Rotor wake instability triggered by imperfections

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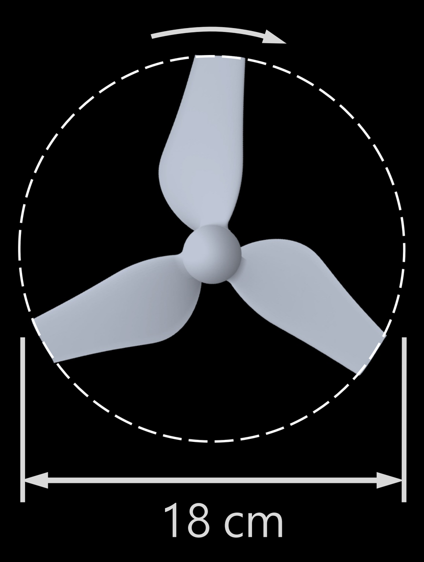
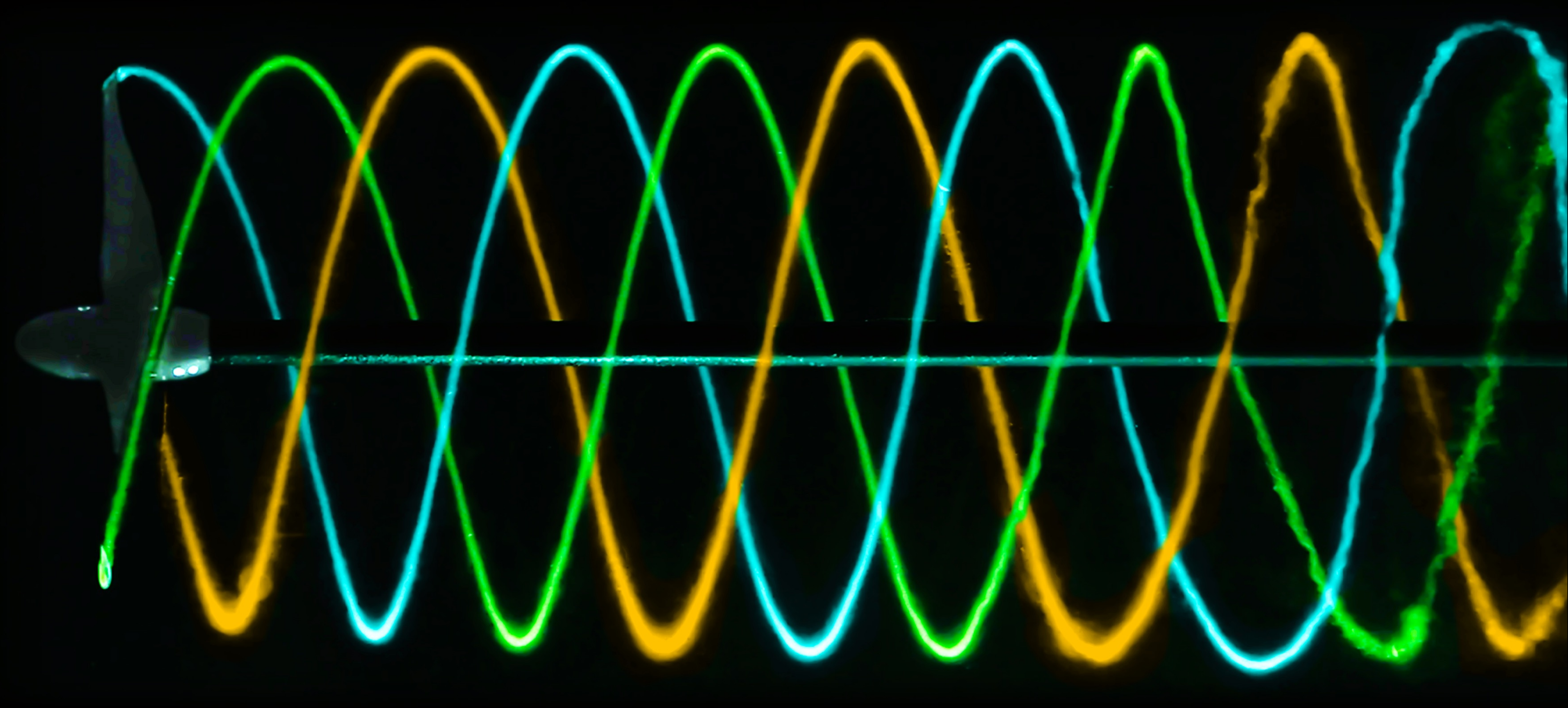
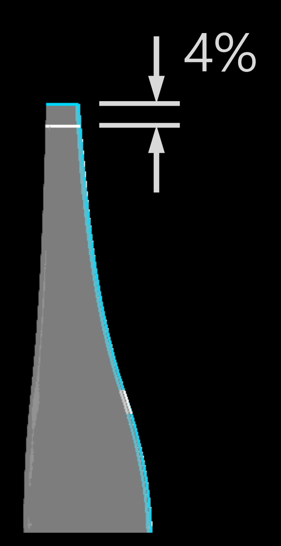
Blade tip vortices

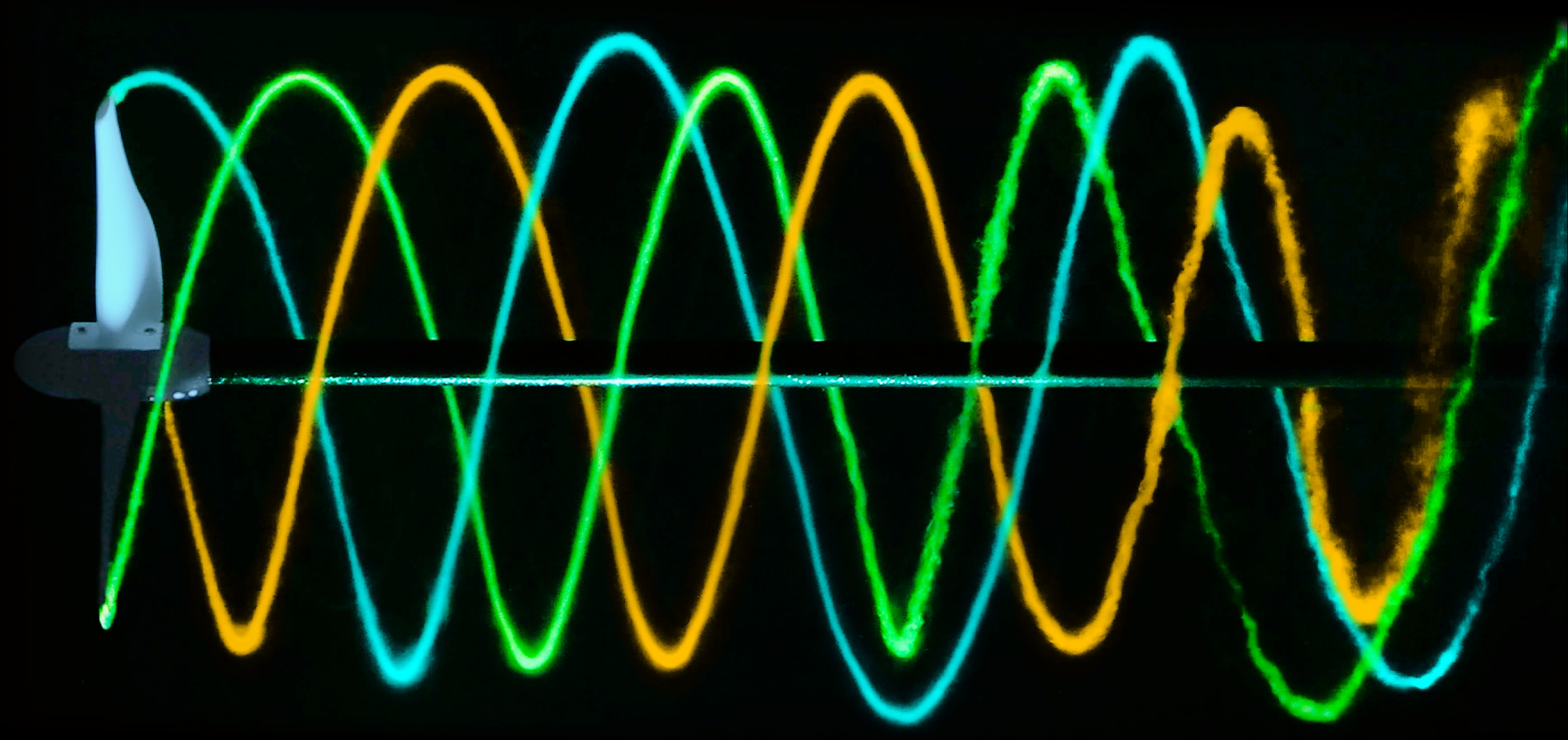




The wakes of multi-bladed rotors are characterized by a system of interlaced **helical vortices** generated at the blade tips, which can have detrimental effects on downstream structures in applications involving wind turbines, helicopters, or marine propellers. In this work, we investigate experimentally the wake of a 3-bladed model rotor of diameter 18 cm, placed in a water channel with freestream velocity 56 cm/s and spinning at a frequency f_0 = 3 Hz. The vortices are visualized by applying **fluorescent dye** to the blade tips and illuminating the volume with LED panels. The image on the left shows the unperturbed rotor wake at its actual scale.

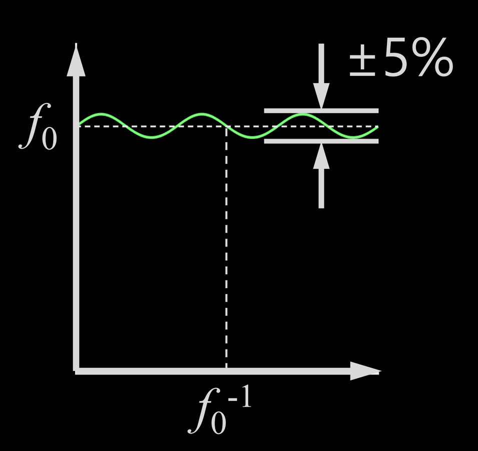
Rotor asymmetry

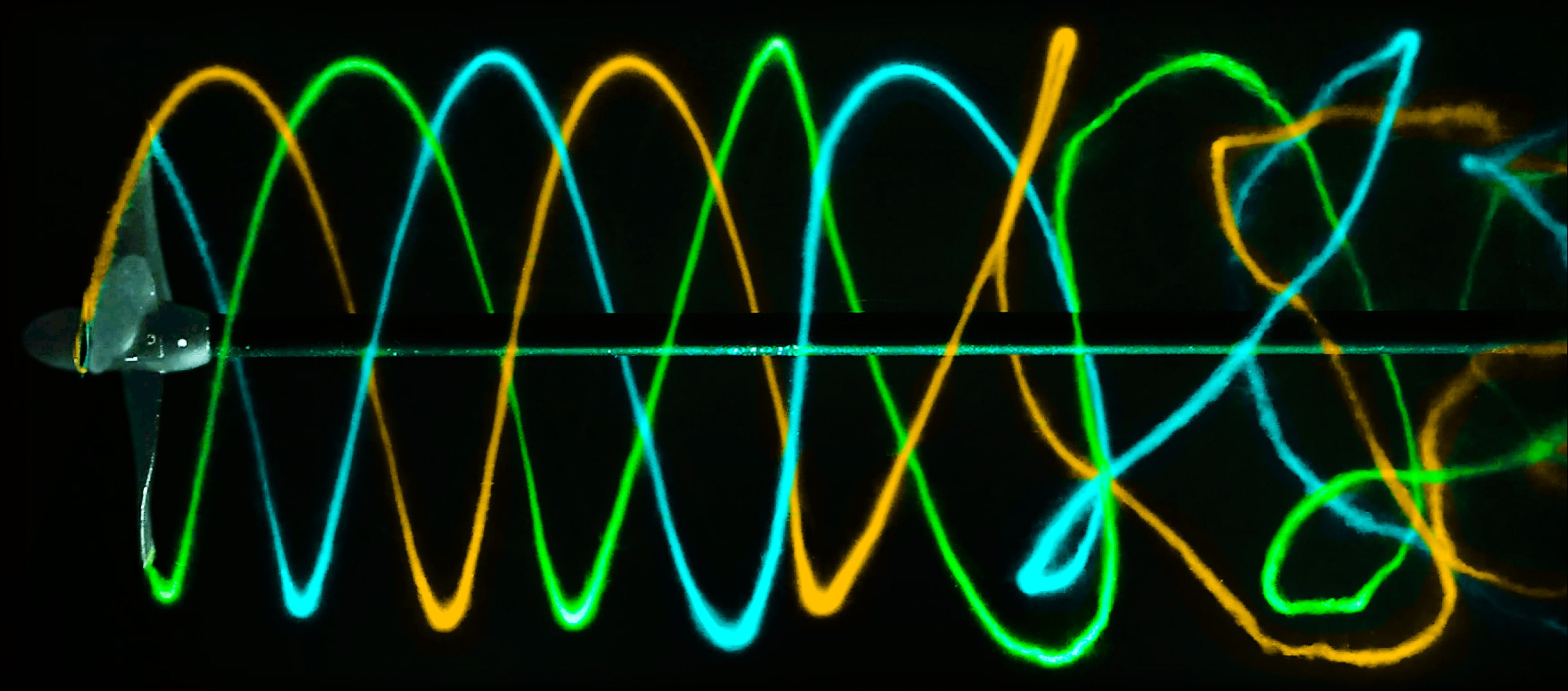




Helical vortices are subject to long-wave displacement instabilities, which initiate the eventual decay of the vortex system. Triggering these instabilities can help accelerate the decay, and thus mitigate unwanted rotor wake effects. One way to set off the instability is to add a passive **asymmetry** to the rotor geometry, e.g. by **elongating one of the blades** by a small amount. The corresponding unstable displacement mode leads to a uniform contraction and expansion of the helices, resulting in a **leapfrogging** phenomenon, where neighboring helix loops switch their axial positions.

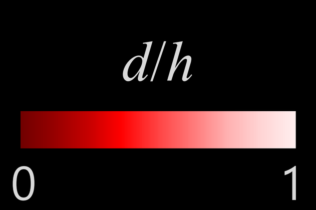
Frequency variation

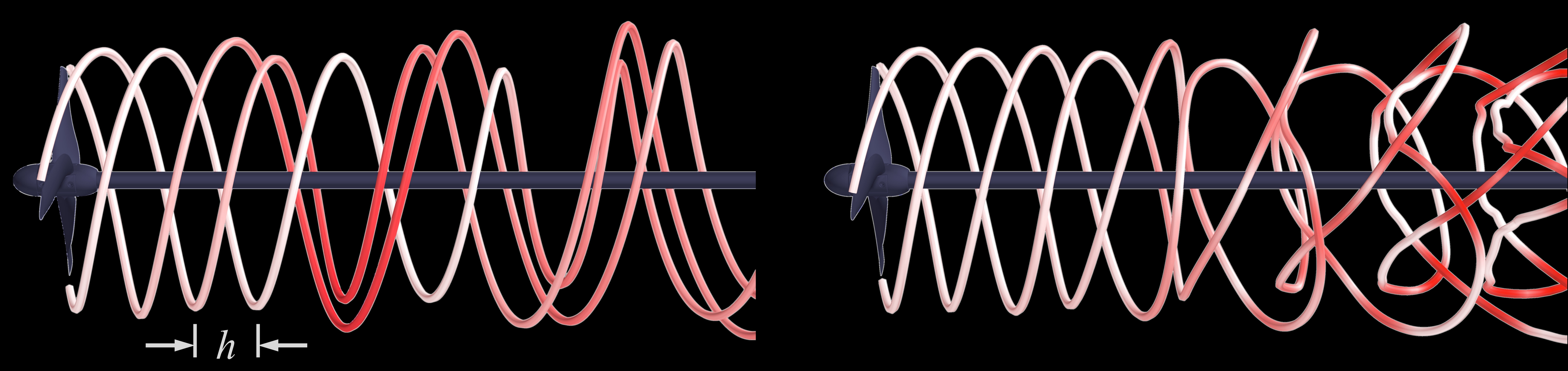




Other instability modes of the helical vortex system can be triggered by **varying the frequency** of the rotor periodically. The resulting **complex distortions** of the wake vortices favor a more rapid breakup. The example on the left shows the growth of the most unstable perturbation that can be excited in this way, with a modulation frequency equal to (3/2) f_0.

Vortex separation





Supplemental numerical simulations using a **vortex filament method** show good agreement with the experiments. They provide further information about the parameters that lead to vortex breakdown, such as the local vortex separation distance (d), coded in red in these images.

Learn more at our presentation – Monday, 1:25 pm, Q11.00001: Simplified model for helical vortex instabilities with applications to asymmetric rotor wakes