Meandering of a wind mill wake vortex

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A meander in nature commonly refers to a sinuous watercourse or river. Here it denotes the sinusoidal transverse oscillation of a wind mill wake. This oscillation occurs a few rotor diameters downstream of the turbine (Hirth et al., 2012). Periodic vortex shedding (Medici and Alfredsson, 2008) or the advection of the wake by large upstream eddies (Trujillo et al., 2011) have been discussed as causes for the meandering motion.

We approach the wind mill wake vortex tube with diameter D from a theoretical perspective and conduct a linear stability analysis of a Rankine vortex in shear flow using the vorticity equation (Fig. 1). Corresponding idealized numerical simulations show the onset of the meandering motion for $1/f$-*noise* of different intensity and spectral properties (Schröttle et al., 2014).

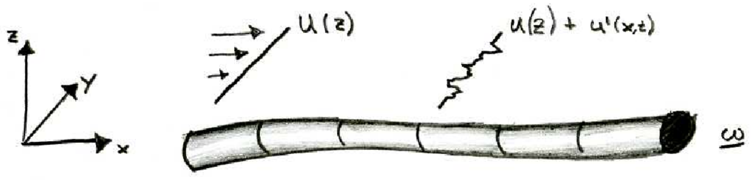

Figure 1: Vortex tube with vorticity $\boldsymbol{\omega}$ in strong shear flow $U(z)$ with perturbations u'.

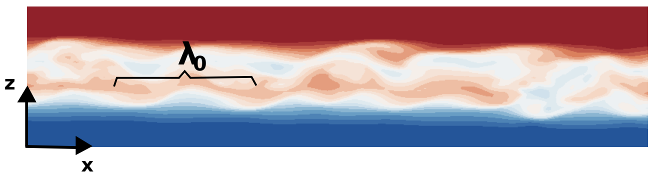

Figure 2: Streamwise velocity field $\tilde{u}(x,z)$ after onset of instability.

Strong background shear initiates and sustains the meandering in the stability analysis and in the simulations (Fig. 2). The scale where instabilities arise depends on the initial noise. For *one-dimensional* noise, meanders evolve with a wavelength $\lambda_0 \gg D$ in the perturbed velocity field.

Finally, we implement an actuator disk (Meyers and Meneveau, 2013) by immersed boundary methods in a large-eddy simulation code. The actuator disk represents a rotating wind turbine in the atmospheric surface layer. Passive tracers are used to illustrate the wind turbine wake dynamics. A spectral analysis of the turbulent kinetic energy reveals a maximum at the scale of the wavelength λ_0 of the meanders. Our results suggest strong shear as a third cause for the meandering motion.

References

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