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A Passive Control of Cavity-Induced Pressure Oscillations Using Sub-Cavity System

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보조공동계를 이용한 공동 유기 압력진동의 피동제어

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Key Words : *Compressible flow(압축성 유체), Supersonic cavity(초음속 공동), Pressure oscillations(압력 진동), Passive control(피동제어)*

Abstract

A new passive control technique of cavity-induced pressure oscillations has been investigated numerically for a supersonic two-dimensional flow over open rectangular cavities at Mach number 1.83 just upstream of a cavity, in which a sub-cavity system is installed on the backward-facing step of the main cavity. A third-order TVD (Total Variation Diminishing) finite difference scheme with MUSCL is used to discretize the spatial derivatives in the unsteady compressible Navier-Stokes equations. The results obtained show that the present sub-cavity system is very effective in reducing cavity-induced pressure oscillations. The results also showed that the resultant amount of attenuation of cavity-induced pressure oscillations was dependent on the length and thickness of the flat plate, and also on the depth of the sub-cavity used as an oscillation suppressor.

1. Introduction

The supersonic flow past a cavity induces large pressure oscillations that many undesirable effects in aerospace applications. Those pressure oscillations may lead to increase aircraft noise and drag and also may cause serve structural vibration and fatigue. For these reasons, the area of cavity flow has attracted the researchers for years. in spite of numerous experimental and numerical studies. [1-3], the clear picture of the flow physics governing the cavity behavior is not fully understood and the practical methods of suppressing cavity-induced pressure oscillations have not yet been studied adequately.

In the present study, a new passive control technique has been investigated numerically by modifying the front wall of a cavity with flat and spherical surface. The objective of the study is to determine the effectiveness of the proposed control devices as oscillation suppressors.

2. CFD Analysis

The governing equations are two-dimensional unsteady compressible Navier-Stokes equations coupled with turbulence kinetic energy and eddy viscosity equations. A modified k-R (turbulent kinetic energy-eddy viscosity) turbulence model [5-7] is used in this simulation. A third-order TVD (Total Variation Diminishing) finite difference scheme with MUSCL[8] is used to discretize the spatial derivatives and a second order-central difference scheme for the viscous terms, and a second-order fractional step is employed for time intergration.

(a) Computaional grids(Unit : mm)

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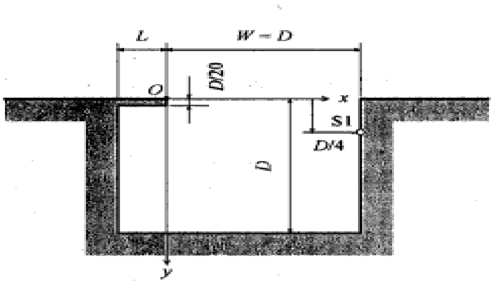
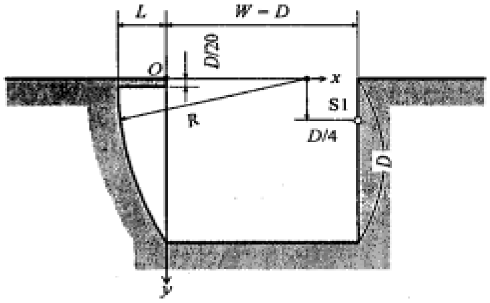


(b) Cavity with leading edge plate



(c) Cavity with spherical wall

Fig. 1 Computational domain

Table 1 Cavity configuration

	L/D	R/D
Without control	0	-
Case 1	0.250	-
Case 2	0.125	-
Case 3	0.250	1.930
Case 4	0.125	2.754

Figure 1 shows computational domain of a supersonic flow section at the entrance of the cavity is 24 mm. The cavity depth D (=12 mm) and its length W are the same S1 in thus figure denotes the measuring position of static pressure. The parameters of cavity configuration are summarized in Table 1. Since a spherical reflector [4] is effective in reducing sound pressure, the cavity front wall is replaced by a spherical surface in order to investigate its effect on flowfield oscillations. The radius of curvature of spherical surface and length of leading edge plate are R and L, respectively. The number of grids is 300? 0 in the region of the nozzle and 50? 0 in the cavity. The origin on x-y coordinate is located at the cavity leading edge. 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. The inlet Mach number M at the entrance of the cavity is 1.83. On the solid walls, the no-slip conditions and no heat transfers were applied as the boundary conditions. Fixed conditions were set for the inflow boundary condition. Zero order extrapolation was used at the outflow boundary.

3. Results and Discussions

3.1 Cavity without control

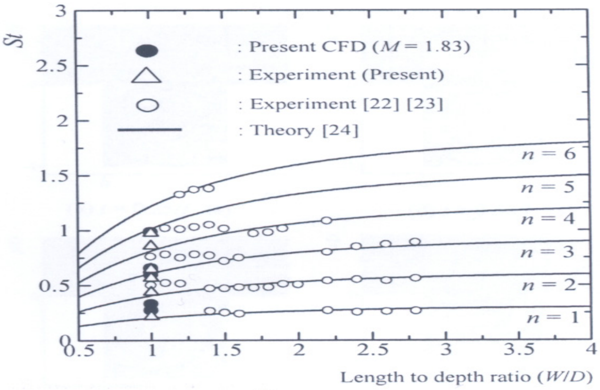
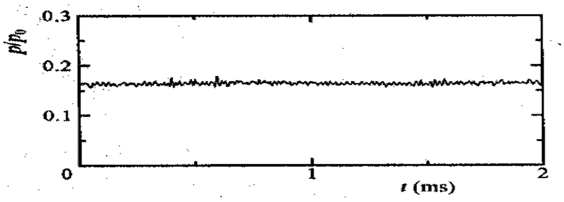


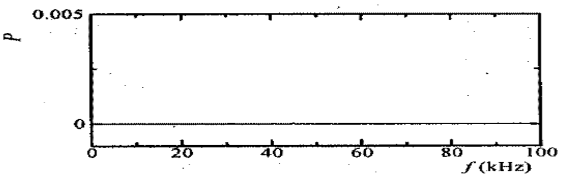
Fig. 2 Comparison of simulation results with experimental and theoretical results

In order to validate the computational code developed for the present numerical simulation, a two-dimensional open square cavity of length to depth ratio=1.0 at Mach number M_{inlet} = 1.83 at the cavity entrance was investigated in case without control and the solutions were compared with the present experimental results. The solutions were also compared with the experimental and numerical results of other researchers [9-11]. Figure 2 shows a comparison of the Strouhal number St among numerical, experimental and theoretical results. Open circle represents the experimental results reported by Zhang and Edwards [9] and Takakura et al. [10]. Solid lines are drawn by using the formulae of predicting oscillation frequencies proposed by Nishioka et al. [11]. Closed circle represents the results of the present simulation and the triangle represents the results of present experiments. The comparsion shows a fairly good agreement between the present stimulated and experimental results. The results also show a good agreement with the experimental and theoretical results of other researchers [9-11].

3.2 Effect of leading edge plate on flowfield oscillations



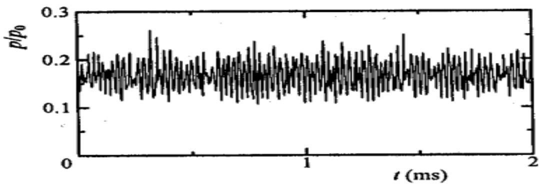
(a) Time history of static pressure



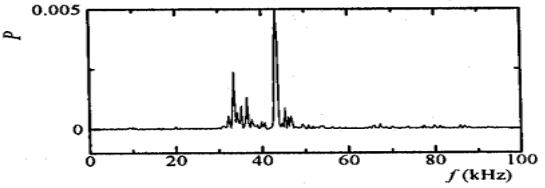
(b) Power spectrum density

Fig. 3 Time history of static pressure and power spectrum density (Case 1)

Figure 3(a) shows the time history of the static pressure at the position S1 inside the cavity with control (Case 1). A substantial reduction of the amplitudes is obtained when a leading edge plate is introduced in the cavity as shown in Fig.3 (a). Distribution of power spectrum density obtained from the static pressure history is shown in Fig.3(b). There is almost no peak frequency for this case.



(a) Time history of static pressure

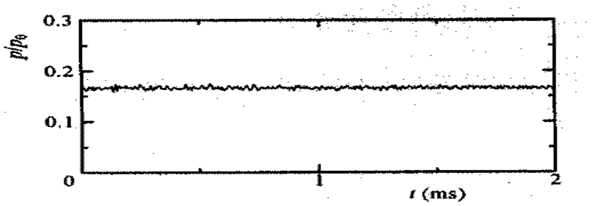


(b) Power spectrum density

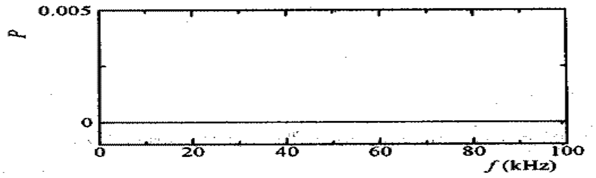
Fig. 4 Time history of static pressure and power spectrum density (Case 2)

Figure 4 shows time history of static pressure and power spectrum density for Case 2. The amplitude showed a similar tendency compared with that of the cavity without control and there were some strong peak frequencies for power spectrum density.

3.3 Effect of spherical surface on flowfield oscillation



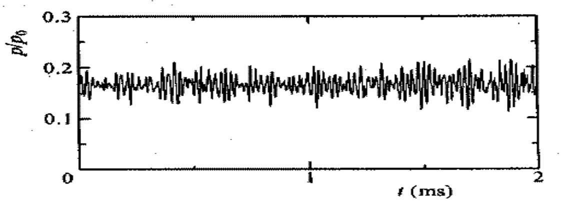
(a)Time history of static pressure



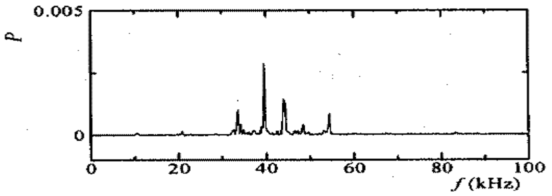
(b) Power spectrum density

Fig. 5 Time history of static pressure and power spectrum density (Case 3)

Figure 5(a) shows the time history of the static pressure at the position S1 in the cavity for Case 3. The result shows that amplitude of oscillations is reduced by spherical surface. Distribution of power spectrum density shows that there is no peak frequency (Fig. 5(b)).



(a) Time history of static pressure



(b) Power spectrum density

Fig. 6 Time history of static pressure and power spectrum density (Case 4)

Figure 6 shows time history of static pressure and power spectrum density for Case 4. The amplitude showed a similar tendency compared with that of cavity without control and power spectrum density showed some small peak frequencies.

4.Conclusion

A computational study has been carried out for a supersonic two-dimensional flow over open, square cavities at Mach number 1.83 at the cavity entrance. The front wall of the cavity has been modified with flat plate or spherical surfaces to suppress the oscillations in a supersonic free stream flow. The results showed that the introduction of flat plate or spherical surfaces in the cavity changed the flow field in a favorable way such that the upstream compression waves became weaker and the disturbance of the shear layer by the reflected compression waves was not strong enough to regenerate the instability waves to sustain the process by completing the feedback loop. Furthermore, resultant amount of attenuation of oscillations was dependent on the length of the flat plate and the radius of curvature of the spherical surface used as oscillation suppressors.

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