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Study of Heating Time of test model and Application in Low Density Wind Tunnel Using Infrared Thermography

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Abstract

The relation between the model heating time and constant heat transfer rate assumption is analyzed. The study indicates that the shorter is the model heating time, the better is constant heat transfer rate approximation. The typical test results obtained with infrared thermographic technique on the hypersonic winged vehicle as well as heating effect on the flat plate model caused by plume flow are presented.

1. Introduction

When heat transfer measurement is made at the low density wind tunnel, experimental model is made out smaller to imitate higher height environment as far as possible. However, it is very difficult to install the thermocouple on such the model. At the same time, aerodynamic heating rate on the aircraft is smaller in the rarefied flow region. Because of the smaller heating rate, the effect of various factors such as experimental air quality, support interference, wind tunnel vibration, environmental temperature on heat transfer measurement becomes severe. It is a tough problem to measure the small value with high accuracy. Having the characteristic of non-contact measurement, not disturbing flow field and intuitionistic, visual image and measurement with high accuracy, infrared thermography is suitable for such measurement at the low density wind tunnel. Jean Allegre of SESSIA in France measured the heat transfer rate on the thin flat panel model, thick 0.5 mm in the rarefied flow by means of infrared thermography technique[1]. M.F.Westby applied infrared thermography technique to measure aerodynamic heating rate on flat panel model and thin long cone models at the low density wind tunnel, and made the comparison with other results[2]. LI Ming at CARDC studied the characteristic of aerodynamic heating on a few of vehicles from near continuous flow region to rarefied transitional flow through infrared thermography technique[3-5]. Besides, such techniques as thin film, thermocouple, with longer development and mature method, are supplementary to infrared thermography technique. However, whether infrared thermography or thin film, thermocouple, the model heating time influences on heat transfer rate measurement greatly. In the article, the relation between the model heating time and constant heat transfer rate assumption, response time of thin wall meter using thermocouple is analyzed, which is helpful to guide a wind tunnel experiment and to raise the accuracy of heat transfer rate measurement. Finally, these test results, obtained with infrared thermographic technique, on the hypersonic winged vehicle as well as heating effect on the flat plate model caused by plume flow, are presented.

2. The relation of model heating time and constant heat transfer rate approximation

When solving one-dimensional heat-conduction equation, usually suppose that heat transfer rate is constant. Under what condition is reasonable the constant heat transfer rate assumption? Aimed at the of the boundary conditions of the constant heat transfer rate assumption and surface temperature depended by heating time, adopt the implied difference format to solve one-dimensional heat-conduction equation, and compare the temperature difference by changing the model surface convective heat-transfer coefficient within given heating time. At the low density wind tunnel, the range of the model surface convective heat-transfer coefficient is from 10 W/m^2·K to 150 W/m^2·K, the model heating time is taken to 1s and 6s.The result is shown as figure 1, which indicates that the shorter is the model heating time, the better is constant

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heat transfer rate approximation; the lower is surface convective heat-transfer coefficient, the better is constant heat transfer rate approximation.

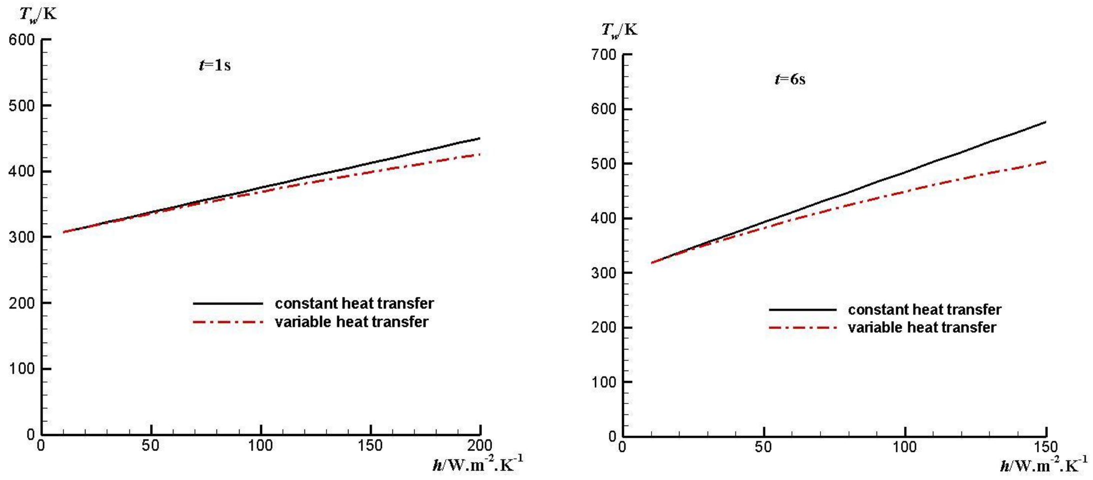

Fig.1 *Heat transfer rate variety with time*

Concerning the semi-infinite slab approximation, from the view of the model heating time, if the model heating time is satisfied

$$t \le 0.12 R_c^2 / \alpha \tag{1}$$

the semi-infinite slab approximation is tenable, and the influence of the horizontal heat conduction could be neglected completely. Where t is the model heating time; R_c is the curvature radius of the model; α is thermal diffusivity of the model material.

For the nonmetal model material, the semi-infinite slab approximation is often used. In fact, the model thickness is impossibly half infinite. Under what condition do the model wall thickness satisfy the semi-infinite slab approximation? Through the LAPLACE anti-transformation of one-dimensional heat-conduction equation, one can get

$$y \ge 4\sqrt{\alpha t} \tag{2}$$

The measurement error of model surface temperature, the surface heat transfer rate is not greater than 1%. Thermal diffusivity of the model adiabatic material at our lab.is 2.448×10-7m2/s, the corresponding depth of heat penetration is 4.8mm at the model heating time 6s.

3. The relation of model heating time and response time of thin wall meter

The surface instantaneous temperature of the thin wall model was frequently measured by means of infrared thermography technique. Through solving one-dimensional heat-conduction differential equation, one can get response time of thin wall meter using thermocouple. The response time of thin wall meter thickness 0.5 mm of the stainless steel is 2.0×10^{-3}s, model heating time at our low density wind tunnel is for several second, the response time is more easily met.

In addition, the biggest temperature of the thin wall meter is limited by the material function. Through getting the biggest temperature allowed in wind tunnel test, the biggest heating time of model is made sure:

$$t_{\max} = \frac{\rho \cdot C_p \cdot \delta^2}{k}\left(\frac{k(T_{\max} - T_i)}{q\delta} - \frac{1}{3}\right) \tag{3}$$

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Where t_{max} is the biggest heating time of the model, T_{max} is the biggest temperature allowed in wind tunnel test, T_i is the initial temperature of the model, q is the surface heat transfer rate. It is clear that, under the condition of the certain model material, wall thickness, the biggest heating time is the function of surface heat transfer rate and the difference T_{max}-T_i. The relation between surface heat transfer rate and heating time could be obtained with experiment and calculation. It is made out, by means of the analysis of the equation(3), that the greater is the surface heat transfer rate, the smaller is the model heating time.

4. The application of infrared thermography in hypersonic wind tunnel

At nominal test conditions of Mach 16, stagnation temperature 930K, stagnation pressure 1560kpa, convective heat-transfer coefficient distributions on the hypersonic winged vehicle are obtained by means of infrared thermography technique, shown as figure 2. The temperature at the head, at the forward edge wing, at the forward edge tail wing of the vehicle varies relatively more quickly, while the temperature at the rest parts does more slowly[6]. In the Figure 2 , among bbottom0-180 ,0 denotes the angle of attack 0°, 180 denotes the generatrix 180° on the bottom surface. *L* is the length of the vehicle. For the sake of the study of influence of heating time of the model on the heat transfer rate measurement, the point *x/L* =0.922 on the hypersonic winged vehicle is taken, and heat transfer rate varies with time, as figure 3. The heat transfer rate at the first second is larger 4% than one at the third second, while larger 8% than one at the 6th second. Because of the existence response time of measurement instruments, heating time of the model could not be taken too short. Comprehensive other factors,5 seconds to 6 seconds taken is suitable.

In order to study heating effect on the flat plate model caused by plume flow, plume flow of engine is established inside the test section of the wind tunnel. Surface temperature on the flat plate model is measured with infrared camera, then heat transfer rate distributions on the flat plate model are deduced at different thrust conditions. The influence of the variety of distance between axis of thrust nozzle and the flat plate model on heating effect impinged by plume flow is studied, shown as figure 4. It is showed that the position and size of high heat transfer rate area on the flat plate model are related with the distance between axis of thrust nozzle and the flat plate model, that is, the smaller is the distance, the higher is heat transfer rate area closed with the flat plate model front edge and the stronger is heating effect on the flat plate model[5].

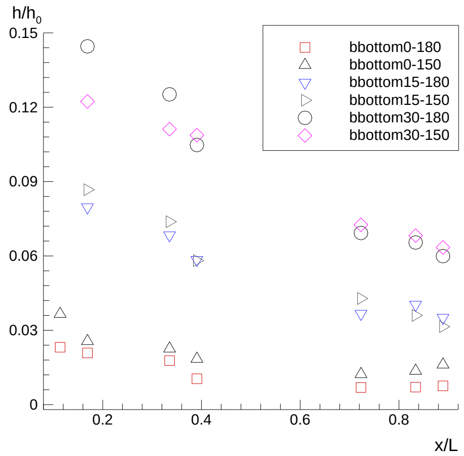

Fig.2 *Heat transfer rate distributions of the hypersonic winged vehicle*

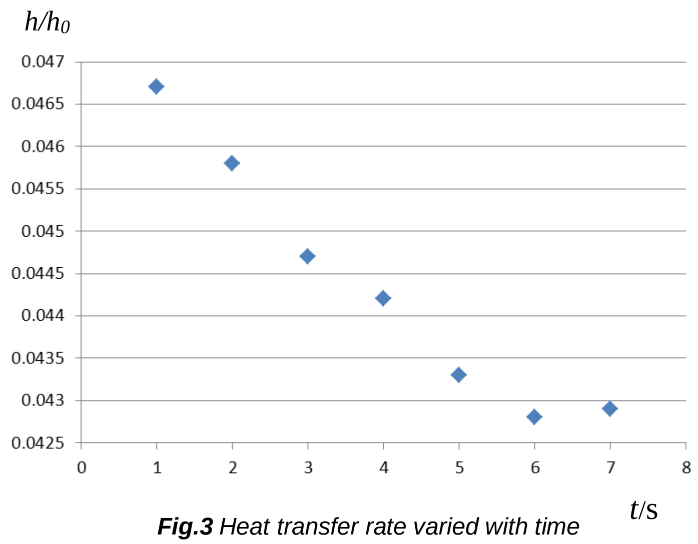

Fig.3 *Heat transfer rate varied with time*

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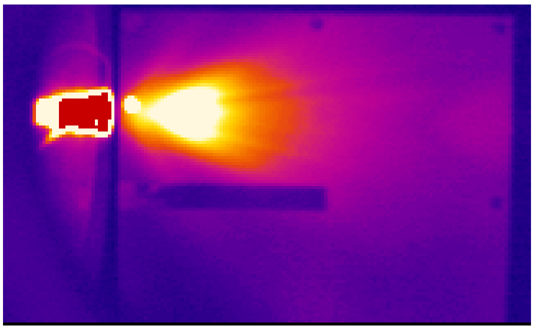

Fig.4*（a） *Infrared map of the plate model impinged by

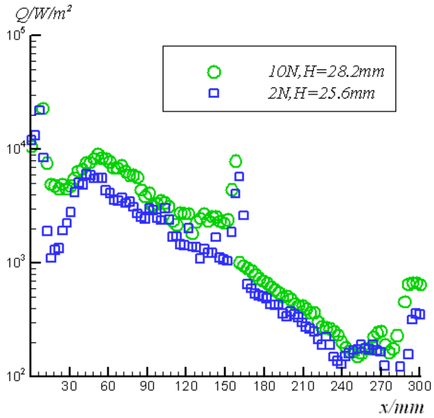

Fig.4*（b）*Comparison of heating effect at different thrusts

5. conclusion

(1) The shorter is the model heating time, the better is constant heat transfer rate approximation; the lower is surface convective heat-transfer coefficient, the better is constant heat transfer rate approximation.

(2) The greater is the surface heat transfer rates, the smaller is the model heating time.

(3) Heat transfer rates on the hypersonic winged vehicle and heating effect on the flat plate model caused by plume flow are obtained with infrared thermography technique. Compared with former other experimental means in plume flow study, the size and the shape of heating effect on the flat plate model caused by plume flow are displayed very much distinctly by means of infrared thermography technique.

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