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INSTABILITY OF THREE INTERLACED HELICAL VORTICES: APPLICATION TO ASYMMETRIC ROTOR WAKES

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Helical vortex filaments are subject to various types of instabilities, including displacement instabilities, which occur when the vortex core is shifted from its baseline position. The theoretical growth rates of unstable displacement perturbation modes have long been established for one helix [1] and multiple interdigitated helices [2], but experimental investigations into the dynamics of helical vortices are scarce. Quaranta et al. [3, 4] experimentally excited different instability modes using one- and two-bladed rotors to generate helical vortices, and found close agreement with theoretical growth rates. The current study investigates the helical vortices in the wake of a three-bladed rotor, focusing on perturbation modes with zero azimuthal wavenumber, which can be triggered by rotor asymmetry.

This instability is explored using water channel experiments, vortex filament simulations and a simplified point-vortex-based model. In the experiments, vortices shed from the tips of a three-bladed rotor with a 9 cm radius are visualized by painting the blade tips with fluorescent dye and illuminating the water channel test section with an LED panel (Figure 1a). The blades are 3D printed and can be removed and replaced individually to introduce different initial perturbations. The simulations monitor the evolution of helical vortex filaments modelled as concentrated material lines of vorticity, as described in [5], with an initial displacement. To provide a tool to explore a wide range of perturbations quickly, a simplified model using a periodic strip of point vortices to represent a cross-section of the helical vortex system is developed. In spite of its simplicity, it is shown to accurately capture the key features of the helical vortex interactions (Figure 1b).

The growth rate and displacement modes obtained using these methods agree well with the theory for the zero-wavenumber perturbations. Results of this study show that the three-helix system is highly sensitive, with small initial perturbations on the order of 5% of the vortex separation distance substantially disturbing the rotor wake within a few turns of the helices (Figure 1). This sensitivity is shown to vary with the direction of the perturbation, with displacements along the positive strain direction developing faster in the non-linear regime than those along the negative strain direction. These findings have applications to industrial flows, such as those found in the wakes of wind turbines, propellers and helicopter rotors, where coherent vortices can induce strong loading on downstream structures. Introducing an asymmetry to these rotors, which represents a means of passive control, could accelerate coherent structure breakdown, mitigating such detrimental wake effects.

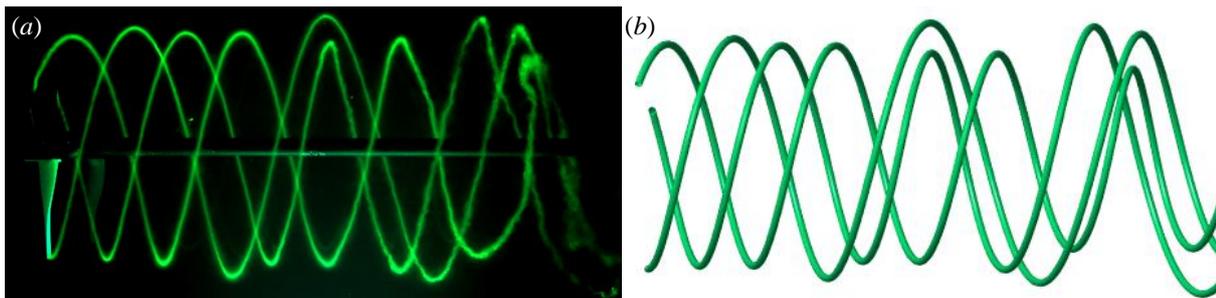


FIGURE 1. (a) Dye visualization of the helical vortices in the wake of an asymmetric three-bladed rotor.
(b) Helical vortices reconstructed from a simplified point vortex model.

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