Flow-Induced Vibrations of a Circular Cylinder and an Upstream D-Cylinder of various Elliptical Ratios

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I. INTRODUCTION & OBJECTIVE

The dynamics of flow-induced vibrations (FIV) of bluff bodies remain a central topic in fluid–structure interaction research due to their practical relevance in offshore, civil, and energy systems. While canonical studies have examined behaviour of isolated circular and D-section cylinders extensively, the coupled response of these bodies in tandem configurations is less understood.The present work highlights that coupling effects in tandem arrangements which introduce additional complexity to both the wake dynamics and structural response for both cylinders. In particular, when a D-section cylinder is placed upstream of a circular cylinder, the wake interference gives rise to complex vibration characteristics that are highly sensitive to the body geometry. The elliptical ratio of the upstream D-section governs the wake topology, modifies vortex shedding patterns, and consequently alters the amplitude and frequency response of the downstream circular cylinder. Elucidating its influence on fluid–structure coupling provides new insight into the mechanisms governing multi-body VIV involving closely spaced structures exposed to crossflow.

The paper investigates numerically the Flow-Induced coupled Vibration of both elastically mounted D-section with different elliptical ratios (ER) and circular cylinder in tandem arrangement. The upstream cylinder has a varying ER values of 0.25,0.5,1.0 & 2.0 , the two cylinders are placed in tandem arrangement with varying gap ratios of G^* = 0.1,0.5 & 2.0. The circular cylinder is moved from wake interference region to proximity-wake interference region by decreasing the gap ratio.

II. METHODS OF ANALYSIS

Our computational domain consists of an both elastically mounted upstream D-section cylinder with downstream circular cylinder in tandem arrangement with equal mass ratio $(m^* = 2.0)$ with damping ratio ζ = 0.005 and diameter (D) in a free stream flow, as shown in Fig. 1(a). The dimensions of the domain, as well as the location of the outer limits relative to the center of the upstream cylinder, and the boundary conditions are presented in Fig1(a). The reduced velocity is varied within the range $(U^* \in [3-12])$, while the Reynolds number (Re = 100) remains constant. The computational method employs an in-house LS-IIM code [3]), LS-IIM involves a block-iterative hybrid Lagrangian–Eulerian method coupled with the finite volume method [2],[1] on a non-uniform Cartesian grid. The fluid flow is modeled by the Navier–Stokes equations, cylinder motion by a linear oscillator, and the fluid-structure interface dynamics are governed by specific non-dimensional boundary conditions.

III. RESULTS AND DISCUSSION

The simulations yield the following results, Fig. $1(b)-(e)$: (i) For upstream cylinders with ER = 0.25 and 0.5, similar behavior is observed at $G^* = 0.1$ and 0.5, where the vibration response shows an increase in peak amplitude and an expanded lock-in region, while for $G^* = 2.0$, the response resembles that of the isolated case.(ii) For ER = 1.0 and 2.0, the upstream cylinders behave similarly at $G^* = 0.5$ and 2.0, with both showing a galloping response similar to the isolated case. However, at $G^* = 0.1$, the cylinders with ER = 1.0 and 2.0 experience galloping suppression, though after a critical U^*, the cylinder with ER = 2.0 exhibits an increase in amplitude. (iii) For the downstream circular cylinder, the vibration response varies with the ER of the upstream cylinder for each G^* value. At $G^* = 2.0$, the circular cylinder undergoes wake-induced vibration for ER = 0.25, 0.5, and 1.0, whereas for ER = 2.0, it shows a gradually increasing trend.(iv) At $G^* = 0.5$, the circular cylinder exhibits a monotonically increasing trend similar to galloping for ER = 1.0 and 2.0, while for ER = 0.25 and 0.5, it shows wake-induced vibration. At $G^* = 0.1$, for ER = 0.25 and 0.5, the vibration response of the circular cylinder is similar to that of the upstream cylinder, while for ER = 1.0 and 2.0, it exhibits a modified-VIV response.

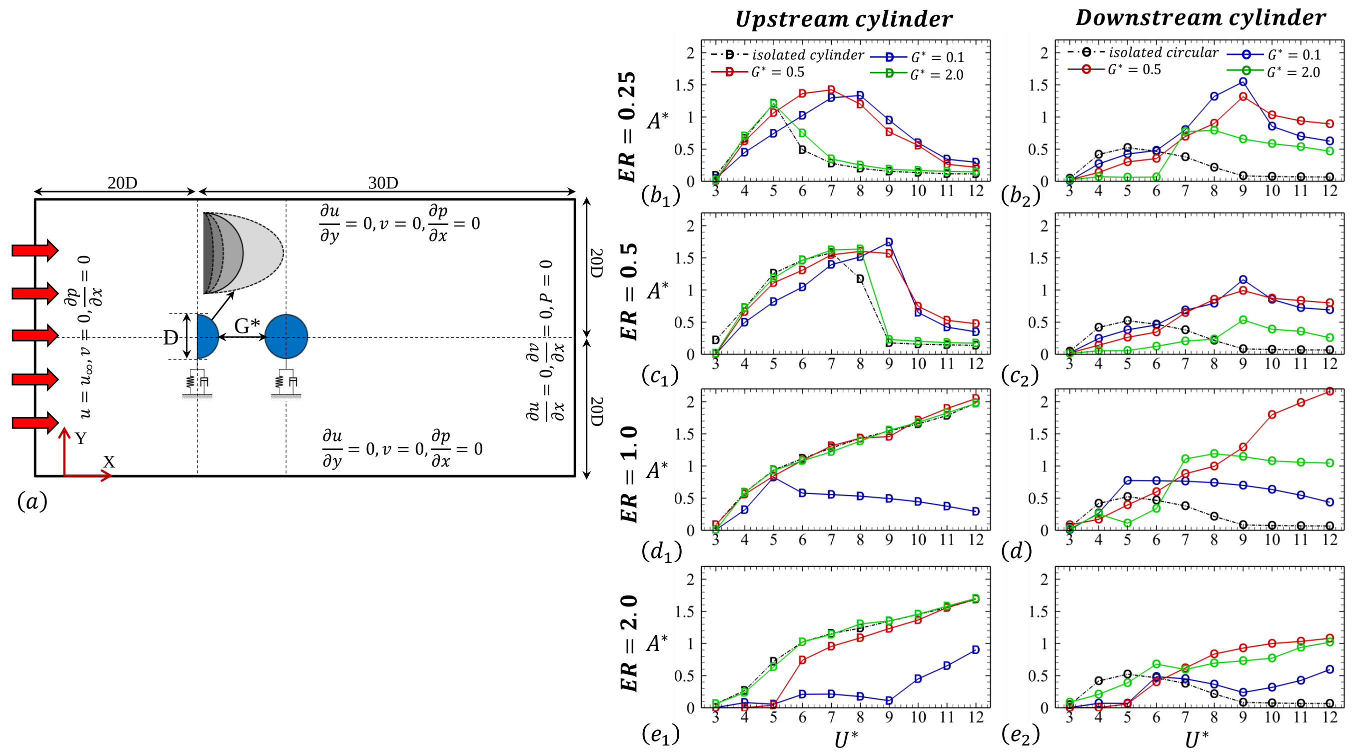

Figure 1: **(a) Computational setup for free-stream flow across an both elastically mounted D-cylinder (with different ER) and circular cylinder in tandem arrangement.Effect of non-dimensional gap G^* and reduced velocity U^*. Amplitude response A^* of (1) Upstream and (2) Downstream cylinders compared with their respective isolated counterpart for ER= 0.25, 0.5, 1.0 & 2.0 respectively for various gap ratios G^*= 0.1, 0.5 $ 2.0**

IV. CONCLUSIONS

The present study explores the impact of elliptical ratios (ER) of upstream cylinder and different gap ratios (G^*) on the vibration responses of elastically mounted tandem cylinders.The elliptical ratio (ER) plays a critical role in modifying the vibrational response. Smaller ER values resulted in higher vibration amplitudes and more pronounced peaks at specific reduced velocities, while larger ER values led to more stable and consistent vibrational behavior. At smallest gap ($G^* = 0.1$), the proximity effect led to substantial wake interference, amplifying the vibration response of the downstream cylinder. The interaction was most pronounced when the gap was minimal, with enhanced vibrations and erratic behavior observed in the amplitude response. As the gap ratio increased to $G^* = 0.5$, the wake interference diminished, but the downstream cylinder still experienced notable wake effects, resulting in elevated vibrational amplitudes compared to isolated cylinders. For larger gap ($G^* = 2.0$), the interaction between the upstream and downstream cylinders was significantly reduced, allowing both cylinders to behave more independently. The vibrational characteristics of the downstream cylinder approached those of the isolated case, with minimal wake interference from the upstream body.This highlights the importance of both geometric and flow parameters in determining the vibrational dynamics of tandem-mounted bodies.

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