A Numerical Method to predict fluid-structure interaction of flow past an elastically mounted circular cylinder

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ABSTRACT
In this paper, a fluid-structure interaction problem is investigated using a strongly coupled numerical method simultaneously solving the Navier-Stokes equations for the fluid phase and the equation of motion for the solid phase. The solution of the Navier-Stokes equations is accomplished through a 2D finite volume method which uses a 3-step Runge-Kutta time integration scheme and second-order central differences for convective and diffusive terms. The structural solver utilizes Hamming’s 4th order-predictor method in order to integrate the equation of motion. Both solvers are strongly coupled in the time domain, which means that communication between solvers takes place as inner iterations within the same time step. A direct forcing immersed boundary method is employed that connects fluid and solid phase at discrete forcing points and ensures the no-slip condition on the cylinder and provides the fluid forces to the structural solver. The method is validated through numerical simulations of a freely vibrating rigid cylinder in cross-stream direction at different Reynolds numbers varying from 90 to 140 for experimental data are available. The method provides a good estimation of the vortex lock in regime and the numerical results are in good agreement with the experiments.

KEY WORDS: Fluid-structure interaction; immersed boundary method; strong coupling; finite volume method.

INTRODUCTION
In many engineering applications, fluid structure interaction phenomena play a key role in the dynamic behavior of a structure (e.g., Aircraft, wind turbines, suspension bridges...etc) Many natural and man-made transportation systems and/or machinery often involve fluid-structure interaction (FSI). Examples include the flapping of butterflies and birds and kites, the swaying of tree branches and sea weeds due to wind and current flow, respectively, blood circulation, the opening and closing of heart valves, fish swimming, turbo-machinery, jet engines, the lifting by airplane wings, floating of boats on the ocean and river and sloshing in the flexible containers. Therefore, the study of FSI (or in fluid dynamics so called Vortex-Induced Vibration (VIV)) is a part of a number of disciplines associated with fluid mechanics, acoustics, structural mechanics, computational fluid dynamics (CFD), statistics and vibrations.

VIV’s for flow past bluff bodies which are immersed into the flows has been studied extensively and observed for centuries. Leonardo Da Vinci observed this phenomenon and named it as “Aeolian Tones”, circa 1500 A.D., but researchers are still today trying to identify the effects of the mechanics of vortex structures. Von Karman studied the Tacoma Narrows bridge collapse in 1940 and asserted that the cause of the destruction was as a consequence of VIV. As fluid passes over a bluff body, large vibration of the structure can be observed when the fluid dynamic forces on the body increase through a nonlinear interactive process. The magnified vibration can control the flow pattern and can be further increased. Berger and Wille (1972) and Parkinson (1972) discussed these self-oscillatory, nonlinear body wake systems. The simultaneous behavior of vibrations between vortex and vibration frequencies is a characteristic of fluid-structure interaction and often called “lock-in”. This means that when the amplitude of structural oscillation passes a critical threshold, structural vibration frequency becomes identical to the vortex-shedding frequency fs, which differs from that estimated by Strouhal relationship. In other words, synchronization occurs as the natural Strouhal frequency which is a characteristic of vortex shedding from a stationary cylinder is repressed. In addition to that, the lock-in effect produces strong correlation of vortex-shedding. This kind of effect is also seen when a cylinder is forced to oscillate in a sinusoidal manner under a uniform current. This time, lock-in takes place either when the oscillation frequency on cross-stream direction becomes equal to the Strouhal frequency or when the driving frequency in the streamwise direction approaches twice the Strouhal frequency (Anagnostopoulos and Bearman, 1992). Therefore, nonlinear behavior of the body-wake systems is noticed as the cylinder vibrates transversely to the fluid flow.