ICA 2022 24th INTERNATIONAL CONGRESS ON ACOUSTICS October 24(Mon) - 28(Fri), 2022 Gyeongju, Korea

Extended abstract

PROCEEDINGS of the
24th International Congress on Acoustics

October 24 to 28, 2022, in Gyeongju, Korea

ABS-0899

Control of flow-induced noise by structural compliance

Muhammad Rehan NASEER[1]; Irsalan ARIF[2]; Randolph Chi Kin LEUNG[3]

Department of Mechanical Engineering, The Hong Kong Polytechnic University, Hong Kong

ABSTRACT

Flow-induced noise generation by external flow devices operating at low to intermediate Reynolds number is an overriding concern associated with their design and operations. Over the years, a number of passive noise control methods have been proposed and developed, however their implementation is limited by the associated aerodynamic performance degradation. In this regard, we propose a novel method of utilizing the structural compliance for noise reduction of external flow devices with minimum or no sacrifice in the overall aerodynamic characteristics. The key idea is to design a structurally compliant elastic surface that vibrates in structural resonance fluid loading for absorbing the energy from the flow to sustain its vibration. We have implemented the method for the two unique noise generation problems: a deep cavity flow driven by flow-acoustic resonance and a symmetric airfoil exhibiting feedback phenomenon. The effectiveness of the compliant surface in tonal noise reduction for both test cases is analyzed numerically using high-fidelity direct aeroacoustic simulations. Despite the prevalence of different flow regimes, the application of compliant surface provides a significant overall noise reduction for each case up to different extents. Design strategy of the compliant surface along with its limitations are also discussed

Keywords: Airfoil Tonal noise, Deep Cavity, Structural Compliance

1. INTRODUCTION

Flow-induced noise generation by external flow devices operating at low to intermediate Reynolds number is an overriding concern associated with their design and operations. Some of the most common physical problems involving flow-induced noise are flow passing over a deep cavity and over the airfoil. Flow-induced noise generation by external flow devices operating at low to intermediate Reynolds number is an overriding concern associated with their design and operations. Two of the most common physical problems involving flow-induced noise are flow passing over a deep cavity and over the airfoil. Flow over a deep cavity produces intense noise [1-3], if potent enough, it may damage the nearby structure upon exposure. Similarly, self-sustained noise generation by an airfoil [4-6] operating at low/moderate freestream Reynolds number is also a significant challenge which merits scientific investigation for the feasible suppression measure. The underlying mechanism governing both the problems is the feedback loop [6-8] between the streamwise moving shear layer and the incident acoustic waves. However, the intimate manner of the aeroacoustic interaction in case of cavity flow slightly differs from the airfoil feedback phenomenon. The favorable phase relationship between the upstream travelling convective disturbances and the incoming acoustic fluctuation at the point of shear layer excitation has been regarded by several authors [4, 6, 9, 10] the main contributor towards the establishment of the aeroacoustic resonance. Therefore, by invoking a phase delay to disrupt the feedback process could be one of the measures for the noise abatement. In recent times, the idea of flow compliant surface has gained attention due to its flexibility in application and the adaptability in compliance to the incident flow, which makes it a suitable candidate for our noise reduction strategy [4, 11, 12]. The aim of the current study is therefore to leverage the potential of an

[1] rehan.naseer@connect.polyu.hk
[2] irsalan.arif@connect.polyu.hk
[3] randolph.leung@polyu.edu.hk

elastic panel based on its flow compliant characteristics to suppress the tonal noise generation in the airfoil and cavity flow problems.

2. METHODOLOGY

The present study utilizes high-fidelity direct aeroacoustic simulation (DAS) for its capability to resolve the coupling between the unsteady airfoil aerodynamic and acoustic solutions with high accuracy. To solve the unsteady compressible Navier-Stokes (N-S) equations, conservation element and solution element (CE/SE) method [13] is adopted and to model the nonlinear response of the elastic, one dimensional plate equation has been implemented [14].

The novel concept of incorporating the flow complaint surface to reduce the tonal noise emission has been successfully implemented for the two external flow cases. First, we tested a deep cavity flow operating at low Mach number of M = 0.09. In this flow regime the deep cavity generates a strongly resonated aerodynamic noise. Such an exacerbated response of the deep cavity flow occurs due to the in-phase relationship between the longitudinally oscillating acoustic mode and the streamwise moving convective disturbances of the shear layer oscillation. The sites around the cavity which promote the onsetting of the nexus between the later and the former are the walls adjacent to the leading and trailing edges of the cavity along with the bottom surface which is exposed to the maximum acoustic pressure. In order to disturb the strongly resonant aeroacoustic feedback process responsible for the higher noise radiation, it is therefore imperative to install the elastic panel at the aforementioned locations. It is anticipated that through aeroacoustic structural interaction (or acoustic-structural interaction based on the elastic panel mounting location and its exposure to the prevalent flow regime), we could be able to achieve the noise reduction by channelizing the flow energy into the sustained panel vibration. In essence, the mutual strengthening of the shear layer and cavity acoustic mode has been targeted for the ultimate noise suppression using the elastic panel vibration.

For the second case, flow over a symmetric airfoil operating at low Reynolds number of 50,000 and Mach number of M = 0.4 which produces a sharp tonal noise involving aeroacoustic feedback loop. We aim to leverage the flow energy absorption phenomenon with self-sustaining panel for effective suppression of airfoil boundary layer flow unsteadiness before their eventual scattering as noise. The optimum location, length and structural properties of the panel are carefully chosen based on the flow characteristics of the rigid airfoil. For the present study, a short elastic panel of 5% of airfoil chord is chosen which is located at 40% airfoil chord due to presence of onset of sharp rise in boundary layer flow instabilities at this location as shown in Figure 2(a). The structural properties of the panel are set in a manner that the panel vibrates in resonance with the flow induced loadings.

3. RESULTS AND DISCUSSION

Case 1: Fig 1. explains the application of flow complaint surface in reducing the sound pressure level (SPL) of open cavity flow. In case of rigid cavity, the shear layer and standing mode remains in-sync with each other which promotes the resonance where the acoustic mode has the dominant role to play by making the shear layer to grow in a certain way along the cavity opening. Upon the enactment of the noise control strategy, the bottom wall of the cavity is replaced with an elastic panel. With the envisaged acoustic-structural interaction the acoustic component gets affected as the amplitude of the standing acoustic waves along the cavity depth is reduced to the 40% of its rigid cavity (RC). The reduction of acoustic component effectively retarded the previously maintained feedback loop with the shear layer growth became independent of the former. Hence the installation of elastic panel reduced the SPL by 3.6 db.

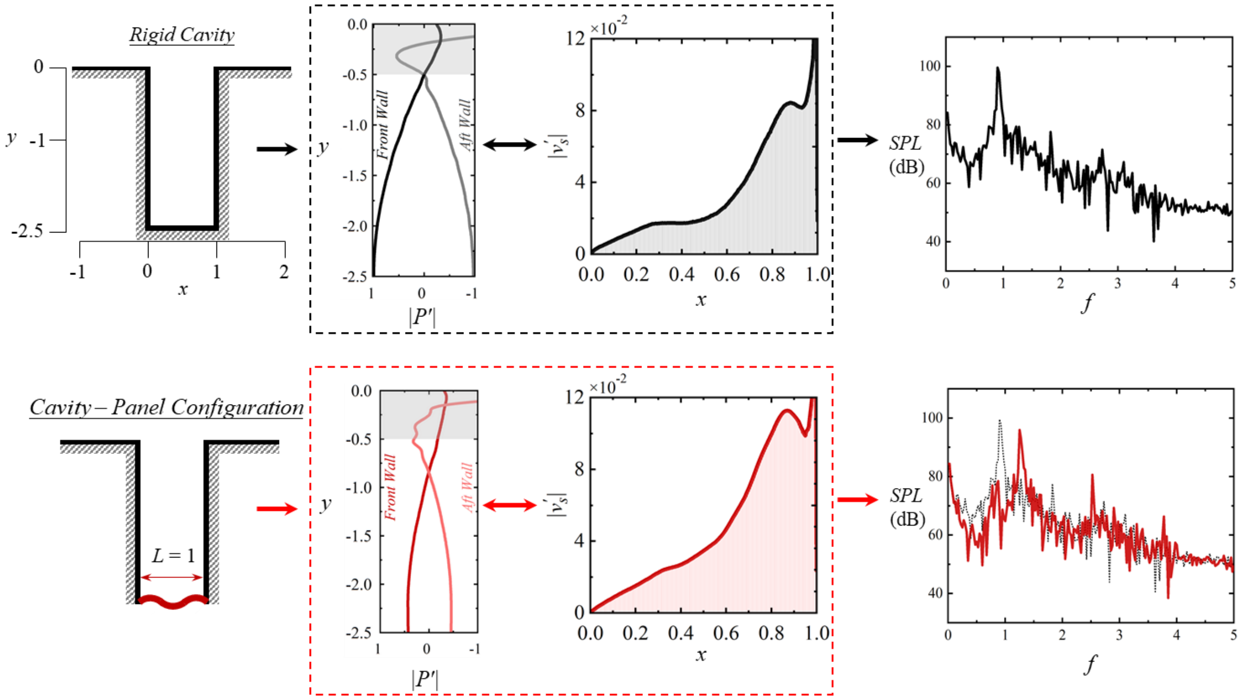

Figure 1. Implementation of noise suppression method of using flow compliant surface at the bottom of the cavity. The encapsulated dashed region infers the cavity acoustic mode and shear layer interaction being affected with elastic panel application leading to the lower sound pressure level.

Case 2: The effect of airfoil configuration with elastic panel (EP) on the acoustic radiation is analyzed and compared with rigid airfoil (RS) by plotting the azimuth variations of p'_{rms} at a radial location of r = 3 above the airfoil trailing edge and shown in Figure 2(b). The reduction in p'_{rms} is observed to be significant in all directions with much higher reduction toward the forward plane. The acoustic characteristics of RS and EP airfoils are evaluated and compared by analyzing their SPL spectra above the airfoil trailing edge and shown in Figure 2(c). The spectra of both RS and EP airfoils remain similar where a maximum noise reduction of 7 dB is observed for the EP airfoil at the peak frequency of f = 3.37.

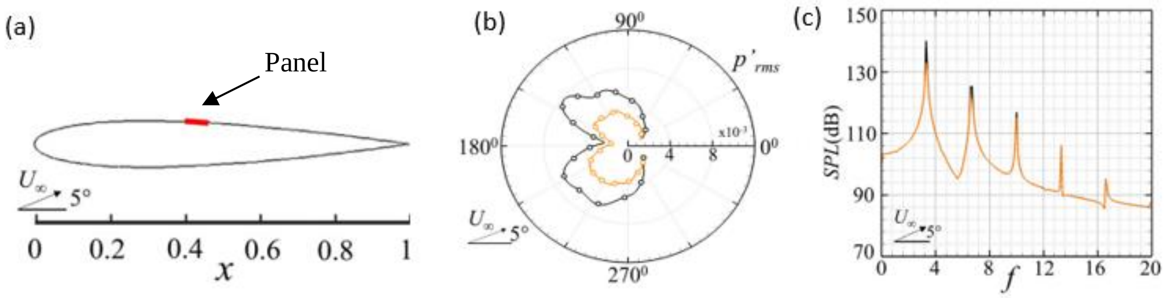

Figure 2. (a) Schematics of the designed airfoil configuration; (b) p'_{rms} comparison of RC and EP configurations at a radial location of $r = 3$; and (c) SPL spectrum of RC and EP configurations at a radial location of $r = 3$. —— RC, —— EP.

Figure 3 illustrates the filtered FFT data of v' and p' flow field data at $f = 3.37$ for RS and EP airfoils. For EP airfoil, no shift in the dominant frequency is observed. The vortex shedding pattern is observed to be similar for both the cases; however, the strength of v' and p' is significantly reduced for EP airfoil. A maximum noise reduction is achieved at this frequency by EP airfoil as observed in Figure 2(c).

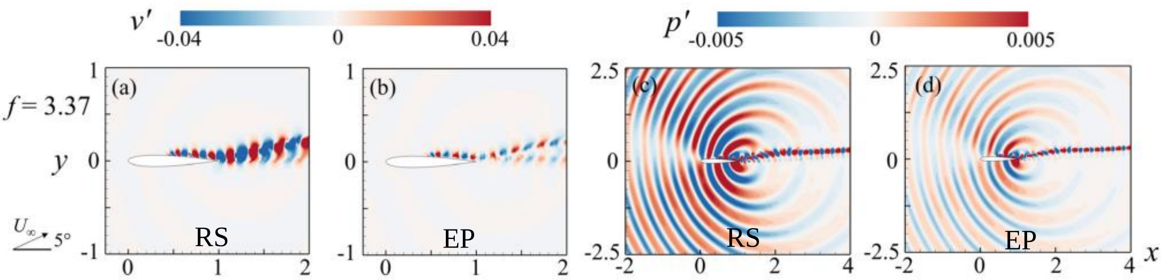

Figure 3. Filtered FFT distribution of v' [i.e., (a) and (b)] and p' [i.e., (c) and (d)] at $f = 3.37$ for RS and EP airfoils.

4. CONCLUSIONS

The effect of structural compliance for flow-induced noise control is successfully implemented and demonstrated for two unique external flow cases. For the case of flow over the deep cavity, an elastic panel is implemented at the bottom wall and a noise reduction of 3.6 dB is achieved. For the case of flow over an airfoil, the panel is mounted at 40% chord location and a noise reduction of 7 dB is achieved. The method can be implemented in other flow-induced noise problems with careful panel design considerations.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support from the Research Grants Council of the Government of Hong Kong Special Administrative Region under grant number 15208520. The first author is grateful to stipend support to his study from the Department of Mechanical Engineering, The Hong Kong Polytechnic University. The second and third authors are grateful to a generous research donation from Philip K. H. Wong Foundation under grant number 5-ZH1X (now N-ZH1X).

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