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# Galloping oscillation of a circular cylinder firmly combined with different shaped fairing devices

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## HIGHLIGHTS

- Galloping oscillation of different shaped fairing devices is numerically studied.
- Fairing characteristic length is found to decide the galloping performance.
- Fairing shape have limited influence on galloping performance.

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## ABSTRACT

The galloping oscillation of a circular cylinder combined with different fairing devices is numerically studied. The fairing devices are integrated with a circular cylinder that is supported by a spring and a damper. An unsteady Reynolds-averaged Navier–Stokes (URANS) model corrected with the arbitrary Lagrange Euler (ALE) method is used as the governing model of the fluid flow while the governing equations are solved with a total variation diminishing (TVD) finite volume method (FVM). The SST turbulence model is used. The fluid–structure-interaction (FSI) simulations are performed under the reduced velocities ranging from 3 to 25. The simulation results are validated with the available experimental and numerical results with a short-tail fairing device. The influences of the shapes and the characteristic lengths of the fairing devices on the galloping oscillation are discussed. The shape of the fairing devices are found to influence the vortex shedding patterns in the wake of the flow field while the characteristic length decides the galloping behavior of the cylinder at different reduced velocities. The fairing devices with the smallest characteristic length have the best vibration suppression performance in the present study.


## 1. Introduction

The fairing devices have been used to suppress the vortex-induced vibration (VIV) in the practical marine risers that are commonly used in the offshore oil exploring, drilling, production and transportation during the recent two decades. The VIV is caused by the alternate vortex shedding at the back rear of the tube in the flow past the marine risers. The alternate vortex shedding causes the oscillating lift and drag forces on the structure and brings the vibration of the structure. When the frequency of the vibration approaches the natural frequency of the structure, the amplitude of vibration will largely increase, which may bring severe damage to the body. The fairing devices are used to change the vortex shedding patterns or even eliminate the vortex shedding in the wake so that the VIV may be avoided. The application of the fairings on VIV

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suppression have been studied by many scholars (Grant et al., 1977; Allen and Henning, 2001a, b; Allen et al., 2003; Assi et al., 2011, 2014; Gu et al., 2012; Khorasanchi and Huang, 2014; Xie et al., 2015). However, past experiences suggest that under certain conditions, the fairing devices may bring strong galloping oscillations and the galloping oscillation is not caused by the 'lock-in' of the structural oscillation frequency with the vortex-shedding frequency. In the work of Assi et al. (2011) and Assi et al. (2014), the effect of the rotational friction on the stability of the faired structures was experimentally studied. The author concluded that a certain level of rotational friction is needed to prevent the free-to-rotate fairing device from amplifying the VIV motion. The fairing device would deflect a stable angle from the inflow stream direction with proper rotational friction and the VIV can be suppressed. However, too much rotational friction would result in severe galloping instability, which is similar to the behavior of the structures with fixed fairing devices. According to Assi et al. (2014), the constant force that brings the deflection of the fairing device is believed to cause the strong vibration when the fairing device is fixed attached to the main cylinder. The author performed experiments on the galloping oscillation of the faired cylinders and the mechanism underneath the oscillation was analyzed. Within a large range of the reduced velocity, the galloping oscillation is prominent and cannot be ignored.

Galloping has been extensively studied in the aerodynamics, while, in the hydrodynamic, the galloping has been studied for the cylinders with protuberances (Blevins, 1990; Païdoussis et al., 2010), the bluff bodies with square cross sections (Bokaian and Geoola, 1984; Robertson et al., 2003; Molin et al., 2011) and riser bundles (Zimmermann et al., 2006; Damblans et al., 2013). The galloping oscillation of the faired cylinders under the hydrodynamic circumstance still lacks systemic study. Pontaza et al. (2006) used the LES to simulate the VIV suppression performance of a short-tail fairing that was outfitted to a circular cylinder. However, the fairing device was free to rotate and the author did not specifically study the galloping oscillation of the structure and only the VIV suppression of the fairing device under two specific Reynolds numbers was discussed.

To successfully use the fairing devices for VIV suppression, the devices should be rotatable with certain level of rotational friction. However, under the practical marine conditions, the devices usually lose the rotatable character and bring the risk of severe galloping oscillation to the structure if not carefully designed. It is therefore necessary to study the factors that influence the galloping characters of the fairing devices. In the present work, we try to examine the influences of the characteristic length and the shape of the fairing device on the galloping performances of such devices.

In a recent study of Zheng and Wang (2017), the galloping oscillation of a cylinder integrated with a short-tail fairing device that takes the shape as described in the work of Assi et al. (2014) was numerically studied. As has been theoretically described by Blevins (1990) and Païdoussis et al. (2010), the galloping is driven by the lift load variation that is caused by the transverse structural motion. The simulation results of Zheng and Wang (2017) suggest that the cylinder movement in the cross-flow direction causes the reattachment of the vortex structures in the wake and it in turn brings the force that is in-phase with the cylinder movement which eventually causes the strong galloping oscillation. The work of Zheng and Wang (2017) focused on the validation of the numerical results with the experimental results while the vorticity field characters was not studied carefully. The influence of the shapes and characteristic lengths of the fairing devices was also not discussed in that work.

In the work of Wang et al. (2015), a CFD analyze was performed on the vortex control mechanism of a water-drop shaped fairing device with different shape angles under different attack angles. The cylinder in that study was fixed and no fluid–structure-interaction (FSI) influences were considered. As is shown in the study of Wang et al. (2015), the water-drop shaped fairing with $\theta = 60^{\circ}$ could effectively reduce the lift and drag forces under zero inflow attack angle. However, under non-zero inflow attack angle, the lift/drag force reduction performance of the fairing device becomes different while the vortex structures in the wake are heavily influenced by the attack angle. It is interesting to see the FSI performance of this type of fairing devices.

In the present work, the galloping oscillations with the short-tail and water-drop shaped fairing devices are compared. The FSI simulation results with the short-tail fairing that has a characteristic length of 1$D$ have been validated with the available experimental result (Zheng and Wang, 2017). Here, $D$ stands for the diameter of the circular cylinder. The cases of the short-tail fairings with the other characteristic lengths are numerically studied in the present work. The water-drop shaped fairing devices are simple in shape and enable an easy discussion of the flow field wake characters while they also provide another type of fairing shape for the comparison in the present study. The simulations are performed for both the two types of the fairing device under the same flow field conditions and the same characteristic lengths. The corresponding galloping oscillation performances are compared to study the influence of the characteristic length and the shape of the fairing device on the galloping characters. A CFD method that is expanded with the arbitrary Lagrange Euler (ALE) method is used to simulate the motion of the cylinders in the fluid flow. A total variation diminishing (TVD) finite volume method (FVM) based on an elemental velocity vector transformation (EVVT) approach put forward by Wang (2010) is used for solving the unsteady Reynolds averaged Navier–Stokes (URANS) equations closed with a shear stress transport (SST) turbulence model (Menter, 1993) to simulate the fluid flow and to get the hydrodynamics parameters in the two-dimensional cases.

## 2. Governing equations

### 2.1. Equations of the fluid flow

In the present work, the governing equations for the incompressible turbulent fluid flow are the URANS equations closed with the SST turbulence model of Menter (1993). This turbulence model can take the pressure gradients near the structure