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Experimental investigations on flow induced vibration of an externally excited flexible plate

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ABSTRACT

Flow-induced vibration of a harmonically actuated flexible plate in the wake of an upstream bluff body is experimentally investigated. The experiments are performed in an open-ended wind tunnel. A flexible plate trailing a bluff body is under fluid induced excitation due to the flowing fluid. The additional external excitation to the trailing plate is applied using an electro-magnetic exciter. The frequency and amplitude of the external harmonic excitation are selected as variable parameters in the experiments and their effect on the plate vibration and is investigated. To know the nature of acoustic pressure wave generated from the vibrating system, near-field acoustic pressure is also measured. A laser vibrometer, a pressure microphone and a high-speed camera are employed to measure the plate vibration, pressure signal, and instantaneous images of the plate motion respectively. The results obtained indicate that the dynamics of the plate is influenced by both the flow-induced excitation and external harmonic excitation. When frequency of the two excitations is close enough, a large vibration level and a high tonal sound pressure are observed. At higher amplitude of external excitation, the frequency component corresponding to the flow-induced excitation is found to reduce significantly in the frequency spectrum of the vibration signal. It is observed that, for certain range of excitation frequency, the plate vibration first reduces, reaches a minimum value and then increases with increase in the level of external excitation. A fair qualitative agreement of the experimental results with numerical simulation result of the past study has been noted. In addition to the experiments, the role of phase difference between the flow-induced excitation generated from the front obstacle and externally applied harmonic excitation is investigated through numerical simulations. The result obtained reveals that the final steady state vibration of the coupled system is independent of the initial phase difference between the two excitations.

1. Introduction

A flexible structure in flow stream exhibits vibration and generates pressure perturbations. The flow field applies unsteady pressure field on the flexible structure that responds through dynamic response. The motion of the structure in turn modifies surrounding fluid pressure distribution. A two-way interaction is developed between the fluid and the

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structure and the strength and level of interaction governs the overall dynamics of the coupled system. In some of the applications viz., aircrafts, micro-air vehicles, wind turbines etc., the structure in the flow experiences dual excitation, one from the external aerodynamic load and second from inherent forces generated within the structure. The source of inherent excitation may be a driving engine mounted on the structure or other mechanisms that generate external excitation independent of the dynamics of the structure; e.g., rotating engines on the wings of an aircraft. These inherent excitations may influence the aeroacoustic performance of the system. Therefore, consideration of both excitations is an important aspect in design of a stable and acoustically quieter system.

Flow induced vibration can be categorized on the basis of the way excitation is applied by the flow field on the structure. Movement induced excitation (MIE) is a self-induced effect that leads to aeroelastic flutter of the structure [1]. The second kind of excitation is Extraneously Induced Excitation (EIE), which is due to an external forcing field generated from an upstream source, viz., turbulence in the incoming flow; while Instability Induced Excitation (IIE) is due to flow instability generated from a bluff body in the flow [2]. One of the common test model to demonstrate flow-induced vibration is a plate with an upstream obstacle, wherein, the unsteady flow generated from the upstream obstacle interact with the trailing plate and induces vibration. A flexible plate behind the upstream obstacle significantly modifies the wake of the front bluff body. The gap between the obstacle and trailing plate and flexibility of the plate are some of the important parameters that influence the overall dynamics of the system [3]. A rigid trailing plate may suppress the vortex shedding from the front bluff body; however, a flexible plate responds to the forcing flow field generated from the upstream obstacle and exhibits oscillations that are termed Vortex-Induced Vibration (VIV). A significant work has been done in the area of vortex-induced vibration [4]. Lee and You [5] have studied the dynamics of a flexible plate attached at the rear side of a square body. They have found that based on the flow velocity and stiffness of the plate, the vortex shedding frequency of the coupled fluid–structure system gets synchronized with the natural frequency of the plate and resonant vibration is observed. The mode of plate vibration changes with increase in the flow velocity. Similarly, based on the gap between the trailing plate and front obstacle, Lau et al. [3] have explained a resonance condition of the coupled system. Recently, Nayer et al. [6] have experimentally and numerically studied the flow-induced vibration of an assembly of rubber sheet with a circular cylinder in a water tunnel. They reported a lock-in phenomenon of the fluid and structure for a range of flow velocity. In majority of these works, the focus of the research has been either on the study of dynamics of the structure in flow or on the development of an effective methodology to simulate the complex phenomenon of fluid–structure interaction.

In many of the studies, the research interest is extended to estimate the acoustic wave field generated from the flow-induced vibration. Graham [7] studied the aerodynamic sound generated from an elastic plate excited by the boundary layer. Similarly, Tang et al. [8] studied the vibration and acoustic due to interaction of unsteady vortex field with a flexible panel. They modeled the flow field using potential flow approach. However, the bi-directional interaction of coupled fluid–structure system is not accounted. In a detailed study, Schafer et al. [9] have carried out a numerical and experimental study of flow-induced vibration and acoustics of a stretched membrane in a high Reynolds number flow stream. Purohit et al. [10] have investigated the vibration and acoustics of a flexible plate with a square bluff body in a low Reynolds number flow. In most of the past studies, the source of the structural vibration is surrounding flow perturbations. However, investigations related to the combined effect of inherent excitation and flow excitation are rare. Manela [11] has examined the dynamics and acoustic radiation of a flexible thin airfoil exhibiting small-amplitude sinusoidal pitching motion. In his work, the fluid–structure interaction is solved by using a potential flow theory and for an excitation frequency close to the eigenfrequency of the system, high amplitude airfoil motion and corresponding acoustic radiation is reported. In a similar work, Manela [12] has estimated the linearized response of a wing actuating with translational and rotational motion from its leading edge.

Recently, the authors [13] have carried out numerical investigations on flow-induced vibration and acoustics from an externally excited flexible plate in a low Reynolds number and low Mach number flow stream. A two-way fluid structure interaction is accounted and non-linear Navier–Stokes equations are solved to calculate the flow field. The authors have found that the dynamic performance of the coupled system is influenced by both the flow-induced and external excitations. For a particular combination of frequency and amplitude of the external excitation, a reduction in overall vibration and so in the acoustics generation is observed. However, to the best knowledge of the authors, an experimental study of flow-induced vibration from an externally actuated flexible structure is not reported in the open literature.

An experimental study of vortex-induced vibration on a harmonically excited flexible plate with a front obstacle is reported in this paper. The inherent excitations are realized by applying an external excitation through an electro-magnetic exciter that is connected to a point on the surface of flexible plate. The experiments are conducted in an open-ended wind tunnel. A laser based vibration sensor and pressure microphone are used to measure vibration and near-field acoustic pressure respectively. A high-speed camera is used to capture instantaneous images of the vibrating plate. The results obtained are qualitatively compared with the numerical results obtained in the previous study carried out by the authors. Additionally, in order to investigate the effect of phase difference between the flow-induced excitation and external excitations, some numerical simulations are also performed. The details of the experimental setup and measurement techniques are given in Section 2. Section 3 discusses the experimental results. The numerical simulations for estimating the role of phase difference of the two excitations are discussed in Section 4.