# THE EFFECT OF HIGH FREQUENCY VORTEX GENERATOR ON THE ACOUSTIC RESONANCE EXCITATION IN SHALLOW RECTANGULAR CAVITIES

**Ahmed Omer**$^{1*}$**, Atef Mohany**$^{1\dagger}$
$^{1}$University of Ontario Institute of Technology, Oshawa, Ontario, Canada

## 1 Introduction

Flow over cavities can be a source of severe noise and/or excessive vibration when the oscillations generated by the shear layer formation in the cavity are coupled with the acoustic waves in the accommodating enclosure. This phenomenon is known as flow-excited acoustic resonance. Enormous research efforts have been made to mitigate the undesirable effects associated with this phenomenon [1]. The basic concept of attenuating the flow-excited acoustic resonance in cavities is by preventing/damping the formation of the shear layer over the cavity mouth, which results from the flow separation at the upstream edge, this can be achieved by placing a cylinder near to the upstream edge. The vortex shedding created by the cylinder interferes with the shear layer developed in the cavity, this interference can dampen the shear layer in the cavity and hence suppresses the acoustic resonance excitation. This interference is affected by many factors including the cylinder location and diameter, which are investigated in this paper.

## 2 Experimental and computational setup

The experimental setup consists of a test section made of 25.4 mm thick acrylic with a cavity installed at 330 mm from the test section inlet. The cavity dimensions are 127x127x127 mm which yields a length over depth ratio of 1.0. The inlet of the test section is attached to a bellmouth to help stabilize the flow and minimize the pressure drop. The outlet of the test section is attached to a diffuser that connects with a suction side of a centrifugal blower that is driven by a 75 horsepower motor controlled by a variable frequency drive and can achieve a maximum flow velocity of 155 m/s with a turbulence level less than 1% in the base case without any cylinder attached. A cylinder with a diameter of 4.57 mm which yields a ratio *L/d* of 27.78, where *L* is the cavity length and *d* is the cylinder diameter, was installed in different locations near the upstream edge of the cavity. Different locations in terms of vertical and horizontal distances were tested. In the results section the locations will be identified with the Cartesian coordinates assuming the tip of the sharp edge is the (0.0, 0.0) point, and the upstream direction is the negative x direction, while the downstream is the positive x direction. Another two cylinders with diameters of 3.81 and 6.35 mm, which yield *L/d* ratios of 33.33 and 20; respectively, were also investigated. Measurements of the acoustic pressure are taken from the cavity floor by means of a flush mounted microphone and analyzed using a Labview program with a sampling rate of 10 kHz and each signal is averaged 60 times which correspond to 60 seconds in real time.

The numerical simulation was performed using ANSYS Fluent 14, the simulation was divided into two parts, firstly, a steady state flow using K-epsilon turbulence model to obtain the average main parameters, secondly, unsteady state flow using Spallart Almaras Detached Eddy Simulation model, which is known in the literature to have a good prediction for flows over cavities. The mesh used consisted of approximately 169,000 quadrilateral cell for a Reynolds number of 43974.

## 3 Results and discussion

The effect of the cylinder on the resonance excitation is assessed by comparing each case when the cylinder attached at different locations with the base case which is the bare cavity without any cylinder attached. In the base case it is found that the first three shear layer modes are developed with Strouhal number of 0.46, 0.98, and 1.44; respectively. The values of the acoustic pressure are observed to be highly intensified when the resonance is materialized with values exceeding 2000 Pa and a lock-in region is observed.

Figure 1 shows the effect when the cylinder is located at a height of 8 mm from the test section bottom wall, the resonance excitation is significantly suppressed and the acoustic pressure is reduced to around 500 Pa. It is also observed that the resonance excitation is shifted to higher velocities, this shift is observed with most of the locations investigated. However, locating the cylinder at 50.8 mm upstream of the cavity results in shifting the resonance excitation to higher velocities without any suppression effect observed. Similar behaviour is observed when the cylinder is located at a height of 12.7 mm, where locations (-25.4, 12.7), (0.0, 12.7), and (25.4, 12.7) are able to suppress the resonance excitation and to keep the acoustic pressure at around 1000 Pa. Generally, it is observed that locating the cylinder at 25.4 mm from the cavity upstream edge has comparatively the best performance. In terms of the vertical distance, locating the cylinder closer to the bottom wall of the duct improves the suppression effect.

The cylinder diameter effect is investigated as well. It is found that increasing the cylinder diameter enhances the suppression mechanism, this is shown in Figure 2, where the cylinder is located at (-25.4, 12.7), it can be seen in the figure that the cylinder with a diameter of 6.35 mm can maintain the acoustic pressure below 150 Pa over the entire flow range investigated. To understand the interaction between the cylinder vortex shedding and the cavity shear layer, a 2D numerical simulation is carried out. For each cylinder location the velocity profiles obtained from the steady simulation at different distances along the cavity are

---

[*] ahmed.omer@uoit.ca
[†] atef.mohany@uoit.ca

compared. Also, the vorticity fields are compared to spot the development of the vortices at the cavity mouth.

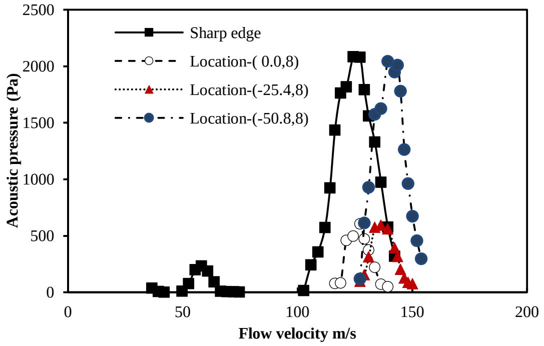

**Figure 1 : comparison between base case and cylinder (d=4.57 mm) at locations of height 8 mm**

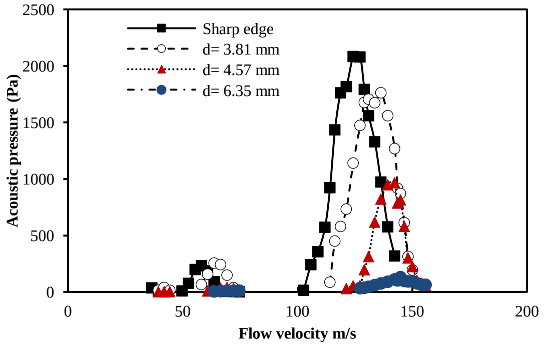

**Figure 2: effect of cylinder diameter on suppressing the acoustic resonance excitation at location (-25.4, 12.7)**

It is found that when the cylinder is located at a height of 25.4 mm, the wake of the cylinder does not interact with the cavity shear layer. It is noteworthy that this location experimentally was less effective in suppressing the resonance excitation. Moving the cylinder lower, to a height of 12.7 mm, at the same horizontal distance, 25.4 mm, is slightly changing the profile of the shear layer. The location at height of 8 mm which is found to be very effective experimentally is clearly influencing the shear layer at the cavity mouth, this can be seen in Figure 3. The wake of the cylinder interacts with the shear layer at the cavity mouth, introducing different profile for the shear layer. The cylinder wake can alter the shear layer in the cavity and increase the momentum thickness of the shear layer which result in more stability and less susceptibility to acoustic resonance excitation as discussed by Bruggeman et al.[2].

The effect of the horizontal location of the cylinder on the shear layer cannot be easily noticed from the shear layer thickness. However, the vorticity fields of each case obtained from the unsteady simulation show the progress of the vortex shedding and the interaction with the cavity shear layer. From the vorticity field it is observed that the cylinder vortex shedding interacts with the cavity shear layer and sends the main vortices developed by the shear layer into the cavity floor, hence, distracting the downstream impingement which results in interrupting the normal oscillations feedback cycle. This observation is evident for the locations that were found to be effective in suppressing the acoustic resonance experimentally, this can be seen in Figure 4 and Figure 5.

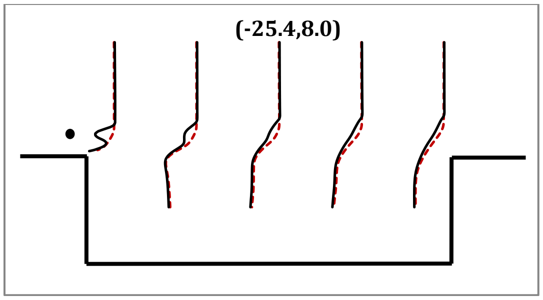

**Figure 3: velocity profiles at x/L =0, 0. 2, 0.4, 0.6, and 0.8, base case (red dotted line), cylinder located at (-25.4, 8.0) (black solid line)**

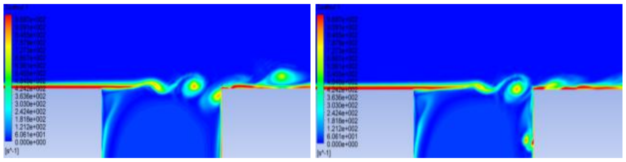

**Figure 4:vorticity fields for base case at t= 0.08 & 0.1 sec**

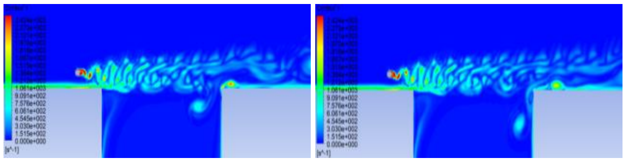

**Figure 5: vorticity fields, cylinder location (-25.4,12.7) at t= 0.08 & 0.1 sec**

## 4 Conclusion

Attaching a cylinder near the upstream edge of the cavity can be an effective technique in suppressing the acoustic resonance excitation. The location of the cylinder has a major influence in the effectiveness of this method, specifically, the vertical location of the cylinder from the bottom wall of the duct. Increasing the diameter of the cylinder generally improves the performance of the method, however, this should be tuned carefully to avoid exciting other modes by the cylinder wake itself. In most of the cases the acoustic resonance excitation is observed to be delayed to higher velocities, this shift is observed to be dependent on the location of the cylinder. The numerical simulation shows how the cylinder increases the momentum thickness of the shear layer at the cavity mouth, which results in more stable shear layer. From the vorticity fields, it is observed that the cylinder vortex shedding interacts with the cavity shear layer and distracts the normal oscillation cycle by altering the vortices impingement at the downstream edge.

## References

[1] S. Ziada and P. Lafon, “Flow-Excited Acoustic Resonance Excitation Mechanism, Design Guidelines, and Counter Measures,” Appl. Mech. Rev., vol. 66, no. 1, p. 011002, Dec. 2013.

[2] J. C. Bruggeman, A. Hirschberg, M. E. H. van Dongen, A. P. J. Wijnands, and J. Gorter, “Self-sustained aero-acoustic pulsations in gas transport systems: Experimental study of the influence of closed side branches,” J. Sound Vib., vol. 150, no. 3, pp. 371–393, Nov. 1991.