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Study on the Unsteady Aerodynamic Heating of the Oscillating Model

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Abstract

A numerical method is developed for studying the influence of the oscillating model to the aerodynamic heating. By using of the method of rigid dynamic grid and Arbitrary Lagrangian- Eulerian(ALE) formulation, a computer code is developed which could be applied to numerical simulate the unsteady aerodynamic heating of the oscillating airfoil models for hypersonic flow condition. The purpose of this study is to investigate the effects of the unsteady flow on the distribution of the heat flux. By comparison with the steady flow field, it shows that the head has little effect, while other part has a significant impact

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Keywords: Aerodynamic heating; Unsteady Hypersonic flow; Unsteady flow; CFD; Navier-Stocks equations; Oscillating model

1. Introduction

As a new branch of the aerothermodynamics, unsteady aerodynamic heating would analyze aerodynamic heating in the view of unsteady flow. As we all know, unsteady flow is kind of flow whoes physical quantities vary with time at any reference systems. To the unsteady flow field, flow parameters distributions are not only relevant to the boundary of the flow field at that moment, but also the initial conditions and the experience of the flow. Study on the unsteady aerodynamic heating, the most important is to analyze its time course.

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Researchers had found that the movement and deformation of the structure have great influence on aerodynamic heating[1,2]. However, unsteady hypersonic flow is much more complex than the steady flow, not only theoretical analysis is difficult to study, but it is also difficult to the hypersonic wind tunnel for the limiting of its function period and simulation conditions. As the development of the CFD(Computational fluid dynamics) in recent years, makes it possible to study the unsteady hypersonic flow in numerical method.

Compared with the unsteady aerodynamics, unsteady aerodynamic heating was not taken seriously. A lot of researches had done to study the influences of the unsteady hypersonic flow on the forces and moments of the oscillating models, but what about the influence on the heat flux? Little research concerned about this. Studying on the unsteady aerodynamic heating of the oscillating models has a great significance to the research on unsteady hypersonic flow field, and would be significant to the design of the hypersonic aircraft.

To study the unsteady aerodynamic heating, the unsteady boundary condition is taken into account. In this paper, the fully implicit upwind Navier-Stokes code based on Roe's FDS has been developed. By using of the method of rigid dynamic grid and Arbitrary Lagrangian-Eulerian(ALE) formulation, the oscillating flat model in the hypersonic flow is numerical simulated.

2. Numerical methods

2.1. Governing Equations

The finite element form of N-S equation, which is described by ALE, is as follows:

$$\frac{\partial}{\partial t}\oiiint_{\Omega}\vec{Q}\,dv+\oiint_{\partial\Omega}(\vec{E},\vec{F})\vec{n}\,ds=\oiint_{\partial\Omega}(\vec{E}_v,\vec{F}_v)\vec{n}\,ds \qquad (1)$$

Where $\vec{Q}=\left[\rho,\rho u,\rho v,e\right]^T$

$$E=\begin{bmatrix}\rho\tilde{u}\\ \rho\tilde{u}u+p\\ \rho\tilde{u}v\\ (e+p)\tilde{u}+x_t p\end{bmatrix}\quad F=\begin{bmatrix}\rho\tilde{v}\\ \rho u\tilde{v}\\ \rho v\tilde{v}+p\\ (e+p)\tilde{v}+y_t p\end{bmatrix}\quad E_v=\begin{bmatrix}0\\ \tau_{xx}\\ \tau_{xy}\\ u\tau_{xx}+v\tau_{xy}-q_x\end{bmatrix}\quad F_v=\begin{bmatrix}0\\ \tau_{yx}\\ \tau_{yy}\\ u\tau_{yx}+v\tau_{yy}-q_y\end{bmatrix}$$

Relative velocity $\tilde{u}$, $\tilde{v}$:

$$\tilde{u}=u-x_t$$
$$\tilde{v}=v-y_t$$

x_t, y_t are the dynamic grid speed.

Heat flux is calculated as follows:

$$q=-k\frac{\partial T}{\partial\vec{n}}\Big|_{wall} \qquad (2)$$

2.2. Rigid dynamic grid

The rigid dynamic grid is adopted, which can described as the grid fixed on the moving surface with the same angular velocity. The model's motion equation is:

$$\alpha=\alpha_0+\alpha_m\sin(2kt^*) \qquad (3)$$