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A Fully Coupled and Efficient Numerical Model for Slender Marine Vegetation in Waves

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ABSTRACT

Numerical modeling of floating seaweed farms is complex due to the intricate network of various infrastructure components and their interactions, including cultivation lines, buoys, and anchor chains, as well as numerous seaweed blades that vary in both size and shape. Additionally, the coupling between the cultivated seaweed and the surrounding fluid adds to the complexity.

To address these challenges, we have developed an efficient numerical solver for highly compliant slender structures, known as the truss-spring model (Wei et al., 2024). This model is shown to be mathematically consistent and can accurately capture large-amplitude vegetation deflections. It also enables explicit time integration with large time steps, making it well-suited for simulating highly compliant vegetation. Alongside the structural model, we have developed a unique flow model using the continuity equation and linearized momentum equations for an incompressible fluid. This flow model incorporates additional terms within the canopy region to account for the presence of vegetation. The resulting linearized flow solver is unconditionally stable and second-order accurate. The coupling between the truss-spring structural model and the flow solver is achieved using an immersed boundary method. The truss-spring model has been utilized to predict the onset of flutter and the hydrodynamic drag loads on flexible blades subjected to cross flows. While a traditional Morison's equation fails to induce flutter, the reactive force model (Leclercq and de Langre, 2018) implemented in our solver successfully predicts the flutter onset and the associated drag reduction. Notably, the same structural model can also be applied to effectively model cultivation lines or other ropes, without requiring additional treatments to couple different slender structures. This flexibility makes the truss-spring model a promising tool for modeling the integrated system of a floating seaweed farm.

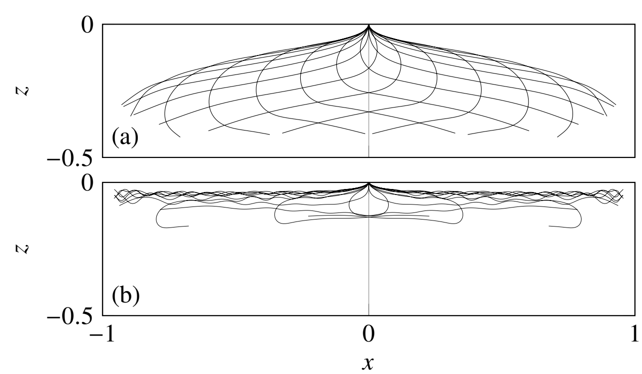

Figure 1: Snapshots of the trajectory from simulations of flexible blades in a sinusoidal oscillatory flow. (a) Before the onset of flutter; (b) Flutter.

References

Leclercq, T., de Langre, E., 2018. Reconfiguration of elastic blades in oscillatory flow. Journal of Fluid Mechanics 838, 606–630. doi:10.1017/jfm.2017.910.

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