XFOIL for Vortex Generators: Fast aerodynamic analysis of Airfoils equipped with VGs

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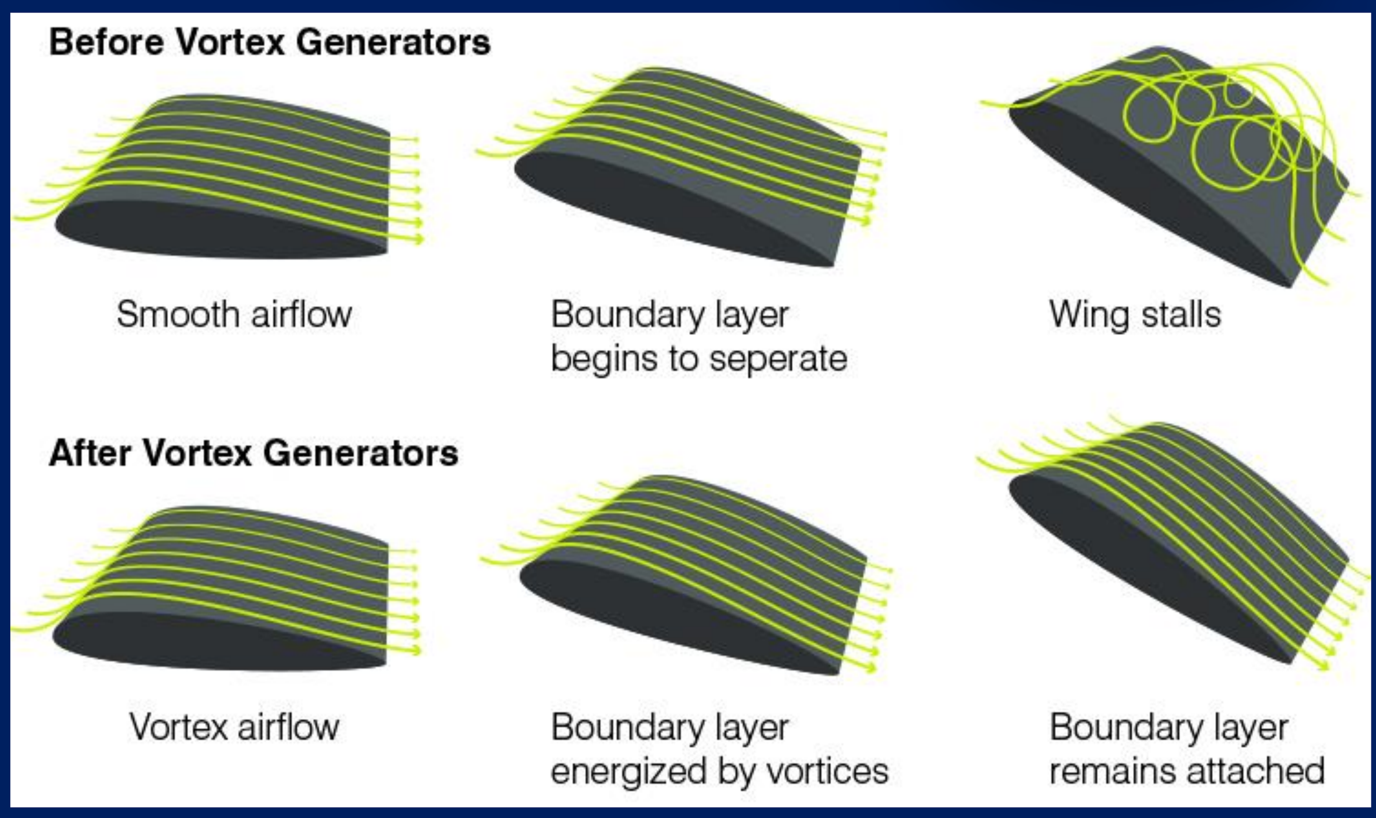


Background:

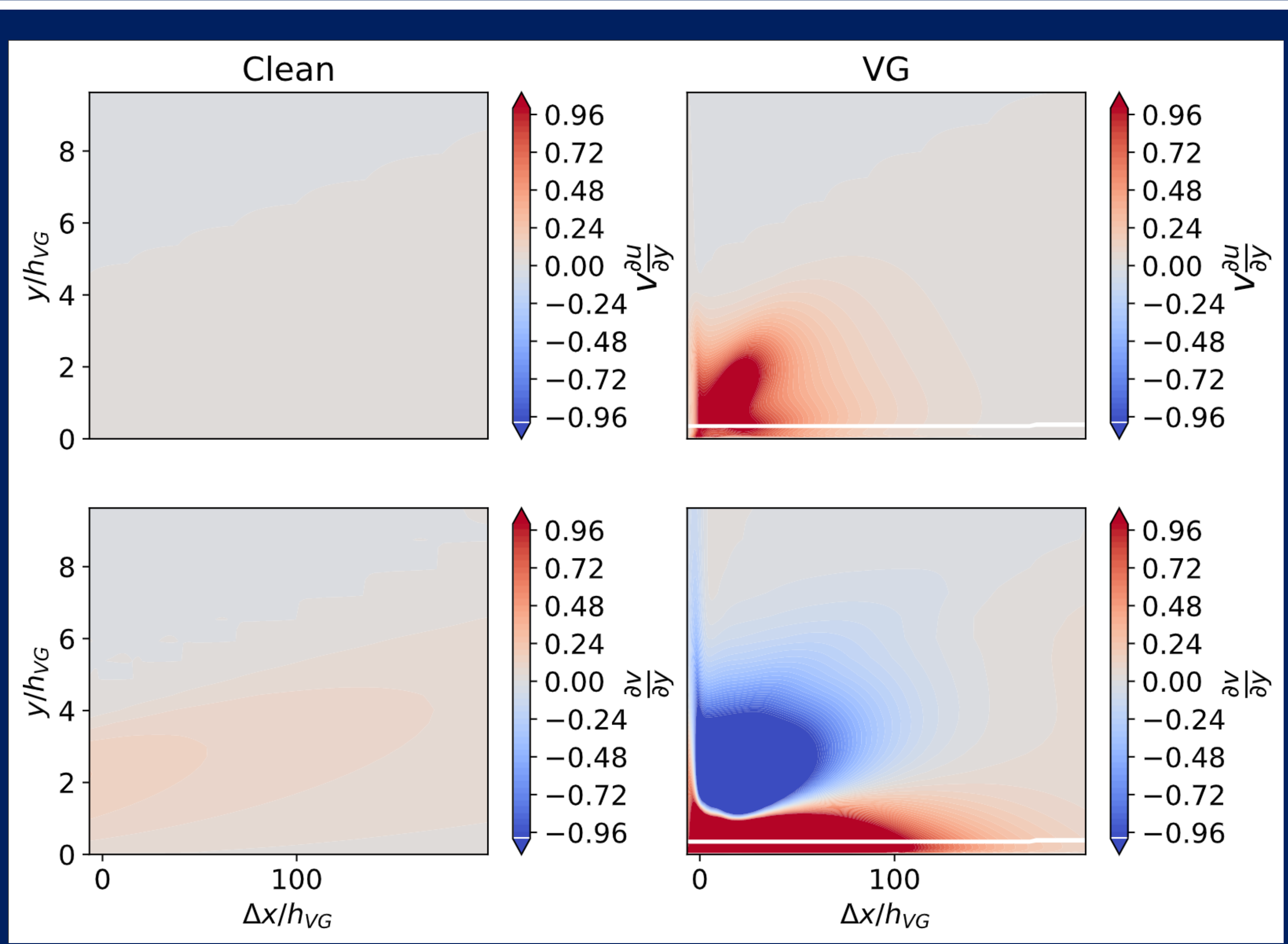
Vortex generators delay flow separation on thick root sections of ever-growing wind turbine blades. Turbine developers want to optimise VG arrays with fast and accurate tools. But, CFD simulations or wind tunnel measurements for a single configuration can take days and weeks.

Goals of my PhD:

- To extend an integral boundary layer framework to vortices in boundary layers to create **XFOIL for vortex generators.**
- To design an innovative blade accounting for vortex generators

Steps:

1. Computational Fluid Dynamics and Particle Image Velocimetry of vortices in flat plate boundary layers
2. Modifying the integral boundary layer equations with additional momentum terms
3. Establishing the relationship between VG geometry and inflow conditions to added momentum



Vertical velocities and gradients **cannot be neglected** for turbulent boundary layers with vortex generators

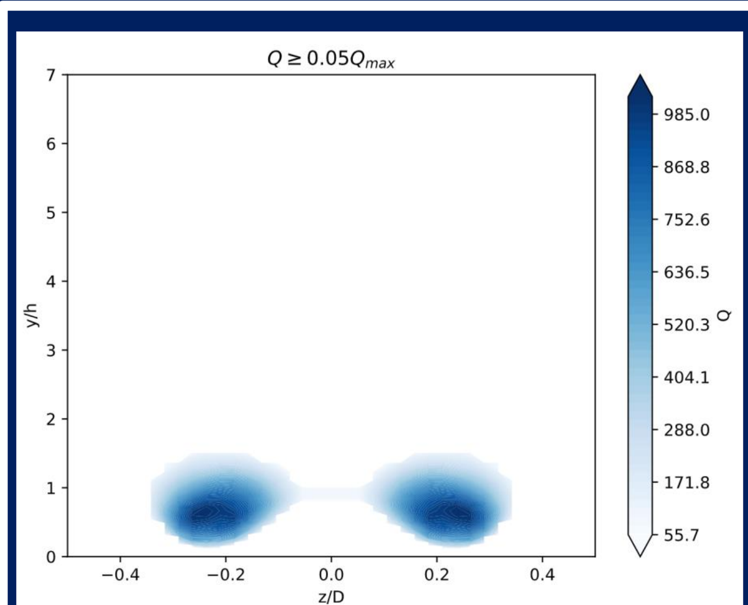
$$\frac{d\theta}{d\xi} = \frac{C_f}{2} - (H+2)\frac{\theta}{u_e}\frac{du_e}{d\xi} + \textbf{\textit{Added Momentum}}$$

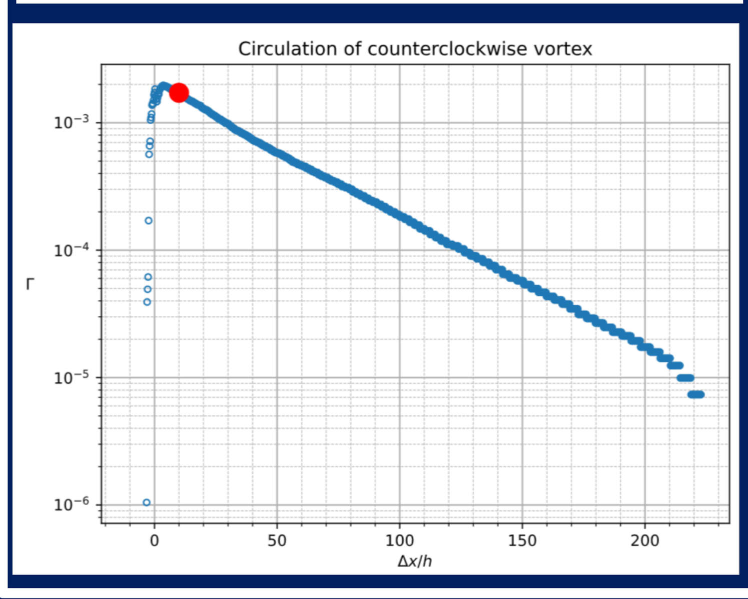
$$\frac{dH_k}{d\xi} = \frac{2C_D}{\theta} - \frac{H_k}{\theta}\frac{C_f}{2} - \left(\frac{2}{H_k} + 1 - H\right)\frac{H_k}{u_e}\frac{du_e}{d\xi} + \textbf{\textit{Added Energy}}$$

$$\frac{\partial(u_e C_\tau)}{\partial\xi} = \frac{C_\tau u_e}{\delta}K_c\left(\left(C_{\tau_{EQ}}^{\frac{1}{2}}\right) - C_\tau^{\frac{1}{2}}\right) - C_\tau\frac{\partial u_e}{\partial\xi} + \textbf{\textit{Added Turbulence}}$$

These integral boundary layer equations, derived from Navier Stokes equations, **now need extra terms** for added momentum, energy, and turbulence

Prototype: A model for the shape factor (representing added momentum) produces accurate lift and drag for airfoils with vortex generators

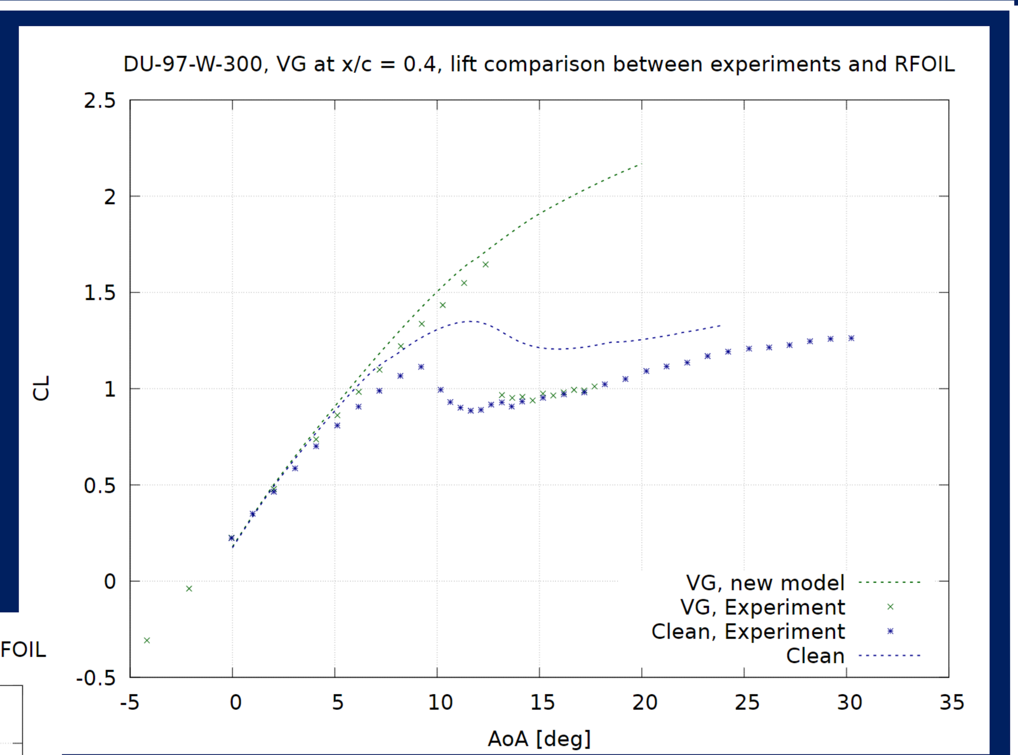


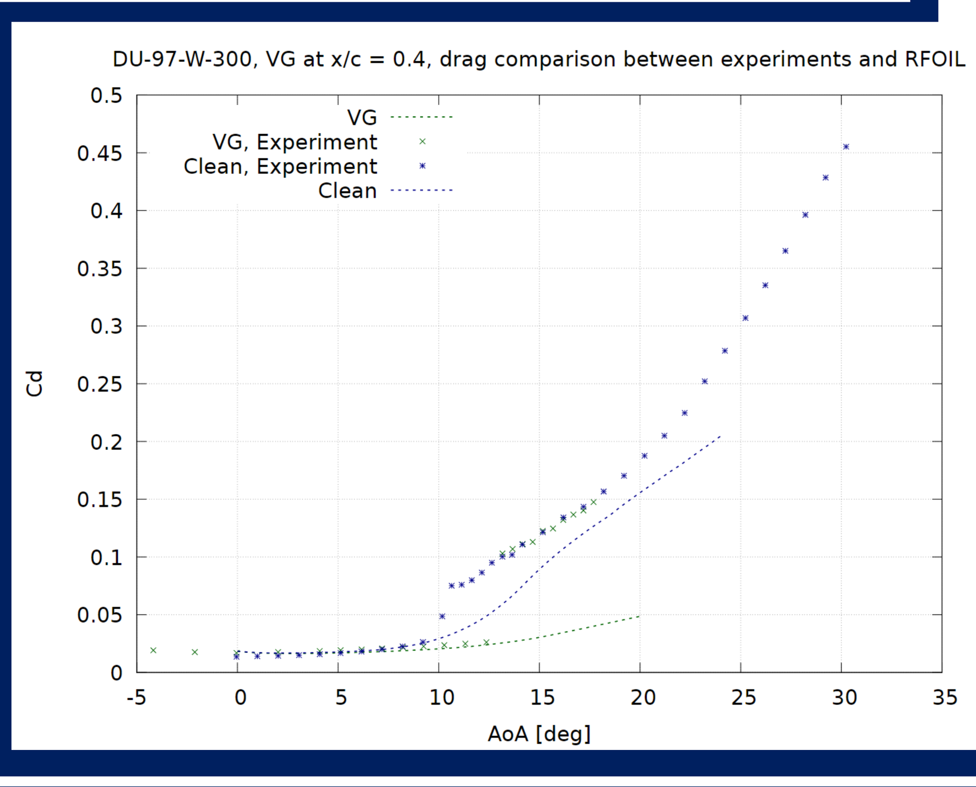


The exponential decay of the vortex is used to model the shape factor for a VG

$$\log\left(\frac{\Gamma}{\Gamma_0}\right) = 0.0028\left(\frac{\Delta x}{h}\right) - 0.4886$$

$$H_{VG} = H_{clean}(1 + A\tilde{x}\cdot\exp(-B\tilde{x}))$$





The prototype predicts stall delay with accurate $dC_l/d\alpha$ and $dC_d/d\alpha$ before stall.

It currently does not predict stall because it forcibly reattaches flow when the separation point has moved downstream of the VG.