Multiscale coherent dynamics in wind turbine wakes

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The wake of a wind turbine is inherently multiscale in nature as coherence is simultaneously shed into the flow from the blades, nacelle, tower etc. We conducted extensive Particle Image Velocimetry (PIV) experiments on a small-scale wind turbine representative of a real scale wind turbine. A number of frequencies are observed in different regions of the flow, including the blade passing frequency ($3f_r$), rotor frequency (f_r) and their harmonics, nacelle and tower's shedding frequency, wake meandering frequency (f_{wm}) etc (see fig. 1(a-b)). We investigate the origin of these frequencies by studying the coherent energy budgets for each of the various coherent modes, which was developed by Baj and Buxton[1]. The coherent energy budget ($\tilde{k}_l$) equation can be represented in a symbolic form as

$$\frac{\partial \tilde{k}_l}{\partial t} = -\tilde{C}_l + \tilde{P}_l - \hat{P}_l + \left(\tilde{T}_l^+ - \tilde{T}_l^-\right) - \tilde{\epsilon}_l + \tilde{D}_l \tag{1}$$

In equation 1, the source terms on the right hand side consists of convection ($\bar{C}_l$), production from mean flow ($\tilde{P}_l$), production of stochastic turbulent kinetic energy ($\hat{P}_l$), triadic energy production ($\tilde{T}_l^+ - \tilde{T}_l^-$), dissipation ($\tilde{\epsilon}_l$) and diffusion ($\tilde{D}_l$). Fig. 1(c) shows the energy budget terms for f_r - $3f_r$. The different sectors correspond to the different terms in equation 1. The radial lengths of the sectors represent the relative contribution of the different terms in logarithmic scale and the red and blue colors represent loss and gain of energy respectively. Note that some of the modes are energised by the mean flow while some are entirely energised by non-linearity, a scenario qualitatively similar to that observed in predominantly 2 dimensional multiscale flows containing multiple cylinders[1 2]. In addition, there are also some modes which are energised by both production from mean flow and non-linearity and some solely due to convection.

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[2]Biswas, Neelakash, and Buxton, Oliver RH, *J. Fluid Mech.* **941**, A36 (2022).

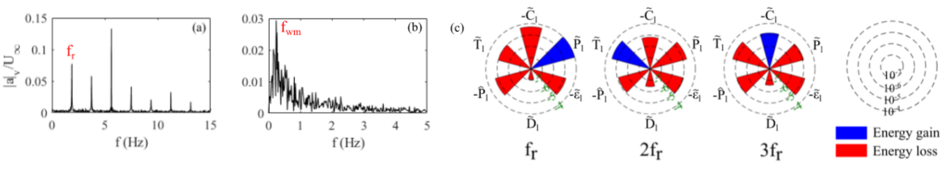

Figure 1: Frequency spectra obtained at the points (a) $x/D = 0.5, y/D = 0.1$ and (b) $x/D = 1.5, z/D = 0$ (D is the turbine diameter). (c) Different energy budget terms for the frequencies f_r - $3f_r$. A red sector denotes loss of energy while a blue sector denotes gain of energy. $\tilde{T}_l^+ - \tilde{T}_l^-$ is represented in short by $\tilde{T}_l$.