COUPLING EFFECTS OF RADIATION HEATING AND ACOUSTIC FIELD OF THERMAL-ACOUSTIC TEST FACILITY FOR HYPERSONIC VEHICLE STRUCTURES

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Summary Advanced thermal protection systems and hot structures of hypersonic vehicle are exposed to severe flight environments, including a combination of aerothermal, aerodynamic and acoustic loads. The thermal-acoustic test facility which simulates simultaneously thermal and acoustic loads is used to validate the integrity and the reliability of hypersonic vehicle skin panels. One scaled thermal-acoustic facility is designed and built for testing research in this paper. Heat flux distribution, acoustic gas flow properties, temperature distribution of testing plate, and acoustic field properties of the thermal-acoustic tests are also investigated. Results show that acoustic gas flow has an important effect on the temperature distribution of testing plate. However, thermal environment has a little effect on acoustic loads.

INTRODUCTION

The design of advanced thermal protection systems and hot structures of hypersonic vehicle present a significant challenge because of the wide variety and severity of environmental conditions. One of more demanding of these is the high intensity noise produced by propulsion systems and turbulent boundary layer. Sound pressure levels in some regions are expected to exceed 180dB. The heat flux values due to boundary layer and local shock interaction in excess of 1200kW/m^2 and the temperature at local region is over 2000℃. The thermal-acoustic test facility is an approach simulating the combined thermal and acoustic environment and has been adopted to validate hypersonic structures integrity for many years. In this research, the coupling effects between radiation heating and acoustic field are studied.

THERMAL-ACOUSTIC TEST FACILITY

The thermal-acoustic test facility mainly consists of a progressive wave tube (PWB) acoustic apparatus, a quartz lamp radiation heater and some other control and testing equipments. The progressive wave is used to produce the high sound level acoustic load and the quartz lamp heater is used to simulate the heat flux thermal load. Figure 1 shows two thermal-acoustic test facilities which are built by NASA Langley and BAE systems respectively. NASA facility has the capabilities for maximal sound pressure 172dB and temperature over1000℃. BAE facility has capabilities for maximal sound pressure 175dB and temperature 800℃. One scaled thermal-acoustic facility is built for testing research.

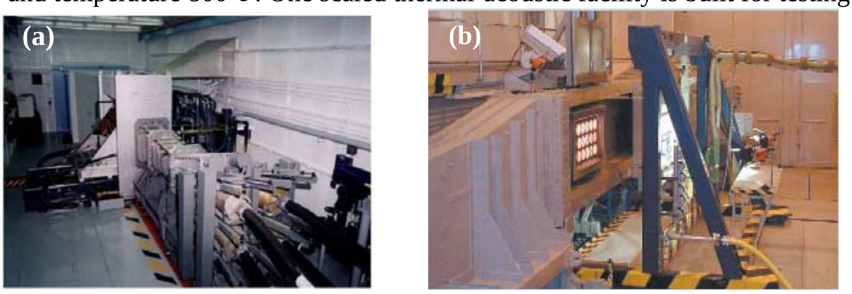

Fig.1 Thermal-acoustic test facility (a. NASA langley b. BAE systems)

HEAT FLUX DISTRIBUTION OF THE QUARTZ RADIATION HEATER

One quartz radiation heater of this thermal-acoustic test facility is designed and fabricated. The heater includes 24 quartz lamps with 3kW power per each. The testing plate structures are heated about 35cm away from the heater. Based on the Monte Carlo method, the numerical model of this quartz lamp heater is created. The reflector plate, the filament and the quartz wall of every quartz lamp and testing plate are all included in this heater model. Plane distribution of heat flux of the quartz lamp heater at the testing plate is shown in Figure 2 (a). It is known that the maximal heat flux is at the centre region and its value is about 84kW/m^2. The heat flux at marginal regions is much smaller and its value is about 65kW/m^2. Figure 2 (b) shows heat flux distribution along the horizontal and the vertical direction. The varied regularities of heat flux at these two directions are approximately the same. The mean heat flux value of this heater is about 76kW/m^2.

It is estimated that if a 2mm metal titanium needed to be heated to 500℃, the minimum heat flux should be 54 kW/m^2 using heat transfer theoretical analysis. When the number of lamps and work voltages are increased, the heat flux of this heater is also improved.

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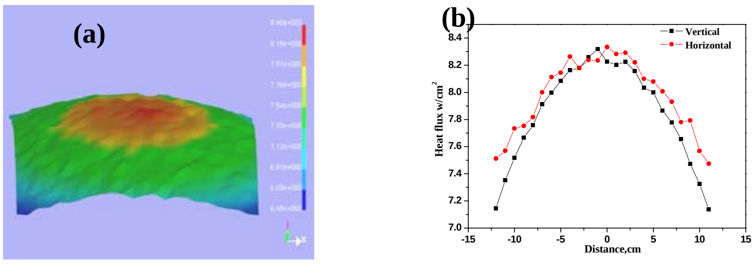
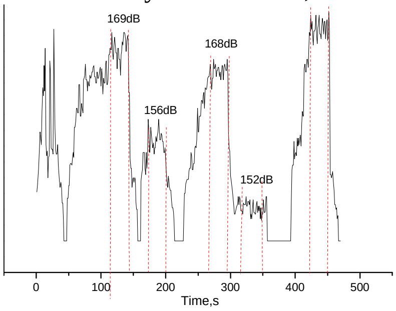


Fig.2 Quartz lamp heater and heat flux distribution

EFFECTS OF ACOUSTIC GAS FLOW ON TEMPERATURE DISTRIBUTION

The PWB acoustic apparatus is driven by electropneumatic gas modulator. So a large amount of gas is needed and flows along the progressive wave tube. The acoustic gas flow velocity near testing plate is measured using a differential pressure type anemoscope at different sound levels, as shown in Figure 3. It is shown that when the applied acoustic load is 152dB,156dB and 169dB, the gas velocity will be 2m/s,6m/s and 12m/s, respectively. It is clear that the gas velocity within PWB is influenced by sound levels ,the work gas pressure and cross-section sizes of PWB。



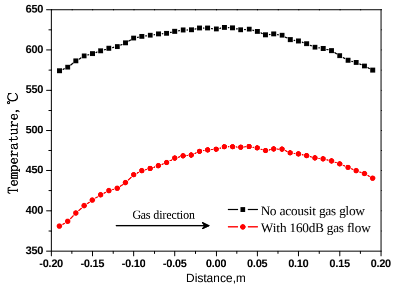


Fig.3 Acoustic gas flow velocity in PWB Fig.4 Temperature distribution with or no acoustic gas flow

The temperature distributions of testing plate with and without acoustic flow are shown in Figure 4. Without acoustic gas flow, the temperature distribution is symmetrical and the maximal value is 627℃ .With acoustic gas flow, the temperature distribution is not unsymmetrical and the maximal temperature is decreased to 485℃.

EFFECT OF RADIATION HEATING ON ACOUSTIC FIELD

On the other hands, the acoustic gas in the vicinity of the plate is also heated when the temperature of the plate is increased. Since the gas density and the sound velocity are temperature dependent, the acoustic field in PWB is also changed. Based finite element method and acoustic theory, the sound level of acoustic field in PWB will be decreased in thermal environment. But the effect of heating on acoustic filed is small.

CONCLUSIONS

Thermal-acoustic test facility is one of the most important combined environments apparatus of hypersonic vehicle structures verification. Acoustic environment has some disadvantages on heating environment. The mean heat flux of quartz lamp heater is about 76kW/m^2.The acoustic gas flow velocity in PWB is above 12m/s. The maximum temperature value and temperature distributions are all changed because of the acoustic gas flow. Acoustic load applied on the testing plate in PWB is also influenced by thermal environment produced by quartz lamp heater. It can be concluded that coupling effects of radiation heating and acoustic field will affect the testing results and these factors must been considered in carrying out a thermal-acoustic test.

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