Experimental Investigation of the Turbulence Effect of Incoming Flow on Unsteady Pressure Field and Flow-Induced Noise Around Circular Cylinder

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ABSTRACT: Surface pressure fluctuations on a circular cylinder model are the main sources of far-field noise emitted and have complex physical behavior. So far, limited studies have been devoted to identifying the unsteady surface pressure behavior, especially for turbulence incident flow. In the present study to measure the surface pressure fluctuations under both smooth and turbulence incoming flows, a circular cylinder with an outer diameter of 22mm has been used. In order to change the turbulence characteristics of free stream incoming flow, different biplane grids with square meshes were designed. Power spectral density, coherence, autocorrelation and cross-correlation, spanwise length scale, and convection velocity were different interesting parameters which were calculated using measured unsteady pressures in order to better clarify the flow structure and flow noise around the model. The results revealed that the energy level of both tonal and broadband noises is increased when incident flow changes from smooth to turbulent. Moreover, the tonal noise frequency in the turbulence flow ($f' = 88\,\mathrm{Hz}$) shifts to low frequencies compared to that of smooth flow ($f = 98\,\mathrm{Hz}$). Furthermore, results showed that the physical size of eddies and their convection velocity in turbulence flow are greater than corresponding values for smooth flow.

1- Introduction

Many components of bluff body structures can be characterized as circular cylinders of different diameter, aspect ratio, and alignment. Examples of these structures are the rotors for wind turbines, cables, towers, buildings, chimneys, distillation towers, landing gear parts and so on. The noise radiated from flow around circular cylinders has been a topic of interest in wind engineering research and has been an important issue in the design of structures located near high wind velocities. Investigating the flow around a circular cylinder provides a good starting point for flow-solid interaction. Moreover, understanding the nature of acoustic noise emitted by a circular cylinder is beneficial in the determination of noise sources of bluff body structures.

The aerodynamic sound generated from flow around a circular cylinder consists of the narrowband and broadband noises. The narrow band noise or Aeolian tone corresponds to vortex shedding frequency and is manifested as fluctuating pressure on the surface of the body and in the resulting unsteady wake. Often the fluctuations are periodic, leading to an Aeolian tone which first recognized by Strouhal [1]. Strouhal's general conclusions further confirmed by Lord Rayleigh [2] in 1879. Observation of the staggered vortex street in the wake of a cylinder by Bernard [4] in 1908 and the theoretical demonstration of its stability by von Karmin [5] in 1912 led von Kruger and Lauth [6], Borne [7], and Rayleigh

[8] to associate the tones and vibration with periodic vortex shedding.

The main studies related to the aerodynamic noise of circular cylinders are mostly conducted for the laminar or smooth incident flow while many structures including circular cylinders are normally located in the turbulent incident flow field. Davis and Pan [8] were one of the few researchers that studied the noise generated from a circular cylinder in the turbulent jet. However, their experimental study devoted to measure far field noise. Therefore, in the present study, the characteristics and properties of aerodynamic noise are investigated by measuring surface pressure fluctuations acting on a circular cylinder model under both laminar and turbulent incident flows. The model equipped with several azimuthal and spanwise miniature condenser microphones, Pa-WM-61A, to measure surface pressure fluctuations. Moreover, pressure fluctuations are used to calculate different interesting parameters such as power spectral density, azimuthal and spanwise coherences, spanwise length scale and convection velocity of eddies. These parameters were used to characterize the physics of the flow around the model under consideration.

2. Experimental Setup

The experiments were carried out in an open subsonic wind tunnel of Yazd University with a test section size of 46 × 46 × 240cm. At the maximum air velocity of 20 m/s, the free

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stream turbulence intensity has been measured to be less than 0.3%. Due to contamination of the surface-pressure signals by facility background noise, the measurements of wall-pressure fluctuations are often carried out at free jet of the wind tunnel. In the present wind tunnel, the centrifugal fan is forward inclined blades type which creates nearly low to moderate broadband noise. However, by covering the internal surfaces of the test section with an appropriate porous material, the background noise of the facility is reduced up to 15 dB.

The circular cylinder used in the present work has a diameter of 22 mm and a span of 500 mm. The model is composed of a middle body and two similar side parts, which allow spanwise and azimuthal microphones to be installed inside the middle part. The two side parts are attached to the main body by two side bushes. All parts of the model were manufactured from stainless steel to ensure having the necessary strength and surface finishing. The experiments were conducted at three different free stream velocities, 10, 15, and 20 m/s. The blockage ratio of the cylinder model is less than 5% for all the experiments and hence the wind tunnel walls effects on the measured quantities are negligible. View of the circular cylinder model located in the free jet is shown in Fig. 1.
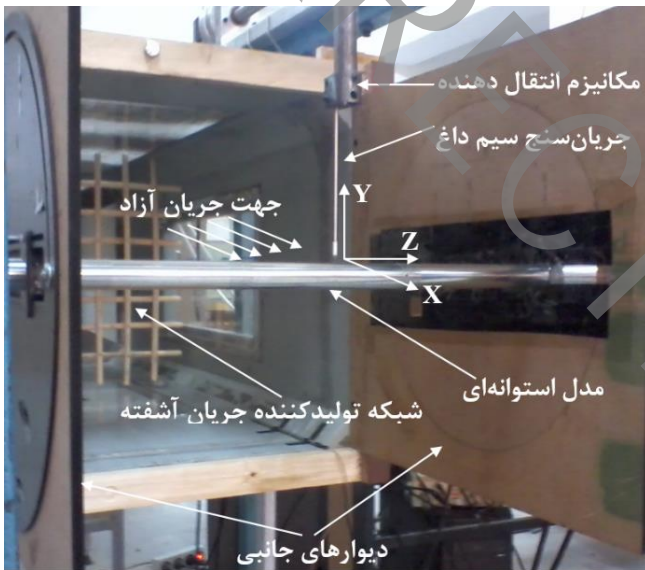

Fig. 1. Cylindrical model in the free turbulence jet

3. Results and Discussion

The surface pressure power spectral density measured by microphone No. 15 (at z/D=0 and azimuthal angle of) referenced to p0 = 20 μPa for laminar and turbulent incident flows is shown in figure 2 for various upstream grid sizes. The microphone correction function applied in all data. The wind tunnel background noise power spectral density is also shown in this figure for comparison. As can be seen, results in all frequency range are not contaminated with the background noise. Fig. 2 also shows that the tonal noise at a velocity of 10m/s for laminar and turbulent flows occurs at vortex shedding frequencies of 98Hz and 88Hz, respectively. As a result, in the turbulent incident flow, fundamental frequency shifts to lower frequency compared to that in the

laminar incident flow condition. In both smooth and turbulent flows, first and second harmonics are also visible at two and three times vortex shedding frequency. Furthermore, it may be seen from Fig. 2 that the energy level of surface pressure fluctuations in the turbulent flow is higher than that of the laminar flow case.
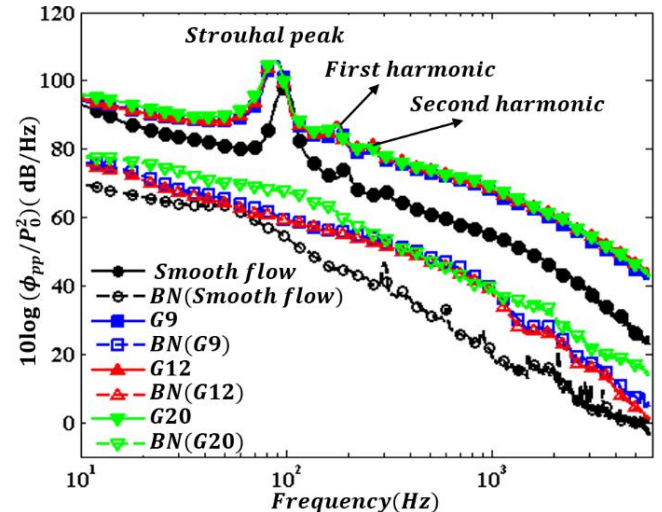

Fig. 2. Surface pressure spectra at z/D=0 and wind tunnel background noise

In order to characterize the physical size of vortices, a variation of spanwise coherence measured between spanwise microphones No. 1 to 2 ( ) at a velocity of 10m/s for both laminar and turbulent incident flows are depicted in Fig. 3. Results show that the coherence at low frequency is bigger than that of high frequency and it can be concluded that eddies responsible for creating pressure fluctuations at low frequency are bigger in size. However, the maximum coherence takes place at the fundamental frequency and its harmonics for both flow regimes considered. Moreover, increasing turbulence intensity and turbulence length scale results in a higher coherence value which is a sign of bigger structures in this condition.
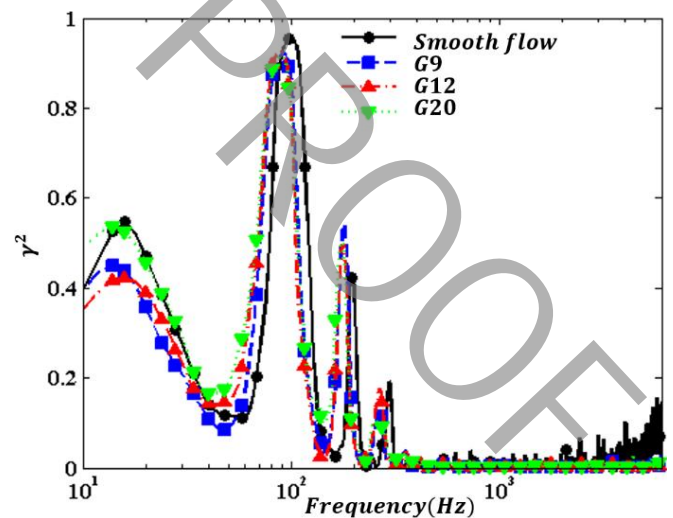

Fig. 3. Lateral coherence variations for $\eta_z = 15\,mm$ at 10 m/s

4. Conclusions

In the present study, aerodynamic noise due to the flow around a circular cylinder model was measured using several azimuthal and spanwise miniature condenser microphones mounted on the model. All the experiments were carried out in a subsonic wind tunnel for incident air velocity of 10m/s in both laminar and turbulent flow conditions. The results showed that tonal noise emitted in turbulent flow occurs at a lower frequency compared to the laminar incident flow which is an indication of Strouhal number reduction. Moreover, the lateral coherences results showed that bigger eddies have higher energy content and higher lifespan compared to the smaller eddies. It is also noted that maximum coherence takes place at the fundamental frequency and their harmonics for both flow regimes considered.

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