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Global pairing instabilities of three interlaced helical vortices in the wake of an asymmetric rotor

A. Abraham^a, A. Castillo-Castellanos^a and T. Leweke^a

Helical vortex filaments are susceptible 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 helix¹ and multiple interdigitated helices², but experimental investigations into the dynamics of helical vortices are scarce. Quaranta et al. experimentally excited different instability modes using one³- and two⁴-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 the zero-wavenumber instability mode, 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 visualised using fluorescent dye (figure 1a). The simulations monitor the evolution of helical vortex filaments modelled as concentrated material lines of vorticity with an initial displacement perturbation. 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. Despite its simplicity, it is shown to accurately capture the key features of perturbed helical vortex interaction (figure 1b).

The growth rate and 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; small initial perturbations ($\sim 5\%$ of the vortex separation) substantially disturb the rotor wake within a few turns of the helices.

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¹ Widnall, *J. Fluid Mech.* **54**, 641 (1972).

² Gupta and Loewy, *ALAA J.* **12**, 1381 (1974).

³ Quaranta et al., *J. Fluid Mech.* **780**, 687 (2015).

⁴ Quaranta et al., *J. Fluid Mech.* **863**, 927 (2019).

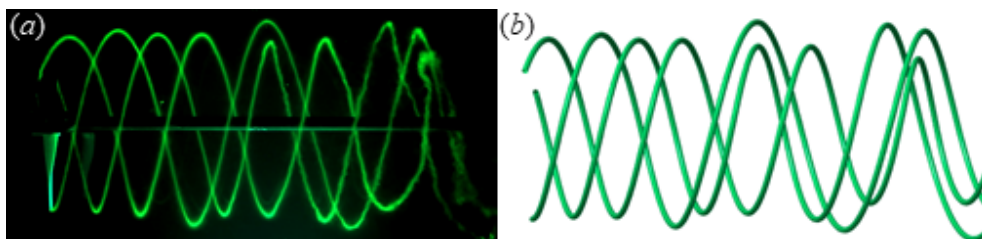


Figure 1: (a) Dye visualization of the helical vortices in the wake of an asymmetric three-bladed rotor. (b) Helical vortices reconstructed from the simplified point vortex model.