technology to the missile configuration design, in order to give full play to the optimal flight performance of aircraft, improve flight efficiency and realize economic flight. Therefore, many countries have carried out a lot of research on the structural design and related aerodynamic performance of the deformable wing [2-4]. The application of deformed swept-back wing technology in the field of aircraft control has attracted renewed attention from the defence industry. The material, structure, aerodynamics, manufacture and flight control of the deformed aircraft have been extensively and deeply studied. However, the research on missile is still at the theoretical research stage, and many of its theories and related technologies need further study and exploration. [5].

This article is based on the different aerodynamic configuration of the wings, according to the overall missile design principles, missile flight dynamics, through three-dimensional modelling of variable swept-wing missile aerodynamic shape design, and the application of CFD simulation software to five groups of variable sweep angle folding wing missile model in different flight speeds to analyse the aerodynamic characteristics, resulting in different sweep angles on the applicability of missiles in different flight states, and summarize the variable sweep angles folding wing missile aerodynamic characteristics to provide theoretical reference for missile aerodynamic design. [3, 4, 5].
2. Aerodynamic configuration of missiles

2.1. The missile body design

In this article, based on the aerodynamic shape of reference [6], the wing is designed as shown in the figure. The cross-sectional diameter of the missile body is 0.40m, the total length of the body is 5.8m, the length of the head is 1.4m, the wing span is 1.55 m, as illustrated in Figure1.

![Figure 1. Parameters.](image)

Considering that the studied missile model needs to fly at different speeds of subsonic, transonic, and supersonic, so as to give the missile a better supersonic flight performance, this paper chooses the modified double wedge airfoil profile as the analytical model of the wing [7], as illustrated in Figure2.

![Figure 2. Airfoil profile.](image)

2.2. Establishment of missile 3D model

According to the different layout of the current missile aerodynamic shape, the establishment of variable back-sweep angle folding wing missile 3D model is shown in Figure 3.

![Figure 3. The establishment of model.](image)

In this paper, we adopt the shear variable sweep mode [8], which makes the change of the swept back angle from 15° to 75°. The three-dimensional model of the missile is designed with the wing sweep angle of 15°, 30°, 45°, 60°, 75°, as illustrated in Figure 4.

![Figure 4. Models under different sweep angles.](image)
3. Simulation analysis of missile aerodynamic characteristics

3.1. The division of the mesh
The missile shape is complex, so unstructured meshing is adopted. First of all, the edge mesh is divided, and evenly arranged, the mesh spacing size is 1, then the mesh is divided, all edges are selected, Elements is selected as Tet/Hybrid, and Type is selected as TGrid to divide the outer body mesh.

3.2. Loading of boundary conditions and output of mesh
Specify the boundary type of the model after completing the meshing. Set the symmetric surface of the air flow field as symmetric SYMMETRY boundary condition. Set the two semicircular ends of the outermost outer half of a large cylinder and the outer surface of half a cylinder to be the pressure far field PRESSURE-FAR-FIELD boundary conditions. GAMBIT can automatically define WALL boundary conditions for undefined parts of the calculation field. Select the PRESSURE-OUTLET boundary condition for the bottom cross section of the missile. The boundary conditions of the design model are now set.

3.3. Simulation analysis of the aerodynamic characteristics of missiles with different swept-back angles
The MSH files with 5 different swept angles (15°, 30°, 45°, 60°, 75°) are imported into CFD software for aerodynamic analysis of the missile model. In order to better analyze the aerodynamic characteristics of the variable swept-wing missile at different speeds, the flight MA number is set as 1.5, 2.0, 2.5, 3.0, 3.5, according to the actual situation of the missile flight speed from pressure to supersonic speed. The attack angle is set as 4° according to the missile speed, so as to do the constant analyze of the variable sweep wing missile.

3.4. Simulation results
A total of 25 groups of simulation date from 5 groups of missile models with different swept back angles at 5 different flight speeds are shown below.

Figure 5. Pressure contours.
Figure 6. Velocity contours.
4. Conclusion
With the continuous progress of aviation science and technology, the demand for missiles to adapt to transonic flight and supersonic flight capability is increasing. The advantages of deformed-wing technology are becoming more and more obvious, and the folded-wing missile with variable swept-back angle can control the swept-back angle of the missile's wings through the servo mechanism, so that the missile can adjust the swept-back angle at different flight speeds to increase the missile's attack range and other technical and tactical indicators.

This paper briefly describes the present condition of deformed wing missiles at home and abroad, and carries out three-dimensional modelling, numerical calculation and simulation analysis on five groups of folding-wing missile models with variable back-sweep angle. Through the simulation analysis and the comparison of missile flight data at different Mach numbers, the applicability of different backsweep angles in different missile flight states is concluded, and the conclusions are as follow:

(1) As the Ma number rises, increasing the wing sweep angle can increase the lift drag ratio of the missile when 1 < Ma ≤ 3. This is suitable for missiles entering a high speed and precision attack or crossing the danger zone at high Mach numbers.

(2) In supersonic flight stage, when the sweep angle is greater than 60 °, the missile model has smaller drag coefficient, but the lift coefficient is also decreasing, which cannot continue to provide good lift drag ratio. When Ma > 3, the optimal sweep angle of missile wing is 60 °.

(3) By folding the wings to change the swept back angle, the aerodynamic shape of the missile can be adapted to different flight conditions, improving the missile's Aerodynamic performance, saving fuel and increasing the attacking range of the missile.

5. Prospect
The swept folding wing studied in this paper is left-right symmetrical, and the span of sweep angle variation is not detailed enough. What's more, it studies the case of no directional deflection angle, and does not analyze the heeling moment, so the analysis results have certain limitations. In the follow-up study of variable sweep folding wing, it is necessary to analyze the asymmetric sweep to make the deflection moment generated by asymmetric sweep resist the influence of heeling moment, and the theoretical basis for the aerodynamic shape design of variable sweep angle folding wing missile needs to be further enriched and perfected.

Figure 7. Lift drag ratio.
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