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Effect of Recession on the Re-entry Capsule Aerodynamic Characteristic

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Abstract

Numerical simulation and analysis of aerodynamic characteristics of Soyuz ablation shape is carried out in this paper for the adverse influence coming from recession. The result indicates that the shape change caused by the recession will increase absolute value of trim angle of attack and trim lift-drag ratio. The conclusion offers reference for the aerodynamic layout design and improve of the Soyuz re-entry capsule.

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Keywords: re-entry capsule; recession; trim angle of attack; trim lift-drag ratio

1. Introduction

The air environment is complicated during the re-entry of capsule. It must go through hypersonic, supersonic, transonic and subsonic flow. The aerodynamic characteristic of the re-entry capsule are variant in different flow[1,2]. In order to make the re-entry flight stable and credible, we need to forecast flow field accurately, including the aerodynamic characteristic and trim characteristic. Trim angle of attack reflects balanceable flight of re-entry capsule. And stable trim angle of attack during re-entry is needed in engineering design. During the high-speed re-entry, airflow compression makes high temperature and high pressure on ball crown surface of the re-entry capsule, so that thermo-chemical ablation is occurred in the thermal protection system. The ball crown surface will undergo recession, gradually changing the shape of the re-entry capsule, and therefore changing the aerodynamic

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characteristic and trim characteristic of the vehicle.

There are some research about re-entry capsule at home[3-10], while study on the changes of aerodynamic characteristic caused by recession is rarely seen. However, impact of recession on the ORION Crew Exploration Vehicle(CEV) aerodynamics is analyzed abroad[11-14]. Numerical simulation of Soyuz re-entry capsule is carried out in this paper. Soyuz is blunt body aircraft, and when the large end is put forward, axial force is larger than normal force, and therefore the lift mainly comes from axial force, so that the lift is positive when the angle of attack is minus. The aerodynamic characteristic of Soyuz is calculated and analyzed in this paper, and also the impact of recession is researched.

2. Numerical method

Compressible flow and viscous gas kinetic equation is used as flow field control equation:

$$\frac{\partial}{\partial t}\int_{\Omega}\boldsymbol{Q}\mathrm{d}V+\int_{\partial\Omega}\boldsymbol{F}\cdot\hat{\boldsymbol{n}}\mathrm{d}S=\int_{\partial\Omega}\boldsymbol{G}\cdot\hat{\boldsymbol{n}}\mathrm{d}S \tag{1}$$

$$\boldsymbol{Q}=\begin{pmatrix}\rho\\ \rho u\\ \rho v\\ \rho w\\ E\end{pmatrix},\qquad \boldsymbol{F}=\begin{pmatrix}\rho u\\ \rho u^2+p\\ \rho uv\\ \rho uw\\ u(E+p)\end{pmatrix}\hat{\boldsymbol{i}}+\begin{pmatrix}\rho v\\ \rho vu\\ \rho v^2+p\\ \rho vw\\ v(E+p)\end{pmatrix}\hat{\boldsymbol{j}}+\begin{pmatrix}\rho w\\ \rho wu\\ \rho wv\\ \rho w^2+p\\ w(E+p)\end{pmatrix}\hat{\boldsymbol{k}} \tag{2}$$

$$\boldsymbol{G}=\begin{pmatrix}0\\ \tau_{xx}\\ \tau_{xy}\\ \tau_{xz}\\ u\tau_{xx}+v\tau_{xy}+w\tau_{xz}-q_x\end{pmatrix}\hat{\boldsymbol{i}}+\begin{pmatrix}0\\ \tau_{yx}\\ \tau_{yy}\\ \tau_{yz}\\ u\tau_{yx}+v\tau_{yy}+w\tau_{yz}-q_y\end{pmatrix}\hat{\boldsymbol{j}}+\begin{pmatrix}0\\ \tau_{zx}\\ \tau_{zy}\\ \tau_{zz}\\ u\tau_{zx}+v\tau_{zy}+w\tau_{zz}-q_z\end{pmatrix}\hat{\boldsymbol{k}} \tag{3}$$

Where ρ is density, p is pressure, u、v、w is velocity of three direction, E is total energy:

$$E=\frac{p}{\gamma-1}+\frac{1}{2}\rho\left(u^2+v^2+w^2\right) \tag{4}$$

$$\boldsymbol{\tau}=\mu\begin{bmatrix}2u_x & u_y+v_x & u_z+w_x\\ u_y+v_x & 2v_y & v_z+w_y\\ u_z+w_x & v_z+w_y & 2w_z\end{bmatrix}-\frac{2}{3}\mu(u_x+v_y+w_z)\boldsymbol{I} \tag{5}$$

Grid center of finite volume method is used to disperse computational domain, and Roe format is used to compute inviscid flux, and entropy correction is used to avoid non-physical solution. In order to achieve high-order accuracy, least square method is used to obtain gradient distribution in the unit. Time stepping adopts LU-SGS method, which is foremost introduced by Jameson and Yoon.

3. Results and analysis

3.1. Configuration changing caused by recession

Soyuz re-entry capsule recession configurations in different trajectory are obtained by material ablation calculating. Figure 1 shows contrast of original shape and recessed shape of Soyuz at re-entry terminal (Ma=5、H=40km), where the recession is most serious. There is an obvious disfigurement in the large end, which is deep windward and shallow leeward.