초음속 공동내부의 압력진동 제어에 미치는 기류 마하수의 영향

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Effects of Mach Number on the Control of Supersonic Cavity Pressure Oscillations

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ABSTRACT

Numerical computations were carried out to analyze the effect of inlet Mach number and sub-cavity on the control of cavity-induced pressure oscillations in two-dimensional supersonic flow. A passive control method wherein a sub-cavity was introduced on the front wall of a square cavity was studied for Mach numbers 1.50, 1.83 and 2.50. The results showed that sub-cavity is effective in reducing the oscillations at different inlet Mach numbers. The resultant amount of attenuation of pressure oscillations depended on the inlet Mach number, length of the flat plate, and the depth of the sub-cavity used as an oscillation suppressor.

초 록

본 연구에서는 2차원 초음속 공동유동에서 발생하는 압력진동을 제어하기 위하여 수치해석적 연구를 수행하였다. 본 계산에서는 압력진동을 제어하기 위하여 보조공동의 형상을 변화시켰으며, 유동의 마하수를 1.50, 1.83 그리고 2.50로 변화시켰다. 그 결과, 보조공동은 압력진동을 상당히 감소시켰으며, 압력진동의 제어효과는 유동의 마하수와 보조공동의 상세형상에 크게 의존함을 알았다.

Key Words: Compressible flow(압축성 유동), Supersonic cavity(초음속 공동), Pressure oscillations (압력진동), Passive control(피동제어), Shock wave(충격파)

1. Introduction

Intense pressure oscillations generated by the supersonic cavity flows are significant in many engineering applications. The control of cavity-induced oscillations has been studied by many researchers [1-4], but the practical means of effective control in a wide range of flow conditions are yet to be investigated. Heller and Bliss [1] suggested that oscillations could

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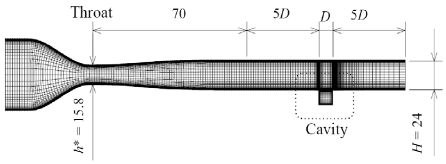
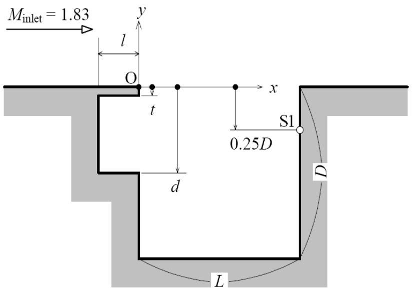
be controlled by slanting the trailing edge of a cavity. Shaw et al. [2] conducted wind tunnel tests with cavities installed on a model of an aircraft to assess the leading-edge saw tooth suppressor and the slanted trailing edges. The slanted trailing edge was found to be effective in attenuating cavity tones but the leading-edge spoilers were not fully successful. Sarno and Franke [3] studied static and oscillating fences and found that the static fences were effective in suppressing cavity pressure levels. Alam et al. [4] studied sub-cavity at Mach number 1.83 and showed that a sub-cavity was very effective in reducing oscillations. Although most of the methods mentioned here have been successful in reducing the oscillations, their effectiveness should be investigated in a changing flow environment.

2. CFD Analysis

The governing equations are the unsteady compressible Navier-Stokes equations coupled with turbulence kinetic energy and eddy viscosity equations for modeling the turbulence [5]. A 3rd order TVD finite difference scheme with MUSCL [6] was used for spatial discretization with a second order-central difference scheme for the viscous terms. A second-order fractional step was employed for time integration. Fig. 1 shows the grids and computational domain for the cavity. Height of main flow section above the cavity is 24 mm. Depth D and the length L of the cavity are the same and equal to 12 mm. The ratios of the length l of the flat plate to the depth of the cavity D are l/D = 0, -0.125, -0.1875 and -0.25, and the ratio of the lip thickness t to the depth of the baseline cavity D is t/D = 0.05. Ratios of the depth of sub-cavity d to the depth of the baseline cavity D are d/D = 0.25, 0.30, 0.35, 0.45, 0.65, 0.70 and 0.75 in the simulations. S_1 in Fig. 1(b) denotes measuring position of static pressure. Grid size is 200×80 in the region of the nozzle and 50×60 in the cavity. Dry air is used as a working gas and assumed to be thermally and calorically perfect. Pressure p_0 in the reservoir is 101.3 kPa. Inlet Mach number M_{inlet} at entrance of the cavity is 1.50, 1.83 and 2.50. The Reynolds number is 2.1×10^5. No-slip and no heat transfer boundary conditions were applied on the walls. Fixed conditions were set for the inflow. Zero order extrapolation was used at the outflow.



(a) Computational grids (Unit: mm)



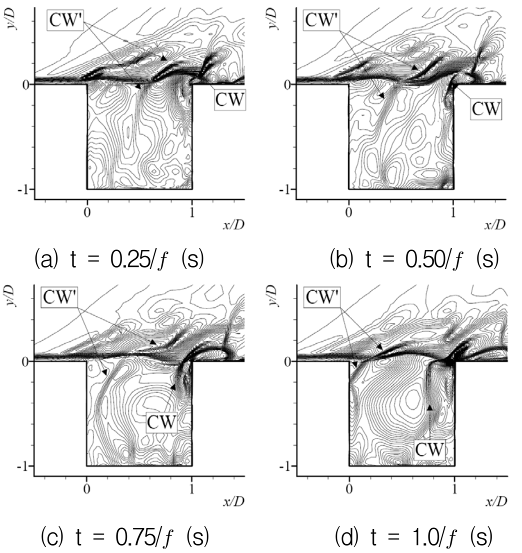
(b) Details of cavity configuration

Fig. 1 Computational domain

3. Results and Discussion

3.1 Baseline Case

Figure 2 shows contour maps of density during one period of flow oscillation for the cavity without control at Mach number 1.83. Here, f represents the dominant frequency, which is equal to 17.5 kHz (see Fig. 5(b)). It was observed that a compression wave (CW) from the trailing edge of the cavity moves upstream as time proceeds. The upstream compression waves impinge on the cavity leading edge (Fig. 2(d)) and disturb the shear layer. This disturbance regenerates instability waves in the shear layer. While the shear layer reattaches at the rear wall of the cavity, generation of compression waves (CW) occurs due to the impingement of instability waves on the wall as shown in Fig. 2(b) and thus completing the formation of feedback loop which is widely believed to be the reason for intense pressure oscillations. Contour maps of density in case of inlet Mach number 1.50 and 2.50 also showed similar wave interactions.



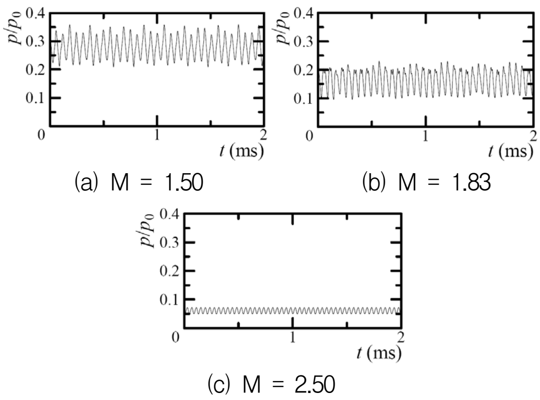
(a) t = 0.25/f (s) (b) t = 0.50/f (s)

(c) t = 0.75/f (s) (d) t = 1.0/f (s)

Fig. 2 Contour maps of density without control at Mach 1.83

3.2 Effect of Mach Number

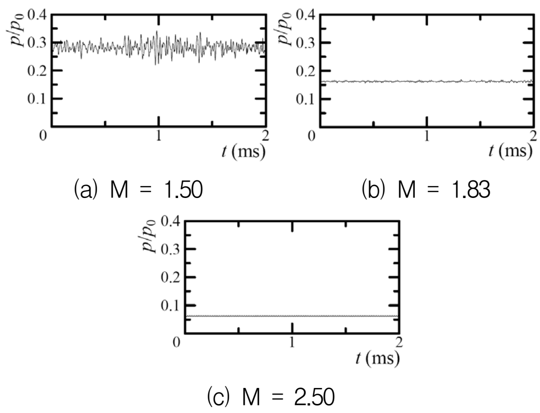
Figure 3 shows the time histories of static pressure at the position S_1 on the trailing edge of the cavity without control at inlet Mach numbers 1.50, 1.83 and 2.50 at the cavity entrance. Amplitudes of oscillations of the static pressure variation are high in all the cases of different inlet Mach number without control and the magnitudes of mean static pressure vary with the variation of inlet Mach number. Amplitudes of oscillations are reduced with the application of control device (Sub-Cavity) in all the cases of different inlet Mach numbers as shown in Fig. 4. Fig. 5 shows the distributions of power spectrum density without control at Mach numbers 1.50, 1.83 and 2.50 at the cavity entrance. There are dominant peak frequencies in all the cases of different inlet Mach numbers as shown in Fig. 5(a) to 5(c). It is seen that oscillation frequency varies with the variation of inlet Mach number. There is no peak frequency for cases with control at Mach numbers 1.83 and 2.50 as shown in Fig. 6(b), 6(c). However, there is a small peak at Mach number 1.50 as shown in Fig. 6(a).



(a) M = 1.50 (b) M = 1.83

(c) M = 2.50

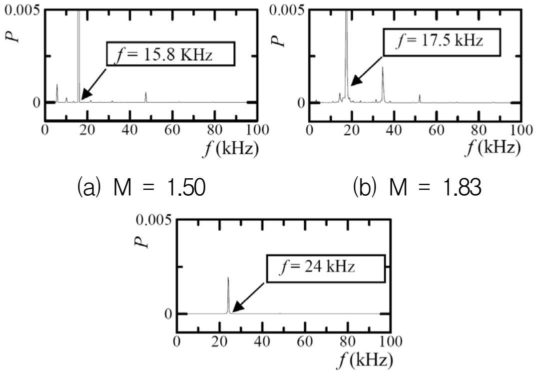
Fig. 3 Time histories of static pressure without control



(a) M = 1.50 (b) M = 1.83

(c) M = 2.50

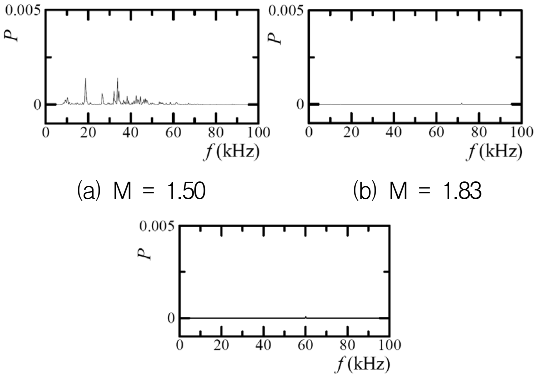
Fig. 4 Time histories of static pressure with control



(a) M = 1.50 (b) M = 1.83

(c) M = 2.50

Fig. 5 Distributions of power spectrum density without control



(a) M = 1.50 (b) M = 1.83

(c) M = 2.50

Fig. 6 Distributions of power spectrum density with control

4. Conclusion

A computational study has been carried out for supersonic cavities with a sub-cavity at different Mach numbers at the cavity entrance to investigate the effectiveness of controlling the cavity-induced pressure oscillations in two-dimensional supersonic flow. The results showed that the sub-cavity attached near the front wall of a square cavity was very effective at a wide range of inlet Mach numbers in reducing cavity-induced pressure oscillations. The reduction of pressure oscillations was dependent on the inlet Mach number and the dimensions of the sub-cavity used as oscillation suppressor. Therefore, the proposed control device could be a very effective tool in reducing cavity-induced pressure oscillations in different flow conditions.

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