ERCOFTAC Symposium on "Multiphysics critical flow dynamics involving moving/ deformable structures with design applications", Toulouse, France, 7-8-9 June 2023

Instabilities in the wake of multiple freely-oscillating cylinders

THÉO MOUYEN, JAVIER SIERRA-AUSIN, DAVID FABRE, FLAVIO GIANNETTI
Address of author(s)
tmouyen@unisa.it, javier.sierra@imft.fr, david.fabre@imft.fr, fgiannetti@unisa.it

Introduction

Vortex induced vibrations are of great interest to many fields of engineering. One of their latests practical application worth mentioning is the design of submerged deformable structures that are able to convert energy from marine currents and waves (see for instance the Wave Carpet project of Caltech University). Although a lot of VIV systems, as the case of a single oscillating cylinder (Williamson & Govardhan (2004)), have been extensively studied, some other remain widely misunderstood. The case of multiple cylinders has for example been mainly studied for fixed cylinders. Recently, Hosseini (2020) used an immersed boundary method to explore the flow past multiple rigidly-mounted cylinders. Tandems of elastically-mounted cylinders have also been studied. For instance, Griffith, Jacono, Sheridan & Leontini (2017) have mapped the flow patterns for two cylinders with respect to the distance separating them. We propose an Arbitrary Lagrangian Eulerian method to further explore the dynamics of multiple freely-oscillating cylinders.

1 Methodology

The Arbitrary Lagrangian Eulerian (ALE) method allows to conform the fluid domain with the solid domain at the fluid-solid interface. By introducing a displacement field $\hat{\boldsymbol{\xi}}$ and an extension displacement field $\hat{\boldsymbol{\xi}}_e$, the solid deformation and fluid velocity can respectively be expressed in Lagrangian coordinates. All the unknowns are therefore expressed in a stress free configuration. The motion y_n of each cylinder in the transversal direction is governed by the following equation

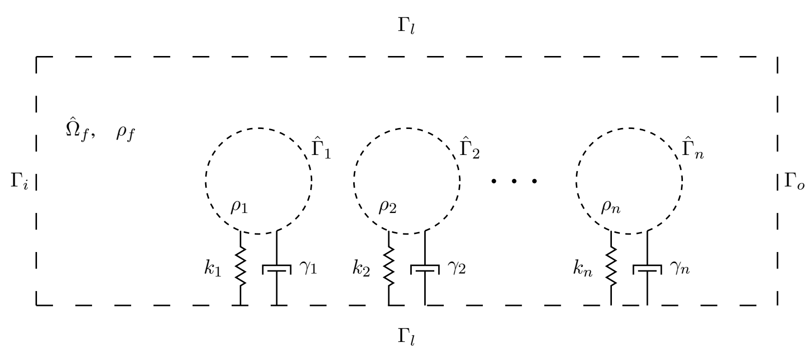

Figure 1: Array of n spring mounted cylinders with densities, spring stiffness and damping parameter: ρ_n, k_n and γ_n. The cylinders are immersed in a fluid domain $\hat{\Omega}_f$ of density ρ_f. The domain is delimited by inlet and outlet boundaries, Γ_i and Γ_o as well as lateral boundaries Γ_l.

$$\ddot{y}_n + \frac{4\pi\gamma_n}{U_n^*}\dot{y}_n + \left(\frac{2\pi}{U_n^*}\right)^2 y_n = \frac{2C_{y_n}(t)}{\pi m_n^*} \tag{1}$$

where U^* is the reduced velocity, $C_{y_n}(t)$ is the vertical force coefficient and m_n^* the mass ratio between the cylinder and fluid densities.

Following the method used by Pfister, Marquet, & Carini (2019) a weak formulation of the ALE system is written, for N spring-mounted cylinders. Together, equations (1) and the weak formulation can be written as a system of $4N+5$ equations, N being the number of cylinders. The $4N+5$ unknowns of our system can be decomposed into a three field problem (cylinder, extension and fluid). Defining $z_n = \dfrac{\partial y_n}{\partial t}$ as the velocity of a cylinder, we solve our system and obtain the the following unknowns $\hat{\boldsymbol{q}}_c = (z_1, ..., z_n, y_1, ..., y_n)$, $\hat{\boldsymbol{q}}_e = \left(\hat{\boldsymbol{\xi}}_e, \hat{\boldsymbol{\lambda}}_{e_1}, ..., \hat{\boldsymbol{\lambda}}_{e_n}\right)$ and $\hat{\boldsymbol{q}}_f = (\hat{\boldsymbol{u}}, \hat{p}, \hat{\boldsymbol{\lambda}}_1, ..., \hat{\boldsymbol{\lambda}}_n)$.

2 Outline

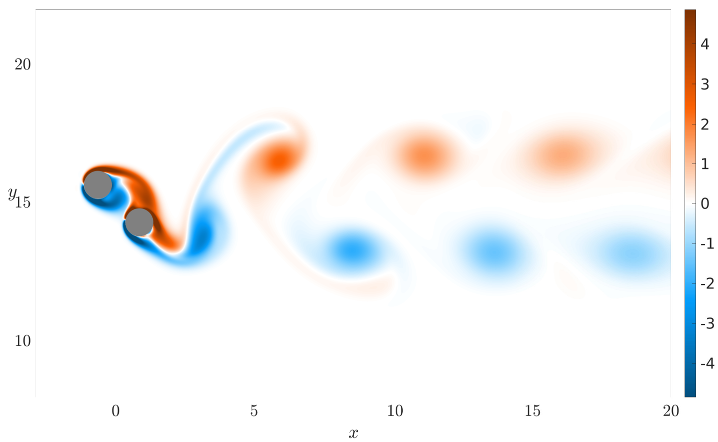

Figure 2: Vorticity field of a tandem of elastically mounted cylinders at $Re = 100$.

Tirri, Nitti, Sierra-Ausin, Giannetti, & de Tullio (2023) recently showed that for low values of U^*, one mode linked to the stationary wake is unstable. At $U^* = 4$ the second mode loses stability which marks the beginning of the lock-in region. A beating phenomenon arises from the modes interaction at $U^* = 5$. Finally, for larger values of the reduced velocity, one dominant mode induces large oscillations of the second cylinder which then governs the dynamics (see Figure 2). To extend these results to multiple elastically-mounted cylinders, a parametric study will be presented. The influence of the number of cylinders, and their characteristics, on the wake dynamics will be shown.

References

1 Williamson, C.H.K and Govardhan, R:
Vortex-induced vibrations. Annual review of fluid mechanics, **36** (2004) 413–455.

2 Hosseini, N., M. D. Griffith, and J. S. Leontini: The flow past large numbers of cylinders in tandem. Journal of Fluids and Structures, **98** (2020) 103103.

3 Pfister, J. L., Marquet, O., Carini, M.: Linear stability analysis of strongly coupled fluid–structure problems with the Arbitrary-Lagrangian–Eulerian method. Computer Methods in Applied Mechanics and Engineering, **355** (2019) 663–689.

4 Griffith, M. D., Jacono, D. L., Sheridan, J., & Leontini, J. S.: Flow-induced vibration of two cylinders in tandem and staggered arrangements. Journal of Fluid Mechanics, **833** (2017) 98-130.

5 Tirri, A., Nitti, A., Sierra-Ausin, J., Giannetti, F., & de Tullio, M. D.: Linear stability analysis of fluid–structure interaction problems with an immersed boundary method. Journal of Fluids and Structures, **117** (2023) 103830.