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Suppression of vortex-induced vibrations by fairings: A numerical study

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ABSTRACT

Fairings are nearly neutrally buoyant devices, fitted along the axis of long circular risers to suppress vortex-induced vibrations (VIV) and possibly reduce the drag force. Here we study numerically how VIV can be practically eliminated by using free-to-rotate fairings. Since the rotational inertia is low for the fairings, direct numerical simulations based on standard fluid–structure interaction algorithms may fail because of the so-called added mass effect. To resolve this problem we introduce fictitious methods and successfully stabilize the simulations. We then investigate the effect of rotational friction C_f on the stabilization effect of the fairings. In particular through two-dimensional (2D) simulations we find that when the Reynolds number is low ($\mathrm{Re}=100$), $C_f=0$ is the most effective choice in suppressing VIV. Moreover, at this low Reynolds number there exists a critical value of C_f around which large oscillations and non-symmetric trajectories are observed. On the other hand, at higher Reynolds number ($\mathrm{Re}=500$) a different behavior emerges, i.e. VIV are suppressed continuously as C_f increases. At $\mathrm{Re}=1000$, we perform 3D simulations to investigate the effects of three-dimensionality of the flow on the vibration and rotation responses. In this work we quantify numerically for the first time various salient features of free-to-rotate devices for VIV suppression and relate them to modified flow structures in the near wake.

1. Introduction

In deepwater offshore oil operations, riser interference and vortex-induced vibrations (VIV) are severe problems for risers, umbilicals and tendons in areas of strong currents. Such industry demands have greatly motivated the investigations of various methods for suppressing vortex-induced vibrations either experimentally (Cimbala and Garg, 1991; Owen et al., 2001; Assi et al., 2009, 2010, 2011; Korkischko and Meneghini, 2010) or numerically (Dong et al., 2008; Baek and Karniadakis, 2009), over the past decades. In theory, an effective VIV suppression device should not only eliminate the

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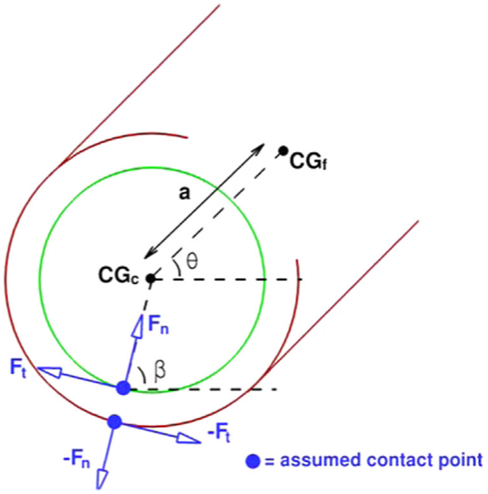

Fig. 1. Coordinate system and symbol definition for fairing and cylinder motions. Here we use green to represent the cylinder and red to represent the fairing, while the contact forces are marked by blue. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

vortex shedding, but also help in reducing the drag force thereby resolving the concern of the loads caused by strong currents. To get a comprehensive review of solutions for VIV suppression, we refer the readers to the works of Zdravkovich (1981) and Every et al. (1982) and the references therein. Among all these VIV suppression solutions, free-to-rotate suppressors such as splitter plates and fairings with different shapes are widely studied and employed to mitigate VIV and avoid interference as they reduce both drag forces and VIV (Cimbala and Garg, 1991; Assi et al., 2009, 2011). Assi et al. (2009) found that with a pair of parallel plates installed on the sides of the cylinder, the maximum VIV suppression and drag reduction occurred, and the level of rotational friction between the fairing and the cylinder played an important role. Specifically, the rotational damping and friction needs to be high enough to stabilize the device and achieve a better suppression performance. This requirement draws attention to the importance of parametric studies in fairing design and analysis. Hence, the critical parameters for fairing stability and performance need to be identified, and the effects of varying Reynolds number needs to be investigated. However, experimentally the hydrodynamic performance evaluation for fairings is done by tank testing, which is expensive and very difficult to find model basis availability. On the other hand, although the rotational friction is found to be a critical factor in the fairing effectiveness, it is difficult to determine it in the experimental tests. Therefore, computational fluid dynamics (CFD) can be employed as a helpful tool for fairing design and analysis, because it avoids schedule issues with testing, reduces the cost of testing, and provides possibilities of investigating the effect of varying rotational friction. In the present work we will contribute to the understanding of a type of fairing (see Fig. 1) employed in industry, by running fluid–structure interaction (FSI) simulations with our general purpose spectral element solver NEKTAR. To the authors' best knowledge, this is the first thorough numerical study of the VIV suppressing performances for varying rotational damping and friction coefficients, and also for a fairing with a pair of parallel plates attached. In the real world applications, the Reynolds number is higher than 10 000, hence requiring careful treatments and also large computational costs in CFD. To gain some insights on the fairing effectiveness while keeping the computational model simple, in this paper we will focus primarily on low Reynolds cases ($Re=100$ and 500), which can be simulated as two-dimensional problems. To evaluate the three-dimensional effects, we also conduct 3D simulations for the case $Re=1000$, which reveals similar trends as the ones observed in 2D simulations at $Re=500$.

In the numerical simulations, we are going to adopt the partitioned method where the fluid–structure interaction system is split into separate fluid and structure solvers, because of its better computational scalability and software modularity. However, the partitioned procedure in the fairing simulations is problematic, because of the so-called added-mass effect (Causin et al., 2005). Especially when the structure is light, or when the fairing has low rotational inertia, the added-mass effect becomes stronger and severely affects the stability of the fluid–structure interaction (FSI) procedure. To resolve these instabilities, a strong coupling is required to impose continuity at the interface at each time step. A number of approaches have been developed more recently to accelerate the convergence of the partitioned algorithm, including the Robin-Robin scheme (Astorino et al., 2009; Badia et al., 2008; Roux and Garaud, 2009), the interface artificial compressibility (Degroote et al., 2010, 2011), the stabilized explicit method (Burman and Fernández, 2007, 2009), and our fictitious methods (Baek and Karniadakis, 2012; Yu et al., 2013). In this work, we will adopt and generalize the fictitious methods, by developing a similar modified governing equation for the fairing rotational equation. In this new *fictitious inertia method*, additional acceleration terms are introduced in the structure solver to balance the added-mass effect caused by low rotational inertia and to provide further stabilization for problems with large fairing rotations.

The paper is organized as follows. In Section 2 we describe the FSI governing equations and discretization methods: firstly the governing equations of cylinder and fairing models are derived in Section 2.1 from conservation laws; then the