# Synchronization Study on the Vortex-Induced Vibrations using Wake Oscillator Model

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**Abstract**. Vortex-Induced Vibration (VIV) is often modeled as a two-way coupled phenomenon wherein the structure and the wake behave like two interacting oscillators. In the present study, we analyze the coupled interactions between these two oscillators from the purview of the synchronization theory. To that end, a low-order wake-oscillator model comprising of a classical Van der Pol (VDP) oscillator, describing the wake dynamics, and a 1-dof structural oscillator is considered. Frequency and phase synchronization of this fluid-elastic system are characterized by evaluating the mean frequency and phase locking values, respectively, based on Hilbert transform. The route to synchronization is established with the varying nonlinearity in the wake oscillator.

## Introduction

VIV is a special class of fluid-structure interaction, which is commonly observed in many physical systems, such as marine risers, suspended cables etc., due to the coupled interactions between the structure and the wake generated by it. Due to the ubiquitous occurrence of VIV, extensive experimental, analytical, numerical studies are available in the literature. Several analytical studies have been carried out using low-order models, involving classical oscillator equations [1] and the results are compared with those obtained from numerical simulations and experimental observations [2]. During VIV, one of the important events is the synchronization between wake and structure. A systematic investigation of phase and frequency synchronization can shed more light on the coupled interaction between such oscillators. In the present study, a low order model comprising of a van der Pol oscillator and a linear structural oscillator is considered in order to study the synchronization behavior with respect to different control parameters, such as reduced flow velocity, mass ratio, fluid and structural damping etc. The coupled response dynamics is analyzed under the parlance of synchronization theory in terms of the relative phase difference and phase-locking values (PLV). Furthermore, the nonlinearity term of the VDP oscillator is varied to capture a synchronization route from chaos to order in the concerned VIV system. To the best of the authors knowledge, this has been largely unexplored in the existing literature.

## Results and Discussions

Figure 1(a) presents the schematic of the VIV system. The wake and the structure are observed to exhibit resonant amplification in the flow range of $4.5 < U_r < 5.6$; see Fig. 1(b). Outside this range, the structure does not exhibit any significant oscillations ($Y_0$) although the wake oscillator shows a periodic oscillation ($Q_0$) with amplitude 2. Interestingly, in both the regimes, these oscillators are found to be frequency and phase locked, as can be seen from the corresponding PLV value of 1 and zero relative mean frequency ($\omega_y - \omega_q$); see Fig. 1(c). In the full paper, the synchronization behavior of this system will be studied by varying the coupling strength and the extent of nonlinearity parameters. To that end, phase synchronization will be quantified by the change in the corresponding phase locking values. The primary focus will be on establishing the route to synchronization as the system dynamics transitions from chaos to order for varying nonlinearity of the wake oscillator.

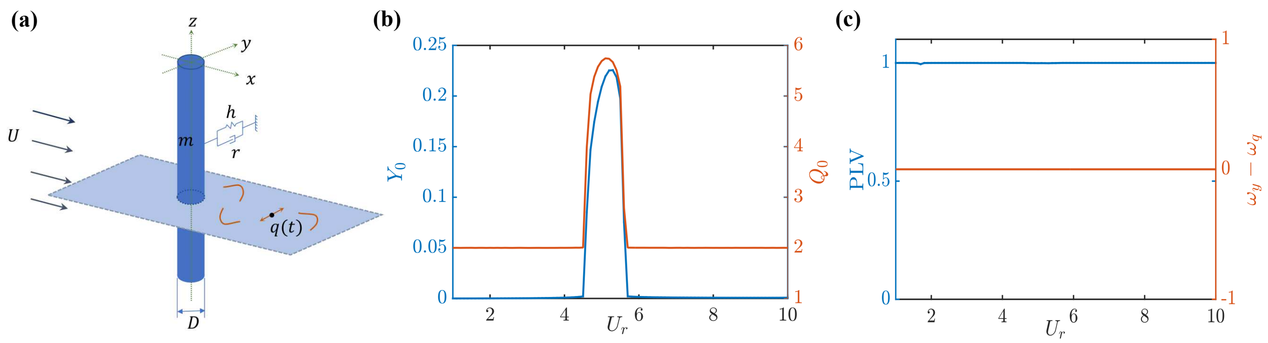


Figure 1: (a) Schematic of the VIV model for a coupled structure and wake oscillators; (b) Variation in $Y_0$ and $Q_0$ oscillations with respect to $U_r$; (c) Variation of PLV and relative mean frequency between structure ($y$) and wake ($q$) oscillations with respect to $U_r$.

## References

[1] Facchinetti, M. L., De Langre, E., & Biolley, F. (2004). Coupling of structure and wake oscillators in vortex-induced vibrations. Journal of Fluids and Structures, 19(2), 123-140.

[2] Ellingsen, . M., & Amandolese, X. (2020). Amplitude hysteresis and the synchronization region: Prediction of vortex-induced vibration using a freely forced van der Pol oscillator. arXiv preprint arXiv:2003.03838.