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A study on simulation method of starlight transmission in hypersonic conditions

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ABSTRACT

By taking a hypersonic vehicle as the research object, the simulation method of starlight transmission in hypersonic conditions is established to qualitatively and quantitatively research the platform aero-optical effects on starlight navigation, and to provide a theoretical basis for the extended application of the starlight autonomous navigation. At first, based on Reynolds average, the k–ω/SST two-equation turbulence model is used to calculate the density distribution of external flow field when the star sensor is installed at different locations in the vehicle (head, middle and tail), and then the spatial refractive index distribution of the flow field is obtained. On this basis, we use the geometrical optics method and physical optics method to calculate the optical path difference, the point spread function, the image offset and such optical transmission effects caused by the laminar flow field, and then obtain a laminar flow diagram to lower clarity. At the mean time, we calculate wavefront distortion, density, standard deviation, variance and other optical phase-transfer effects of turbulent flow field by using statistical theory optical, and obtain a turbulent flow diagram to lower clarity.

1. Introduction

Starlight navigation is a fully autonomous navigation technology, which has a strong anti-interference ability and high precision, so starlight navigation has been a research hotspot at home and abroad in the field of autonomous navigation technology. However, because of aero-optical effects caused by high-speed flow field, if used in the hypersonic vehicle, it will appear blur, offset, jitter and other fuzzy effects on the imaging of starlight in CCD area array [5], and also bring adverse effect on the pointing accuracy of star sensor which will reduce the star sensor ability on the detection, recognition and tracking for star target.

The main study content of platform aero-optics is the impact on starlight spread of the flow field surrounding the platform, which is a density distribution field with complex refractive index change, and it causes a deflection of starlight producing a characteristic change of path and imaging for star transmission, that is a deviation of the rectilinear propagation law of light in the homogeneous medium. All of the aircrafts using starlight navigation have optical windows, near which the flow field will make the incident starlight generate phase distortion, beam deflection or imaging defocus, leading to a deformation of star map to generate foresight error [4] or measurement error, as shown in Fig. 1.

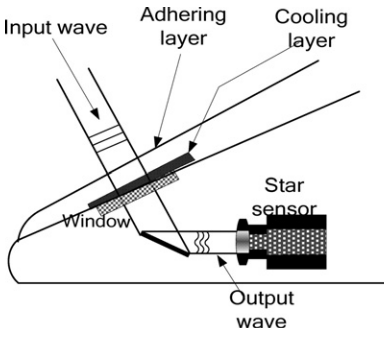

Fig. 1. Platform aero-optical effects diagram of starlight.

This paper has researched transmission characteristics and simulation method of starlight in the pneumatic and inhomogeneous medium. The platform aero-optical effects on starlight navigation can be determined with qualitative and quantitative analysis, and then a reference basis for extending the starlight navigation to the hypersonic vehicle can be afforded.

2. The numerical model of starlight in hypersonic flow field

Aero-optics is an interaction result of light and air flow medium. Before researching the transmission and imaging models of starlight in hypersonic flow, we should have a research on the correlation property and numerical simulation method of hypersonic flow field, in order to establish the numerical model of

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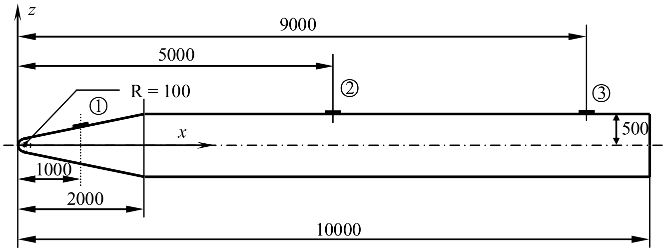


Fig. 2. Geometric diagram of the sphere–cone combination.

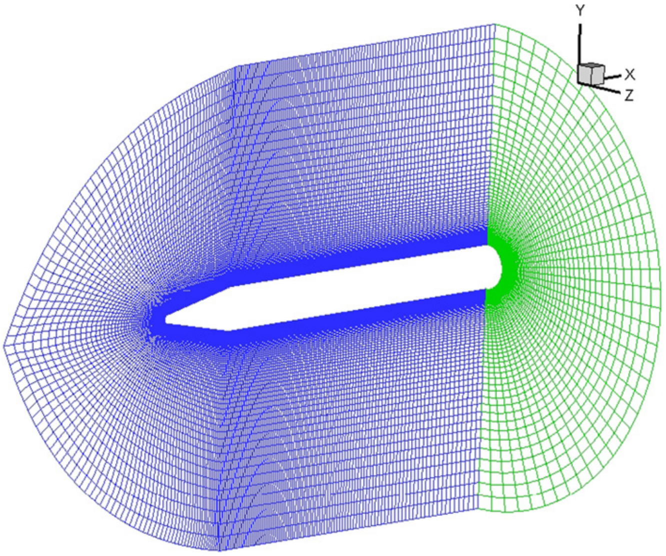
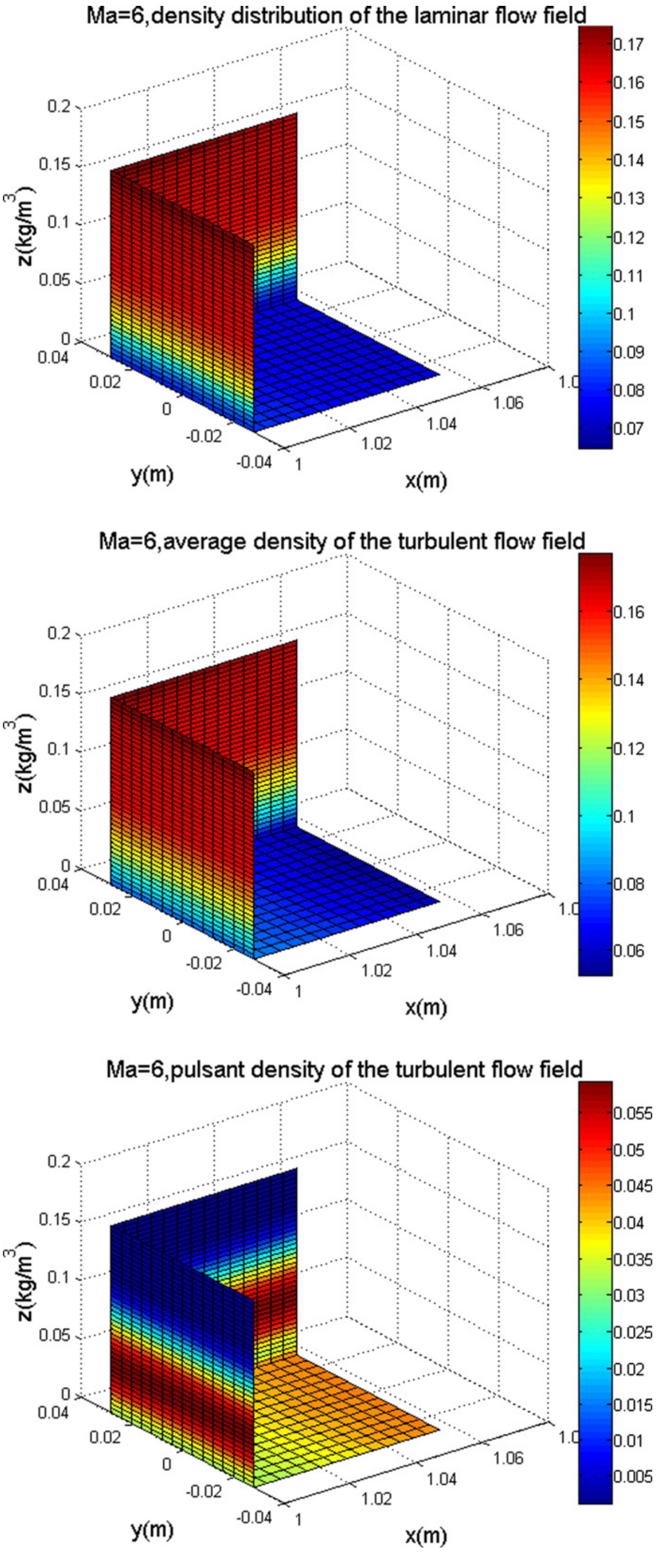


Fig. 3. Three-dimensional grid structure of the sphere–cone combination.

optical window for starlight navigation in hypersonic flow field [8]. In this paper, CFD technology has been used to realize the numerical calculation on the flow field. We has finally obtained the data including flow density, density fluctuation, velocity, pressure and boundary layer thicknesses by the way of grid nodes, which afford a basis for starlight transmission and imaging to determine the model and simulation in laminar and turbulent flow field.

This paper uses an imaginary missile which had a conical head as the experimental model. Its geometric dimension is as shown in Fig. 2. Missile head position ①, central position ②, tail position ③, these three positions were as putative optical window locations installed for CCD star sensor. Using Reynolds average method based on two k–ω/SST equations of turbulent mode, we calculate the data of the flow near three positions where the star sensor is installed respectively. We select the optical sensor window with size of 40 mm × 40 mm, when $Ma = 6$, the maximum of boundary layer thickness would increase to 154.9 mm, so the density distribution calculated can cover this area. Therefore, the interception of the flow field for modeling is a cube area, which is taken reasonably by 56 mm × 56 mm, and the height is 160 mm above the body surface.

In addition, the paper has used GAMBIT software to divide the hypersonic flow field into grids, to create non-uniform grids. The densities of grids close to the aircraft parts increase, and away from the aircraft position decrease, in this case, not only do we ensure with a higher precision, but also control effectively the calculation complexity [1]. Due to the symmetry of the flow field, the computational model was only taken half of the sphere–cone combination. In Fig. 3 we can see the three-dimensional grid structure of the sphere–cone combination. Dense grids near the wall can help us distinguish the changes of the boundary layer flow accurately. The number of total grids is about 7 million.


Ma=6,density distribution of the laminar flow field

Ma=6,average density of the turbulent flow field

Ma=6,pulsant density of the turbulent flow field

Fig. 4. Density distribution of the window installed at the head of the vehicle, $Ma = 6$.

When inflow $Ma = 6$, the density distributions of the laminar and turbulent flow field in the head are as shown in Fig. 4

From above diagram, we can find that flow density distribution along the thickness direction of flow field shows downtrend. This is because the surface viscous flow led to the aerodynamic heating, so the temperature close to the surface increases, which makes