CONTROL OF ACOUSTIC RESONANCE IN SHALLOW RECTANGULAR CAVITIES USING SURFACE MOUNTED BLOCKS

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1 Introduction

Flow over cavities has been identified as a potential source of acoustic resonance in many engineering applications [1, 2]. The inherent instability of the shear layer over a cavity can give rise to pressure oscillations. A feedback mechanism can result in sustained oscillations in the flow field [3]. The oscillations of the shear layer at the cavity edge cause an oscillating mode at frequencies determined by, $St_n = f_n l/U = 0.5n, n = 0, 1, 2, \ldots$, where l is the characteristic shear-layer length. St_n is the Strouhal number corresponding to the frequency f of the nth mode at a flow velocity U [4].

At flow velocities where a shear-layer mode frequency coincides with one of the acoustic cross-modes, a look-in may occur, producing a tonal noise of extremely high sound pressure levels. The suppression of the cavity noise using passive devices that distort the shear layer is investigated in the literature [5, 6]. However, the nature of the interactions between an upstream flow disturbance with the shear layer over the cavity mouth on the acoustic resonance mechanism is not fully understood.

A surface-mounted block in the flow is known to cause a complex pattern of vorticity downstream. Hussein and Martinuzzi experimentally studied the channel flow around square cross-section surface-mounted blocks [7]. They found that the complex features of the flow are highly dependent on the width of the block. Wider blocks caused higher turbulence intensity and longer wake region downstream. They also noted that the vorticity field near the cube was characterized by the generation of the hairpin vortices in the near-wake region with relatively low frequencies, and the shedding of lateral vortices from the leading lateral edges of the cubic obstacle.

The objective of this study is to investigate the effect of the attachment of square cross section blocks of different widths at different distances from the shallow cavity upstream edge on the intensity of the resonance resulting from the fluid-resonant interactions of the air flow over the cavity mouth.

2 Experimental setup

The experiments are carried out in an open loop wind tunnel. The dimensions and the used nomenclature for the experiments are shown in figure 1. The cavity depth, length, and width are equal to 0.127 m. The channel height is 0.381 m, which imposes a first acoustic cross-mode with a frequency f_1=465 Hz. The response of the system is characterised by the dimensionless pressure, $P^* = P/(0.5\rho U^2)$, and the flow velocity is indicated in the reduced form $U_r = U/f_1 l$, based
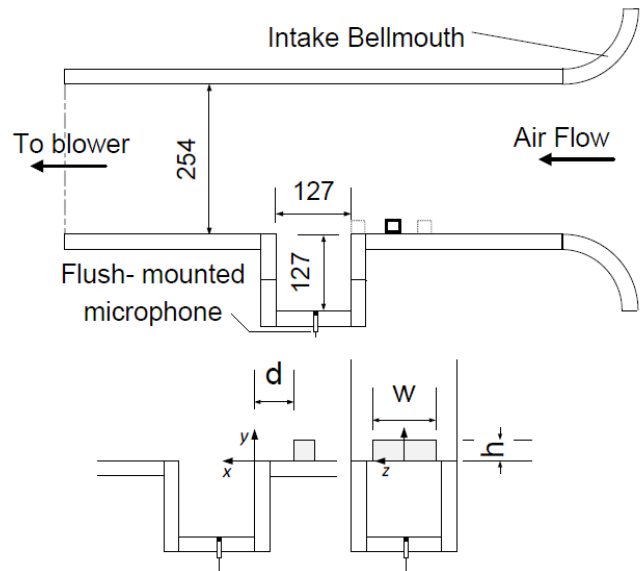
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Figure 1: Test section configuration and the used nomenclature.

on the frequency of the lowest cross-mode of the test section.

Six Blocks of square cross-section with edge length h=0.0191 m are used, with width to height ratios w/h=1, 2, 3, 4, 5, and 6.66. The blocks are attached at different locations upstream of the cavity leading edge with d/h = 0, 3, and 6. These locations are selected to investigate the effect of the reattachment position of the lateral flow around the block sides.

The cavity is tested at air velocities up to 160 m/s. A flush-mounted microphone located at the center of the cavity bottom is used to measure the acoustic pressure. The resonance frequency and sound pressure level are recorded and analysed at each flow velocity.

3 Results

3.1 Cavity response with no blocks

The acoustic response of the cavity in cross-flow provides a base case on which the control effectiveness is assessed. The characteristics of the noise in the cavity and the shear layer modes that excite the resonant sound are identified.

Figure 2 shows the response of the cavity with no block attached. The upper part of figure 2 shows that the peaks of the dimensionless pressure occur at the coincidence of the shear-layer modes with the acoustic cross-modes. The first cross-mode with f_1=465 Hz peaks at St=0.48, 1.11, and 1.61 referring to coincidence with the first, second, and third shear-

layer modes ; respectively. Development of the normalized pressure with reduced velocities is shown in the lower part of figure 2. The pressure reached $P^*= 0.01$ at U_r=0.55 for the third shear-layer mode, P^*=0.12 at U_r=0.95 for the second shear-layer mode, and P^*=0.27 at U_r=2.10 for the first shear-layer mode.
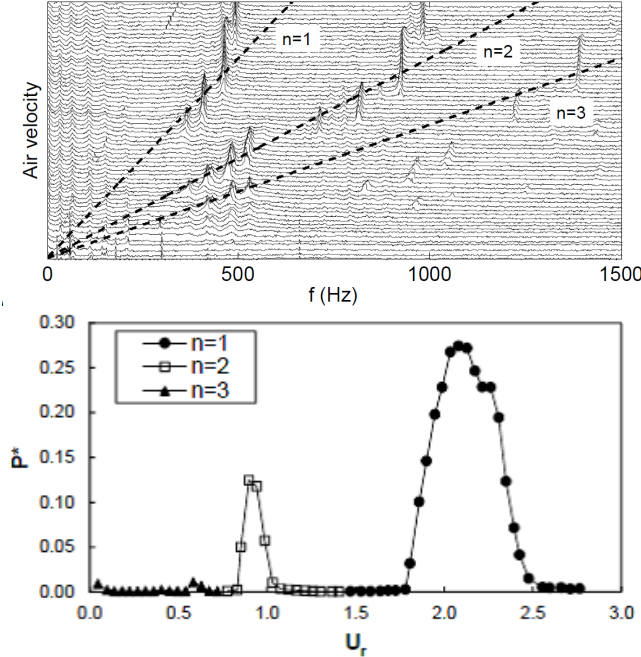

Figure 2: Response of the cavity with no block.

3.2 Effect of block attachment

Figure 3 shows the attenuation obtained using different configurations of the blocks at different upstream locations. Results show that the cases with moderate values for width and distance are the most effective in suppressing the acoustic resonance excitation. Attenuation values of 30 dB are obtained using blocks attached at a distance of d/h=3 with blocks of widths w/h of 3 and 4. Cubic blocks cause less than 5% attenuation levels. Blocks that filled the whole section of the wind-tunnel channel negatively affect the sound pressure level, increasing the noise. These results suggest that the horseshoe vortices that the block induces at its vertical upstream sides are important for noise suppression.

4 Conclusions

A passive method for controlling the acoustic resonance resulting from subsonic flows with Mach numbers up to 0.45 over shallow rectangular cavities is investigated. Experiments are performed to investigate the effectiveness of attaching blocks of square cross-section in suppressing the flow-excited acoustic resonance in shallow rectangular cavities. Six different square blocks with width to height ratios of $w/h = 1$, 2, 3, 4, 5, and 6.66 are investigated. The blocks are attached at different locations upstream of the cavity leading edge with
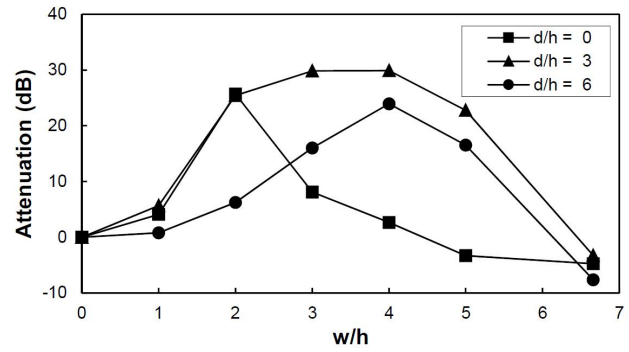

Figure 3: Attenuation of the cavity noise using different block configurations

$d/h = 0$, 3, and 6, where d is the upstream distance from the cavity leading edge and h is the block height.

The results show that significant attenuation of the generated acoustic pressure with up to 30 dB is achieved using blocks of w/h between 2 and 4. Moreover, it is observed that the most effective attenuation of the acoustic resonance is achieved when the blocks are located at a distance of $3h$ upstream of the cavity leading edge. Blocks with moderate widths are more effective than blocks that fills the whole width of the wind tunnel.

Acknowledgement

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