Experimental Study of Effect of Jets Injected into Supersonic Main Flow on Porous Cavity

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In this study, the interaction between the supersonic main duct flow and jet surrounded by a porous cavity was experimentally investigated by means of schlieren flow visualization and measurements of flow direction in a cavity underneath of jets. The detection of flow directions was done with so called thermal tuft probe that has two heat sensors and one heat source middle of the two sensors. The parameters of the experiments are jet arrangements and pressure ratio defined by the ratio of total pressure in the settling chamber to atmospheric pressure. As a result, the backward flow in the cavity is confirmed in case of jet injections. Moreover, it is found that the change in the flow direction has dominant frequency between 300HZ and 400Hz only when the starting shock wave exists around the porous cavity.

1 Introduction

Supersonic mixing enhancements have attracted a great deal of attention because of the potential for important applications to scram jet engines [1] and thermal sprays, for example. A number of studies have investigated the mixing process under the supersonic state using various techniques, such as the use of a swept ramp, and a use of a wedge shaped injector. However, some problems, such as mixing losses, mixing efficiency, still remain. The authors previously proposed a new concept, as shown in Fig. 1 [2], whereby the supersonic main flow is introduced to the cavity for mixing enhancements. In the first stage, the jet is injected in a direction normal to the main flow. The jet is considered as an obstacle to the main supersonic flow.

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Then a bow shock wave is generated and causes a pressure difference between the upstream and downstream sides of the shock wave. Pressure differences also exist on the porous wall and inside the cavity, which drive the flow in the cavity. At the same time, together with the main flow, the injected jet is sucked into the cavity through the porous holes. The flow velocity in the cavity is reduced enough to allow mixing of the injected jet and the main flow. The flow in the cavity is spouted again, achieving small fine injections through numerous small porous holes. We already reported the effect of the jets [3] and brief mechanism of change in the direction of the flow in the cavity. According to our previous report, the flow direction in the cavity is considerably affected by the shape of the bow shock wave and its position which caused the change in the suction and injection region. In the previous report [3], we investigated the cavity flow direction using a thermal tuft probe which is device detecting one dimensional flow direction. To reveal detail of the cavity flow, it is necessary to investigate vertical cavity flow direction to the main flow. So, in this paper, we investigate the vertical cavity flow direction using thermal tuft probe.

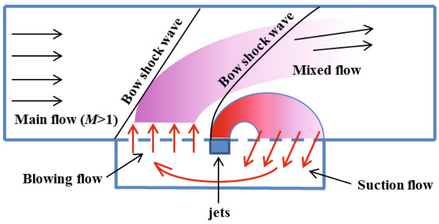

Fig. 1 Schematic diagram of mixing enhancement with porous cavity

2 Experimental Apparatus and Procedure

The blow-down wind tunnel was used for this experiment. A schematic diagram of the nozzle and the test section are shown in Fig. 2(a). The test section is attached to a diverging nozzle with a designated Mach number of 2.2. The x direction, along the flow direction originating at the throat, is non-dimensionalized by the nozzle throat height h^*. A cavity with a porous wall is installed within the range of x/h^* = 7.0 to 11.4. The depth of the cavity is h_c/h^* = 1. Eleven holes are distributed in the streamwise direction and fifteen holes are distributed in the spanwise direction. The porosity, which is defined as the ratio of the total area of the holes to the porous region, is approximately 0.617. The experiments were conducted for wind tunnel pressure ratios p_0/p_b of between 2.0 and 3.0, where the pressure ratio p_0/p_b is defined as the ratio of the stagnation pressure p_0 in the settling chamber to the back pressure p_b. To investigate the flow direction, a thermal tuft probe is adopted for detecting one dimensional flow direction. In this experiment, the thermal tuft probe detects vertical flow direction to the main flow. The thermal tuft probe is installed at x/h^* = 8.6 and 9.8 in the cavity as shown in Fig. 2(a). An enlarged view is shown in Fig. 2(b). In this study, pattern (i) in Fig. 2(b) is defined as downward direction, and pattern (ii) in Fig. 2(b) is defined as upward direction. The sampling number and interval of the output from the thermal tuft probe are 4096 and 100 μs at each pressure ratio, respectively. At the same time, the density field is visualized by the schlieren method. The jet-to-freestream momentum flux ratio for each jet was J=1.9 where the freestream Mach number and jet Mach number are 2.2 and 1.0, respectively in case of the pressure ratio p_0/p_b of 3.0. Figures 3(a) and (c) show the arrangements of the jets. The jets are positioned at $x/h^* = 9.2$ and the diameters of the jets are 1mm. The distance between jet and jet is 6mm.

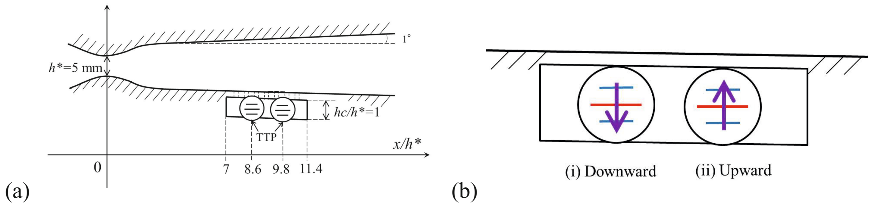

Fig. 2 Schematic diagram of test section. (**a**) test section. (**b**) enlarged view of cavity.

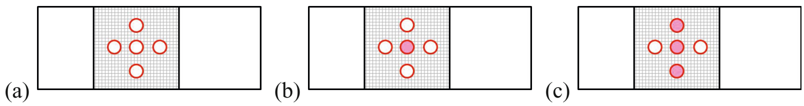

Fig. 3 Arrangements of jets. (**a**) 000. (**b**) 010 (**c**) 030.

3 Experimental Results and Discussions

Figures 4 show schlieren images at p_0/p_b=2.8 for 000, Jet010 and Jet030, respectively. In Fig. 4(a), a starting shock wave is located at x/h^*=13 on the upper wall. Some small disturbances are originating from the porous holes, which seems to have almost no effect on the flow structure. In Fig. 4(b), a starting shock wave exists at x/h^*=13.5 on the upper wall and bow shock wave is generated by the single jet. The large effect on the whole flow field is not observed with schlieren image although the single jet is injected. In Fig. 4(c), the starting shock wave is at x/h^*=13.5 on the upper wall. A bow shock wave due to three jets might be stronger than that by the single jet as shown in Fig. 4(b) because of larger blockage effect on the main supersonic flow. It is confirmed by the contrast or thickness of the bow shock wave and its clear reflected shock wave on the upper wall.

Figure 5 shows the starting shock wave position on the lower wall for 000, Jet010 and Jet030. Vertical axis and horizontal axis indicate the starting shock wave position from the throat and pressure ratio, respectively. the starting shock wave moves downstream in all cases as the pressure ratio increases. the differences of the starting shock wave position each pattern is small. thus the jets have no effect on the starting shock wave position. the pressure ratio of the starting shock wave passing through porous wall for 000, Jet010 and Jet030 is 2.4, so the main flow on the porous region is supersonic state after p_0/p_b=2.4.

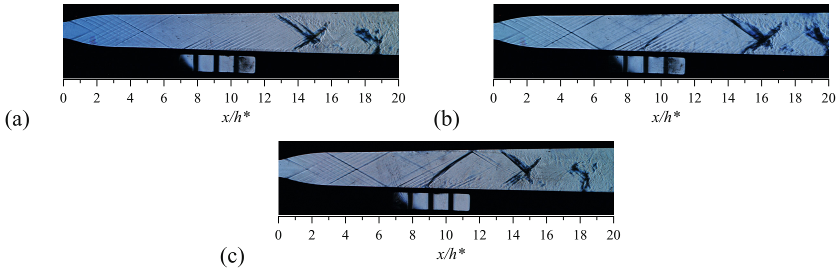

Fig. 4 Schlieren images at p_0/p_b=2.8. (**a**) 000. (**b**) 010. (**c**) 030.

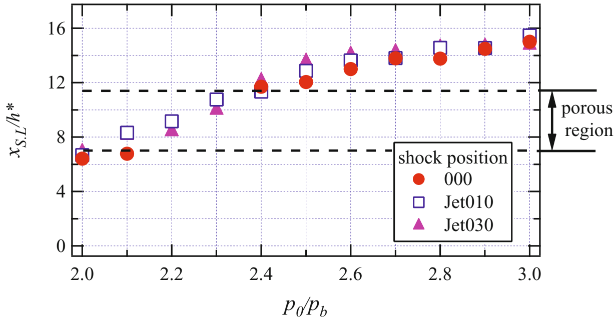

Fig. 5 Starting shock wave position on lower wall

Figures 6(a) and (b) show the upward flow ratio at x_p/h^*=8.6 and 9.8, respectively. the upward flow ratio is calculated by output of the thermal tuft probe. The upward flow ratio is defined as a ratio of the duration time of upward flow to the total measurement time. In Fig. 6(a), the upward flow ratios for 000 and Jet030 keep over 80% in all pressure ratios, so the flow direction is mostly upward at measurement point of x_p/h^*=8.6. On the other hand, upward flow ratio at x_p/h^*=8.6 for Jet010 shown in Fig. 6(a) decreases less than 50% for the pressure ratio p_0/p_b=2.4 and 2.5. For these pressure ratios, the starting shock wave passes through the downstream end of the porous region. In other words, right after the shock wave reaches the end of the porous region, there is neutral flow direction at x_p/h^*=8.6 suggesting the unstable flow in the cavity. After that, upward flow ratio increases. finally, the upward flow ratio reaches 80%. As the pressure ratio increases, absolute pressure becomes large. So pressure difference of point to point becomes large. thus this large pressure difference is considered to make flow direction stable. Consequently, the upward flow ratio increases.

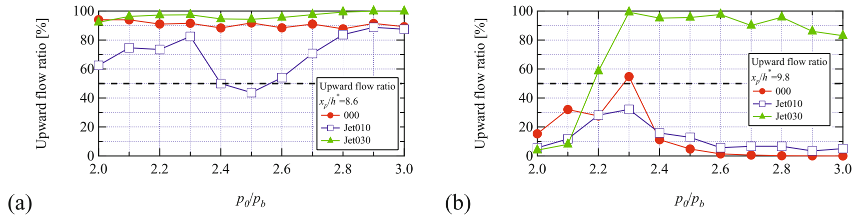

Fig. 6 Upstream flow ratio at x_p/h∗=8.6 and 9.8. (**a**) upward flow ratio at x_p/h^*=8.6. (**b**) upward flow ratio at x_p/h^*=9.8

In Fig. 6(b), it is found that the upward flow ratio for the pressure ratio 2.0 and 2.1 is smaller than 30%, which is quite different from the results at x_p/h^*=8.6 in Fig. 6(a). Moreover, for the pressure ratio larger than 2.4, the upward flow ratio for Jet030 keeps almost 100% whereas the other two patterns decrease down to 0% and maintain.

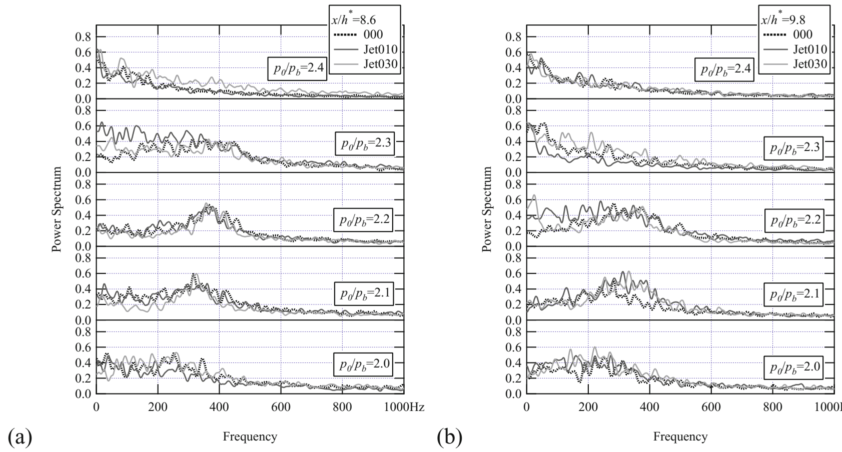

Fig. 7 Upward flow ratio at x_p/h^*=8.6 and 9.8. (**a**) upward flow ratio at x_p/h^*=8.6. (**b**) upward flow ratio at x_p/h^*=9.8

Figures 7 show frequency analysis of output of the thermal tuft probe. In these graphs, vertical axis and horizontal axis indicate power spectrum and frequency, respectively. The power spectrum is normalized by the maximum value of each figure. In Fig. 7(a), the power spectrums for all cases have the same dominant frequencies at the pressure ratios of 2.1 and 2.2, whereas the other pressure ratios, there is no dominant frequencies. Under the pressure ratios of 2.1 and 2.2, the flow directions at x_p/h^*=8.6 and 9.8 are opposite according to Fig. 6(a) and Fig. 6(b). Moreover, considering the same dominant frequencies at x_p/h^*=9.8 observed in Fig. 7(b), there are some possibilities of existence of feedback systems between the cavity and main flow together with the starting shock wave which stand around the porous cavity at these pressure ratios.

4 Conclusions

The one dimensional flow direction in the cavity and flow field were investigated by using a thermal tuft probe and schlieren method. The results are summarized as follows:

Only in the case of three jets, blowing flow from the cavity to the main flow occurs. Injecting the jets can change the flow direction in the cavity and changing the injection patterns may makes optional flow direction in the cavity. The starting shock wave around porous region generates fluctuation of cavity flow.

References

1. Rogers, R.C., Capriotti, D.P., Guy, R.W.: Experimental Supersonic Combustion Research at NASA Langley. AIAA, 98-2506 (1998)
2. Yaga, M., Tabata, S., Doerffer, P., Oyakawa, K.: Numerical Simulation of Supersonic Mixing Enhancement with Porous Cavity. AIAA paper, 2003-3461, (2003)
3. Kuniyoshi, N., Yaga, M., Koda, A., Teruya, I., Ishikawa, M.: Experimental Study of Interaction between Supersonic Duct Flow and Jets Surrounded by the Porous Cavity. Experimental Thermal and Fluid Science 40, 185–194 (2012)