POD Analysis of Hypersonic Inlet Using Fast Response Pressure-Sensitive Paint

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Abstract Fast response PSP is very useful in hypersonic inlet flow diagnostics due to its fast response and high spatial resolution, but the poor signal-to-noise ratio makes it very difficult to extract sufficient information from the PSP data. In this study, the hypersonic inlet with freestream Mach number of 5 was tested in the blow down hypersonic wind tunnel FD-03 of China Academy of Aerospace Aerodynamics(CAAA). The pressure fluctuations on the surface of the inlet was detected by a CCD digital camera with the frame rate of 10000. The proper orthogonal decomposition(POD) method were used to reduce noise in PSP data and extract the dominant pressure features. The PSP results reconstructed from selected POD modes show that the POD analysis could effectively remove noise while preserving the instantaneous pressure information with good fidelity. The POD analysis extends the application range of fast response PSP and will be a new method and a powerful tool for the fast response PSP in hypersonic.

Keywords: Fast response PSP; Hypersonic inlet; Proper orthogonal decomposition

1 Introduction

Hypersonic inlet and isolator are very important for the hypersonic air-breathing propulsion system, the internal flow of which are fairly complicated. There will be shock train which results from shock/boundary layer interaction, and the air in the region would experience the circulative process of compression, expansion and re-compression. In order to take the advantages of shock train to reach a maximum pressure rise with less total pressure loss and suppress the flow oscillation, it is very important to visualize the flow field in the hypersonic inlet and isolator.

2 Experimental facilities and Test Model

Several experiments with incoming Mach number 5 had been conducted in FD-03 hypersonic wind tunnel in China Academy of Aerospace Aerodynamics(CAAA). The FD-03 is a blow-down type wind tunnel, and the outlet of the nozzle is 170mm×170mm.

The test model is a typical two dimensional hypersonic inlet/isolator, which is shown in Figure 1. The first ramp angle of the inlet is 6 degree to the freestream flow direction and the second ramp angle is 14 degree. In order to give a better view of the internal flow-field and the surface pressure. Three pieces of glass were set at the top and both side of the isolator.

A schlieren system is used to record the shock train in the isolator and the fast response PSP system is used to record the pressure fluctuations on the surface of the inlet and isolator.

Fig 1 Sketch of the hypersonic inlet/isolator

3 Results and Discussion

(1) Figure 2 shows the schlieren picture during the experiment. The cowl shock is covered by the test model. But the large-scale separation bubble which is induced by the cowl shock can be seen. Due to the separation,
the separation-induced shock and the reattachment shock were formed here. The shock train reflected in the isolator about 4 times.

(2) Figure 3 shows the fast response PSP result of the isolator surface.

(3) Figure 4 presented the contours of the first 9 POD modes. It can easily identified that modes 3, 4, and 8 mainly contain energy corresponding to the pressure fluctuation of the shocks. So the above modes (3, 4, and 8) are selected to reconstruct the wall-pressure fluctuation fields. Figure 5 presented the comparison results between the schlieren result, the original fast response PSP result and the pressure fluctuations reconstructed result.

**4 Conclusion**

Because the internal pressure of the isolator is high, the signal-to-noise ratio of the fast response PSP is very poor, which makes it very difficult to extract the exact position of the shock and the pressure fluctuation. So the proper orthogonal decomposition (POD) method were used to reduce noise in PSP data and extract the dominant pressure features. It is obviously to see that the shock wave/boundary layer interaction is the main reason to the pressure fluctuate and the POD analysis will effectively remove noise while preserving the instantaneous pressure information with good fidelity.

**References**

