EFFECT OF VORTEX FORMATION LENGTH ON FLOW-EXCITED ACOUSTIC RESONANCE FOR A SINGLE SPIRALLY FINNED CYLINDER IN CROSS-FLOW

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1 Introduction

The sound generation from vortex shedding over bluff bodies has been the focus of numerous research studies over the past century. The vortex shedding caused by fluid cross-flow over bluff bodies confined inside an enclosure can cause excitation of the enclosure's acoustic modes. This occurs if the flow-excitation energy is adequately high enough to overcome the losses due to acoustic damping [1]. This mechanism is the cause of flow-excited acoustic resonance, a phenomenon that is a major design concern in many engineering applications.

There have been many investigations conducted to characterize and understand the complicated flow-sound interaction mechanism in heat exchanger tube bundles. These investigations have been undertaken by breaking up the intricate geometric configuration of tube bundles into simplified cases, such as single, tandem, side-by-side, inline or staggered array bare cylinders [1–4]. These investigations have provided extensive insight on the complex flow-sound interaction mechanism of bare cylinders arranged in various configurations. However, with the exception of [5], [6], the flow-sound interaction mechanism of finned cylinders has never been investigated. Furthermore, these investigations were limited to finned cylinders with straight (annular) fins. Therefore, in this study, the flow-sound interaction mechanism of spirally finned cylinders in cross-flow was investigated.

2 Experimental setup

The experimental apparatus consists of an open loop wind tunnel that is connected to a centrifugal air blower. The wind tunnel consists of a parabolic bell mouth, test section, diverging diffuser, and a flexible connection. The test section is manufactured out of 19.05 mm thick acrylic panels, with duct dimensions of 254 mm high and 127 mm wide. The aeroacoustic response measurements were performed by utilizing a 6.35 mm pressure microphone that was flush-mounted 25.4 mm downstream of the cylinder centerline, as this position corresponded to the point where the highest acoustic pressure was measured. The vortex formation length was calculated by measuring the velocity fluctuation along the wake centerline. This was done through the use of a single hot-wire probe, installed on a traverse mechanism. The vortex formation length was measured before the resonance condition to avoid damaging the hot-wire probe.

To understand the flow-sound interaction mechanism of spirally finned cylinders, three crimped spirally finned cylinders with different fin spacing were investigated. The measurements obtained for the case of the finned cylinders were compared to bare cylinders with the same equivalent diameter. The equivalent diameter was calculated using a modified version of equivalent diameter equations presented in the literature. The modification was done to take into account the added flow blockage imposed by the fin crimps. A schematic of the spirally finned cylinder with important fin parameters labelled is shown in Figure 1. The dimensions of the finned cylinders are listed in Table 1. The finned cylinders were tested while horizontally mounted at the center of the duct test section, as it corresponds to the position of the acoustic particle velocity anti-node of the fundamental acoustic cross-mode of the duct. The acoustic particle velocity is essential to the flow-acoustic coupling during flow-excited acoustic resonance.

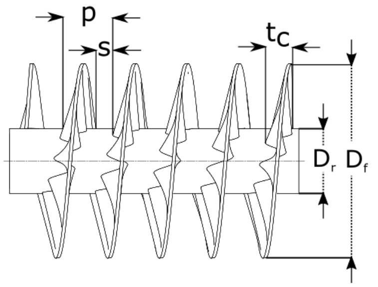

Figure 1: Schematic of crimped spirally finned cylinder.

Table 1: Dimensions of spirally finned cylinders. Dimensions listed in millimeters (mm).

	Fin I	Fin II
Root Dia., D_r	12.7	12.7
Fin Dia., D_f	38.1	38.1
Fin Pitch, p	9.8	4.9
Fin Spacing, s	6.8	3.1
Total Fin Thick., t_c	3.0	1.8
Mod. Equiv. Dia., D_{eq}	20.4	25.3

3 Results

3.1 Vortex formation length

Figure 2 shows the velocity fluctuations (u') measured along the wake centerline ($Y/D_{eq} = 0$). The vortex formation length is the point where the maximum velocity

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fluctuation is measured along the wake centerline. As shown in Figure 2, the bare cylinder exhibits the shortest vortex formation length. With the addition of spiral fins with large fin spacing, the vortex formation length increases. However, reduction in the fin spacing causes the vortex formation length to progressively decrease, approaching that exhibited by the bare cylinder.

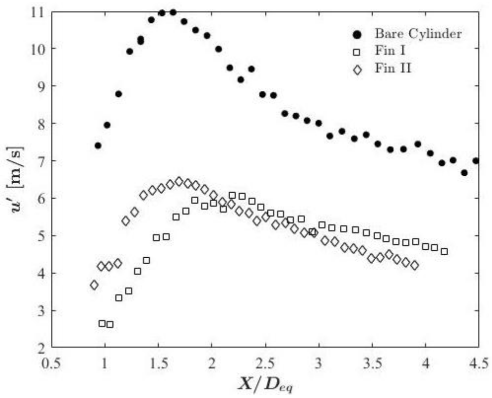

Figure 2: Velocity fluctuations measured along the wake centerline ($X/D_{eq} = 0$) at $Re_{Deq} = 3.5 \times 10^4$.

3.2 Aeroacoustic response

Figure 3 shows the normalized aeroacoustic response of all the finned cylinders compared against their equivalent diameter bare cylinders. It can be seen that the finned cylinder with the largest fin spacing (Fin I) has the lowest generated acoustic pressure during acoustic resonance excitation. Moreover, the gap between the peak acoustic pressure measured during resonance for the case of Fin I to that of its equivalent diameter bare cylinder is quite substantial. Reduction in the fin spacing causes a significant increase in the acoustic pressure generated during acoustic resonance excitation, as well as a reduction in the peak acoustic pressure difference between the finned cylinder and its equivalent diameter bare cylinder. In all cases, however, the acoustic pressure generated during acoustic resonance excitation for the bare cylinders were higher than that of their equivalent finned cylinders.

4 Discussion

As has been shown in Figure 2, the addition of spiral fins elongate the vortex formation length. This increase is associated with an early shear layer formation and separation, which causes the separated flow to be convected further downstream, leading to the formation of vortices further away from the cylinder base. With reduction in the fin spacing, the point of flow separation is progressively delayed, leading to a shorter vortex formation length. During acoustic resonance excitation, cylinders that exhibit a smaller vortex formation length produce higher peak acoustic pressure. This is because the flow-acoustic coupling will occur closer to the cylinder base, which is where the acoustic particle velocity is maximum.

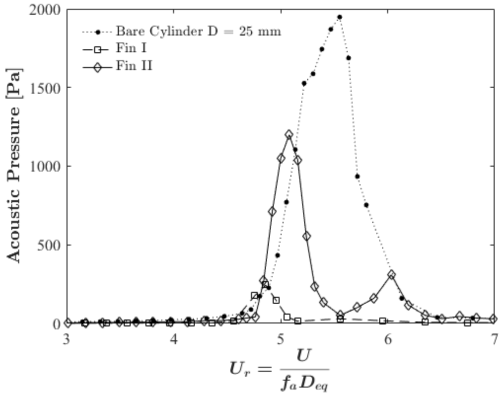

Figure 3: Normalized aeroacoustic response of finned cylinders compared to their equivalent diameter bare cylinders. U = Flow velocity, f_a = Fundamental acoustic cross-mode.

5 Conclusion

The effect of the spiral fins on the vortex formation length, and its consequence on the flow-sound interaction mechanism was studied. It was found that spirally finned cylinders elongate the vortex formation length as compared to their equivalent diameter bare cylinder. Reduction in the spiral fin spacing lead to a gradual decrease in the vortex formation length. This has shown to influence the peak acoustic pressure during acoustic resonance excitation, where cases that exhibited a relatively smaller vortex formation length generated higher acoustic pressure during resonance excitation.

Acknowledgments

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