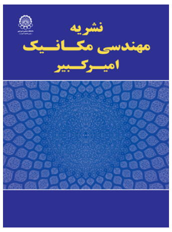

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 53(special issue 3) (2021) 431-434
DOI: 10.22060/mej.2020.17054.6504

Effect of blowing on flow-induced noise reduction in a rod-airfoil

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ABSTRACT: In this paper, the effect of blowing in a rod on the flow structure and its noise in a rod-airfoil is investigated. To this aim, the simulation of the flow around the rod-airfoil was performed using URANS equations and employing k-ω-SST turbulence model. The prediction of the flow-induced noise is performed using F-WH analogy. Since Vortex's periodic production is the main cause of the noise mechanism, by reducing its effect on the airfoil leading edge, the acoustic propagation reduces as well. In the present study, in order to control flow and reduce noise, the blowing active control in the rod has been used. The intensity of the blowing that is the ratio of blowing velocity to the inlet freestream flow, is chosen between 0.1 and 0.5. The results showed that increasing the blowing intensity to 0.5 reduces the noise emitted from the rod by 90% and the airfoil and rod-airfoil by 64%. In addition, by applying blowing, the lift force is increased and the drag force of the rod is reduced, which is aerodynamically favorable. In addition, the vortex shedding frequency decreases when blowing applied.

Review History:

Received: Sep. 14, 2019
Revised: Mar. 14, 2020
Accepted: May, 03, 2020
Available Online: May, 03, 2020

Keywords:

Aeroacoustics
Noise Reduction
Rod-Airfoil
Blowing Method
Flow Control

1- Introduction

Interaction of the fluid flow and the object leads to aerodynamic noise when a bluff body is exposed to a flow. Therefore, it is necessary to study the occurrence of aerodynamic noise and identify related phenomena.

Some devices and turbomachines are designed and tuned to be located downstream of a bluff body. Typically, a set of heat exchanger tubes, air conditioning systems, and helicopter rotors, for example, interact with other components such as fittings, bolts, and aircraft cycles, such as turbochargers. In order to simulate the phenomena in these cases, a combination of rod and airfoil is used to investigate the noise and turbulence structure of the flow. In this way, by locating the rod upstream of the airfoil, the unsteady flow passing of the rod moves downstream and divides at the leading edge. Accordingly, the study of flow structure and methods of reducing aerodynamic noise in the rod-airfoil has been considered by researchers due to its importance. In this regard, Jacob et al. [1] measured the flow on a rod-airfoil and extracted the noise spectra caused by the flow around the airfoil. Their experimental results are an accurate database for numerical validation. Chen et al. [2] in a three-dimensional numerical study examined rod-airfoil noise. They investigated the effect of corrugating the airfoil leading edge on the reduction of aerodynamic noise. Rousoulis et al. [3] numerically studied the effect of the rotating rod at the upstream of the airfoil on the noise generated in the rod-airfoil. Their results showed that the noise was reduced if the rod rotation frequency was twice the natural frequency of the rotation.

Accordingly, the present paper examines the flow-induced noise in the rod-airfoil using the FW-H analogy. A literature review survey shows that the effect of blowing on the back of rod surface in rod-airfoil noise control has not been investigated. Therefore, in the present paper, the effect of blowing on the rod with different velocities to correct the flow structure and control aerodynamic noise is investigated.

2- Methodology

To analyze the flow, the governing equations, including continuity and momentary equations, must be solved.

To analyze the flow-induced noise, aside from Navier-Stokes equations, the FW-H (Eq. (1)) is employed as well. This is a heterogeneous wave equation derived from the continuity equation and Navier-Stokes equations. The stress tensor is according to Eq. (2) and P_{ij} is the compressible stress tensor (Eq. (3)).

$$\begin{aligned}\frac{1}{c_0^2}\frac{\partial^2 P'}{\partial t^2}-\nabla^2 P' = \frac{\partial^2}{\partial x_i \partial x_j}\left[T_{ij} H(f)\right] - \\ \frac{\partial}{\partial x_i}\left[\left[P_{ij} n_j + \rho u_i (u_n - v_n)\right]\delta(f)\right] \\ + \frac{\partial}{\partial t}\left\{\left[\rho_0 \upsilon_n + \rho(u_n - \upsilon_n)\right]\delta\left(f\right)\right\}\end{aligned} \tag{1}$$

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$$T_{ij} = \rho u_i u_j - \tau_{ij} + \delta_{ij}\left((\rho-\rho_0) - C_0^2(\rho-\rho_0)\right) \tag{2}$$

$$P_{ij} = p\delta_{ij} - \mu\left[\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial u_i} - \frac{2}{3}\frac{\partial u_k}{\partial x_k}\delta_{ij}\right] \tag{3}$$

c_0 denotes the upstream sound velocity. $H(f)$ is the Heaviside function, $\delta(f)$ is the Dirac Delta function and T_{ij} is the Lighthill stress tensor. τ_{ij} , δ_{ij} , ρ and P' account for the viscous stress, Kronecker delta, density, and far-field sound pressure ($P' = P - P_0$), respectively. $f = 0$ represents the surrounding surface of the external flow problems, n_i is the vertical unit vector outward region ($f_0 > 0$) is the far-field speed of sound.

FW-H acoustic analogy can be applied to compute the far-field sound pressure for flow over the rigid body, where the dipole term is dominant over the monopole and quadrupole terms. Then, the FW-H equation can be simplified as follows:

$$p'(x,t) = \frac{1}{4\pi c_0}\int_S \frac{(x_i - y_i)n_i}{r^2}\frac{\partial p(y,\tau)}{\partial t}dS(y) + \frac{1}{4\pi}\int_S \frac{(x_i - y_i)n_i\, p(y,\tau)}{r^3}dS(y) \tag{4}$$

where c_0 is the speed of sound in air, τ is the emission time ($\tau = t - r/c_0$), r is the distance between the source and the receiver, and y is the source on the surface of the rigid body S .

3- Numerical Simulation

In the present study, the experimental model of Jacob et al. [1] is used to validate the results. Thus, an airfoil with a chord of 0.1 m is located downstream of a rod with a diameter equal to 0.1C and at a distance equal to the chord of an airfoil (C). A microphone is located at 18.5C of the airfoil center and the top of it. The schematic of the problem along with the boundary conditions is shown in Fig. 1.

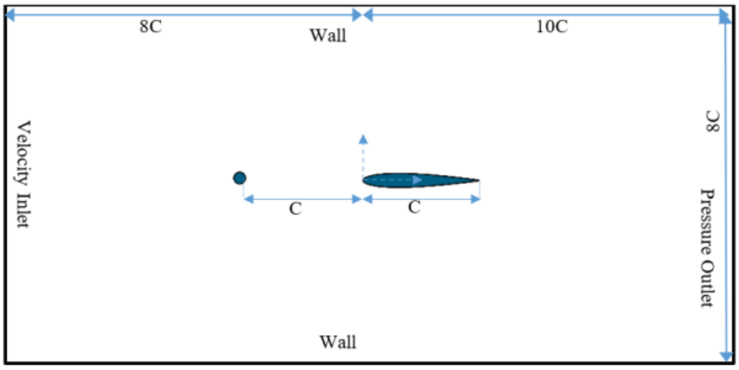

Fig. 1. The geometry of solution field and boundary conditions

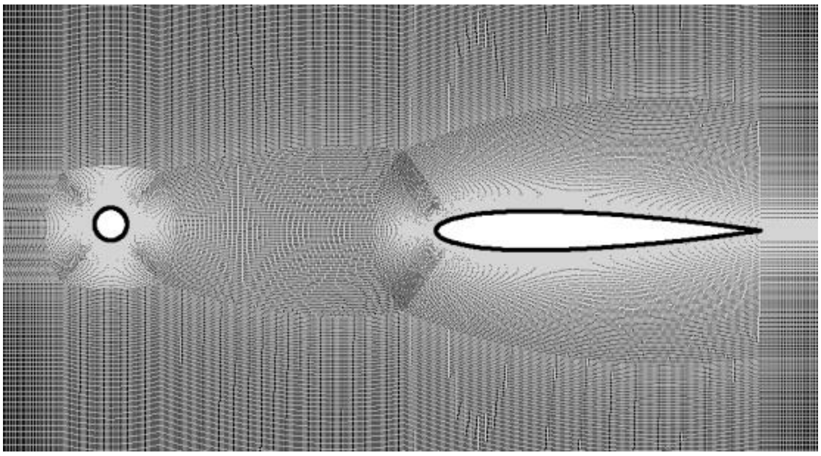

Fig. 2. Closed view of computational domain meshing

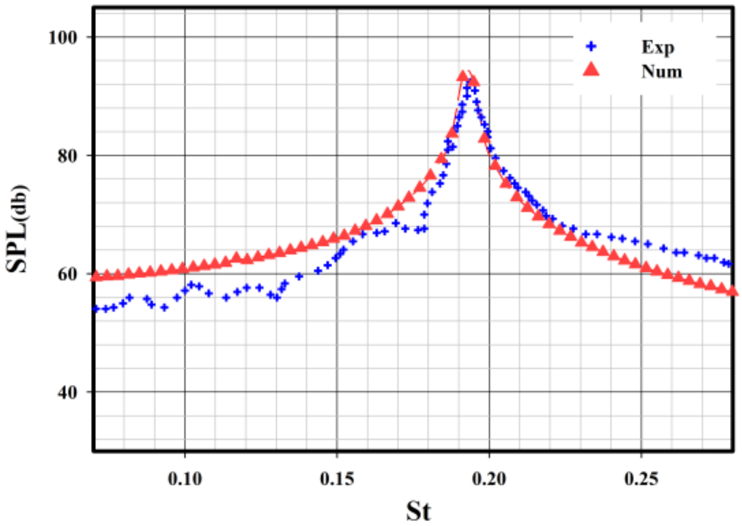

Fig. 3. Sound pressure level in terms of Strouhal number [1]

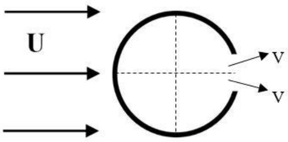

Fig. 4. Schematic of the blowing slot

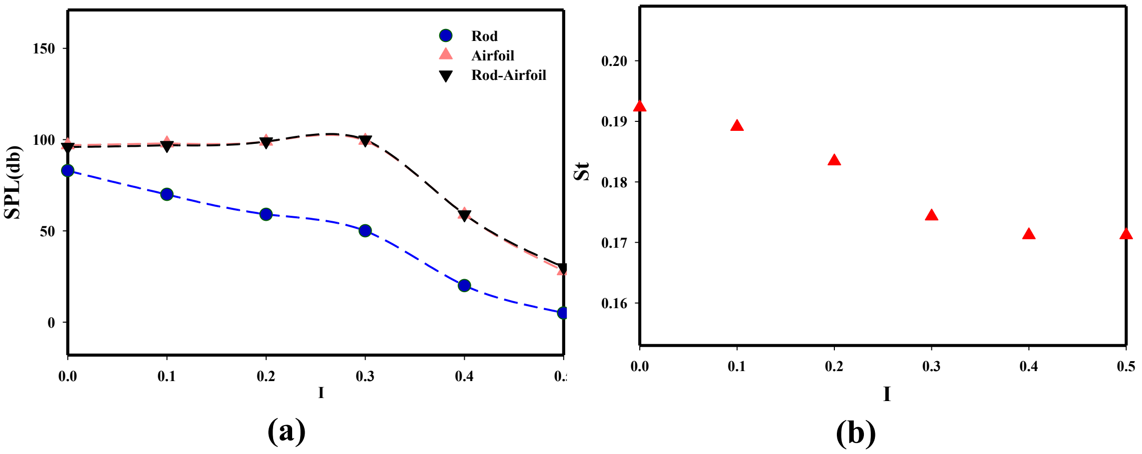

Fig. 5. Diagram of the effect of blowing on the back of the rod surface on (a) Sound pressure level of rod, airfoil, and rod-airfoil, (b) Strouhal number

Computational domain meshing is structured. Fig. 2 shows a close view of the flow network around the rod-airfoil.

In the present study, a two-dimensional URANS approach is implemented to simulate aeroacoustic where the k-ω-SST turbulence model has been employed. In the unsteady simulation process, a time step of 0.0001s was used and the total simulation time was 0.5 s. According to Figure 3, a comparison of the Sound Pressure Level (*SPL*) versus Strouhal number between experimental and numerical results indicates the reliability of the present simulation.

In order to control and reduce the noise caused by the flow, the blowing slot is applied on the back of the rod surface (with a length equal to 0.1 of the rod circumference) (Fig. 4). Also, in the present study, the effects of blowing intensity, which is defined as $I = V / U$ (V blowing velocity and U velocity at infinity) and changed from 0 to 0.5 ($I = 0$ - 0.5) are investigated on the flow structure and aerodynamic noise.

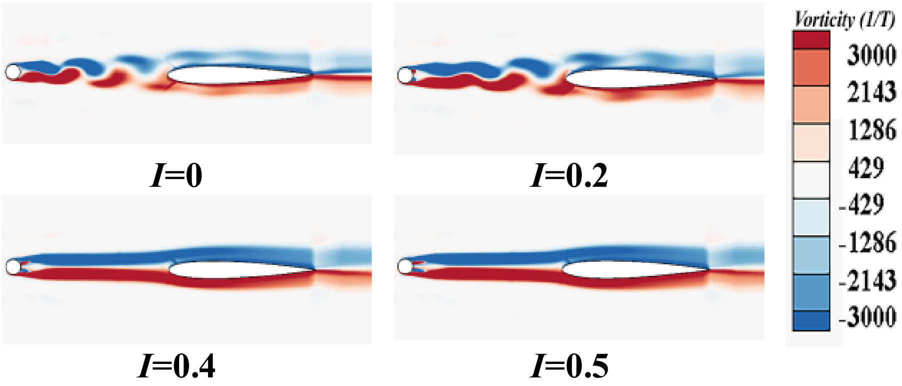

Fig. 6. Vorticity distribution by applying the blowing and increasing its intensity around the rod and airfoil

4- Results and Discussion

Variations in the *SPL* and the Strouhal number in different cases are shown in Fig. 5. Fig. 5(a) shows that increasing the intensity of the blowing from 0 to 0.5 reduces the maximum noise generated by the rod by 90% and the noise generated from the airfoil and the rod-airfoil by 64%. Also, according to Fig. 5(b), it is observed a decrease of 10% in the Strouhal number.

Fig. 6 shows the vorticity contours in different cases. According to Fig. 6, it can be seen that the flow passing the rod causes the vortex shedding and form von-Karman Street. It is quite clear that at $I = 0$ (without applying the blowing), the flow is broken into small structures after separation and is placed on the airfoil. By applying the blowing and increasing its intensity, the occurrence of periodic vortices decreases. In $I = 0.4$ and $I = 0.5$, no vortices have been created at the bottom of the rod and von-Karman Street has not been formed. Due to the lack of vortices in $I = 0.4$ and $I = 0.5$ in the flow structure, it is expected a further reduction in production noise. A review of Fig. 5 confirms this result.

5- Conclusions

In the present paper, a numerical study of the effect of the blowing control method in the rod on aerodynamic noise and flow structure in a rod-airfoil was discussed. For this purpose, a slot located back of the rod surface was employed. Flow blowing was performed at different intensities from 10% to 50% of the inlet velocity. The acoustic mechanism is often periodic that directly relates to the vortex shedding at the rod downstream. The increase in the blowing intensity resulted in the alleviation of the vortex formation. The instability of von-Karman Street around the airfoil leading edge is symmetrical that has been minimized by applying the control method. This reduces the oscillating forces and then the aerodynamic noise

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HOW TO CITE THIS ARTICLE

Sarallah Abbasi, Mohammad Souri , Effect of blowing on flow-induced noise reduction in a rod-airfoil. Amirkabir J. Mech. Eng., 53(special issue 3) (2021). 431-434.

DOI: 10.22060/mej.2020.17054.6504