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Optimization of Leading-Edge Slat Position and Orientation for Thick Airfoils

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Abstract

Wind and tidal turbines use airfoils designed to maximize power production with high lift/drag ratios. Airfoils in the inboard section must satisfy structural requirements and are therefore thicker and less efficient. These thick profiles cause root losses which can reduce efficiency by up to 5% in wind turbines, and more in tidal turbines. Root losses can be reduced by implementing a leading-edge slat, which has been observed in the literature to increase turbine efficiency and delay boundary layer separation to higher angles of attack. This abstract presents an overview of the work conducted to aerodynamically optimize the position and orientation of a slat for the standardized thick DU00-W2-401 airfoil profile. The objective function of this optimization is the lift/drag ratio and is evaluated using Computational Fluid Dynamics (CFD). This informs a three degree of freedom (DOF) local optimization algorithm which determines a new slat position to simulate. The 2D CFD results utilize the k-ω Shear Stress Transport (SST) turbulence model and have been validated against experimental and simulated data in the literature. To facilitate an efficient optimization workflow, a robust automated-meshing script was developed to create high-quality CFD meshes for all feasible slat positions and orientations.

The relative position of the slat is measured between the slat and primary-airfoil quarter-chords and is controlled with two design variables. The relative orientation of the slat is controlled with a single design variable for the pitch angle about the slat quarter chord, for a total of three design variables. Traditional multi DOF local optimization use gradient-based methods, however in this case evaluating the objective function using CFD is computationally expensive relative to the optimization algorithm. Therefore, to reduce the number of function evaluations, a three DOF random-orthogonal search method is used, and golden-section local search is used to find the best set of parameters along each search direction. Optimized designs are compared to the stand-alone airfoil profile to show improvements in the lift/drag ratio. Further work will include slat shape optimization using Particle Swarm Optimization (PSO) or other nature-based global optimization methods to avoid the expensive computation of the gradient. This procedure can be done at multiple radial locations on the turbine to allow for the creation of an improved 3D geometry based on 2D optimization. This work is made possible by the funding contributions of the NSERC Alliance and Biome Renewables.