

EFFECT OF DUCT HEIGHT ON THE MAGNITUDE OF ACOUSTIC RESONANCE FOR SINGLE CYLINDER IN CROSS-FLOW

Omar Afifi ^{*1} and Atef Mohany ^{†1}

¹AeroAcoustics and Noise Control Laboratory, University of Ontario Institute of Technology, Oshawa, Ontario, Canada.

1 Introduction

Flow-excited acoustic resonance is a major concern in many industrial applications, such as in tube bundles of heat exchangers, due to its harmful effects. If not treated, flow-excited acoustic resonance may lead to excessive cycling vibrational loads on the tube bundles, which could subsequently result in premature failure of equipment. Even when structural failure is not a concern, the high tonal noise associated with the acoustic resonance can be damaging to human ears and may exceed the allowable federal/provincial noise regulations.

Due to the complex nature of the flow-sound interaction that occurs between packed tubes of heat exchangers, no unified model has been proposed to date for prediction or suppression of flow-excited acoustic resonance. Moreover, more research has recently focused on studying simplified models, such as single [1,2], tandem [3], and side-by-side cylinders [4], that exhibit flow-sound characteristics similar to those of tube bundles to fully understand and characterize the underlying physics of the phenomena. In an attempt to successfully develop a unified acoustic resonance prediction model, this paper studies the effect of the duct height on the self-excited acoustic resonance mechanism of single bare cylinders in cross-flow for the first acoustic mode.

It is known that the acoustic resonance in ducts containing single cylinders occurs when the frequency of vortex shedding from the cylinder matches one of the natural frequencies of the duct, $f_v = f_a$, and when there is enough energy in the flow to overcome the acoustic damping of the system. The natural acoustic frequency of the system is related to the duct height according to the equation $f_a = nc/2h$, where n is an index referring to the acoustic mode of interest (i.e. 1, 2, 3 .. etc.), c is the speed of sound, $\sim 343\text{m/s}$, and h is the height of the duct. Therefore, by changing the duct height, the frequency at which acoustic resonance occurs changes. The change in the resonance frequency was found to greatly affect the magnitude of acoustic pressure amplitudes at resonance, even at cases when the dynamic head ($0.5\rho U^2$) at coincidence is the same.

2 Experimental setup

Experiments outlined in this paper are conducted in an open-loop wind tunnel facility made up of several sub-parts as indicated in Figure 1. Three different test-sections with

heights of 203, 254 and 305 mm were built for the experiments. The natural frequencies of the ducts are 845, 675, 562 Hz respectively. The width and depth remained constant with values of 127 and 762 mm respectively. The air velocity inside the test section is controlled through a centrifugal blower that is connected to an electric motor with a variable frequency driver (VFD). Maximum air velocity attained by the current setup is $\sim 165\text{ m/s}$.

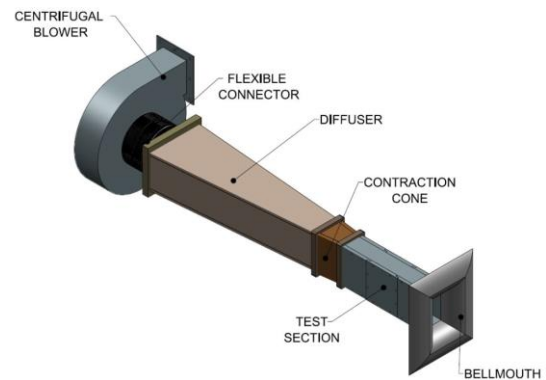


Figure 1: Isometric CAD view of the wind-tunnel assembly at the AeroAcoustics and Noise Control Laboratory (UOIT)

Seven smooth aluminum cylinders with varying diameters in the range of 10 – 25 mm were used in the present work. All cylinders were rigidly attached at the center of each test section, to excite the first acoustic cross mode of the duct. The acoustic pressure generated inside the duct was measured using a $\frac{1}{4}$ -inch pressure microphone manufactured by PCB piezotronics. The microphone was rigidly fixed and flush-mounted at the top wall of the test section at fixed distance from the center of the cylinder. The location of the microphone was set to 25.4 mm downstream the cylinder centerline. This location was determined in a separate experiment. Figure 2 shows a schematic side-view of the test section showing measurement locations.

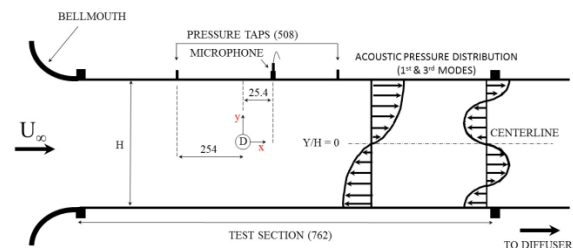


Figure 2: Schematic of the test section showing the position of the measurement devices (all dimensions in mm)

* omara@aercoustics.com

† atef.mohany@uoit.ca

3 Results and discussion

For the sake of brevity, only the acoustic response of the cylinders is presented for discussion. The upstream air velocity and pressure are presented in Pa and m/s.

In order to investigate the effect of the duct height, cases are compared where the cylinder diameter is constant while the height is varied. Figure 3 shows the acoustic pressure response of a cylinder with diameter 21.05 mm tested in all ducts. It is observed that the acoustic pressure amplitude produced by the cylinder at resonance is proportional to the duct height. The cylinder in the tallest duct height produced an acoustic pressure of 1108 Pa, while when the same cylinder was placed in the middle and shortest duct heights it produced acoustic pressure amplitudes of 654 Pa, and 565 Pa respectively.

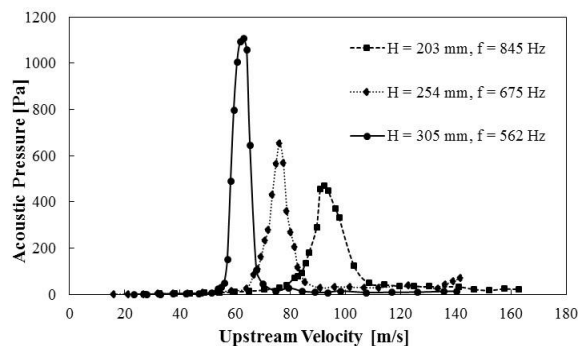


Figure 3: Pressure response for cylinder diameter $D = 21.05$ mm.

Special cases with similar blockage ratio (D/H) were also investigated. For an equal blockage ratio the resonance occurred at the same velocity for all the cases. For example, for the blockage ratio of 6.25%, theoretically all cases should have the velocity of coincidence at 54 m/s. Experimentally the three cases had the velocity at resonance coincidence at the values of 59, 56 and 57 m/s. However, the highest duct produced significantly higher acoustic pressure amplitude at resonance.

Figure 4 shows the pressure response for a blockage ratio of 6.25% presented in all ducts, for the first acoustic mode. It can be observed that the three cases behave similarly in terms of onset and off-set of acoustic resonance, however the acoustic pressure amplitude increases with the increasing duct height.

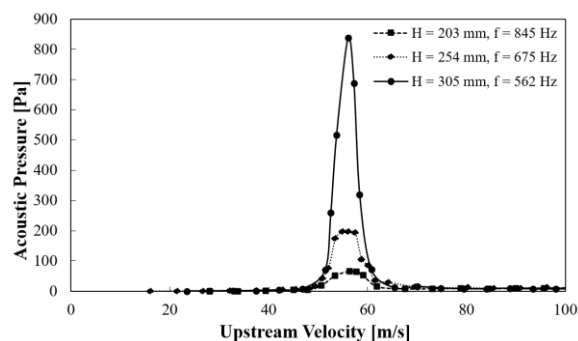


Figure 4: Pressure response for blockage ratio of 6.25%

The difference in acoustic pressure amplitudes despite equal input energies can be attributed to the acoustic attenuation. Acoustic attenuation of sound in ducts occurs due to multiple energy loss mechanisms such as viscosity, heat conduction, turbulence, and convection. In ducts, the acoustic damping is mainly due to the visco-thermal losses within the pipe/duct [5]. Quantifying the visco-thermal losses at the duct walls when a sound wave is propagating can be quantified using the first order model of Kirchhoff, expressed by the equation below.

$$\alpha_o = \frac{1}{2A_s c_o} \sqrt{\frac{\pi f \mu_{\text{dynamic}}}{\rho}} \left(1 + \frac{\gamma - 1}{\sqrt{\text{Pr}}} \right)$$

This equation takes into account the cross sectional area of the duct, as well as other heat parameters that remained constant in the presented cases. From the equation it can be concluded that the visco-thermal damping coefficient varies in proportional to the square root of the frequency which is affected by the duct height.

4 Conclusion

The effect of changing the duct height on the acoustic pressure amplitude for single bare cylinders in cross-flow has been investigated. It has been shown that changing the duct height alters the acoustic characteristics of the system such as the damping and stiffness, which results in different pressure amplitudes at resonance even for cases where the input energy, quantified by the dynamic head, is equal. The results of experiments discussed in this paper shows that the acoustic damping of the duct is an important parameter that may have been overlooked in the past and should be included in prediction criteria proposed for complex geometries such as tube bundles of heat exchangers

Acknowledgments

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