In-blade Load Sensing and Control on 3D Printed Wind Turbine Blades Using Trailing Edge Flaps

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Abstract
As wind turbines become larger the loading on the blades also increases. Controlling a section of the trailing edge of the turbine airfoil is found to reduce the loading on wind turbine blades. This experimental work includes a trailing edge flap that covers 20% of an S833 airfoil with a chord of 178 mm. Surface pressure and strain are measured for varying angles of attack and flap angle. A 3D printed blade section is designed and built to house the actuation and sensing on the airfoil in real time. Initial simulation results show how the coefficient of lift shifts as the flap angle changes.

Keywords: *Trailing Edge Flap, Load Alleviation, Smart Blades*

Introduction

Increasing the rotor diameter on horizontal axis wind turbines increases power production but at the same time increases the loading on the blades especially at the root. To decrease the electricity cost per kWh it is imperative to reduce the loading on the blades to increase the lifetime of the turbine and decrease the cost of manufacturing. Reduction in blade loading would also decrease the loads on the drivetrain, generator, and tower further reducing the cost of manufacturing and maintenance. Unsteady loads on the blades are more problematic than static loads due to material fatigue. In general, extreme static loads are higher than unsteady loads, but fatigue life governs the design factors for larger wind turbines. The aim here is to sense and mitigate load variation on the wind turbine blades.

Various technologies have been developed to reduce the variation in loading on the blades, and they are often referred to as 'smart blades'. The focus of this research will be on trailing edge flaps (TEF) a small movable surface of the airfoil at the trailing edge. Barlas and van Kuik [1] summarized and reviewed different technologies that have been used in producing a 'smart rotor' to reduce the fatigue load on wind turbine blades. Flaps and a deformable trailing edge were found to have the most influence on the coefficient of lift (C_l) of the airfoil. Hulskamp *et al.* [2] used piezoelectric benders covering half the chord to deflect the trailing edge by 2°. Their TEF was tested inside a wind tunnel and on a small scale wind turbine. In both cases it was found that the TEF was capable of reducing the loads on the blades. A full scale wind turbine was instrumented with a TEF at DTU RISO [3]. The results showed that the loads are reduced on average by 14 to 20%. A team from Sandia National Labs (SNL) [4] have been working on designing, fabricating and testing TEF on a full set of 9 m blades. The results clearly showed that the flap actuation was capable of changing the power output of the turbine and the strain on the blades. Abdelrahman and Johnson [5] investigated the influence of TEF on a 3.4 m diameter wind turbine in a controlled environment and found the flap was capable of manipulating the flapwise moment.

Experimental Setup

To quantify the influence of a TEF on the wind turbine blade an experimental setup was designed to sense the aerodynamic forces on the wind turbine in real time and actuate the flap accordingly. The NREL S833 airfoil, designed for small wind turbines, was used during the experiments. The flap width was chosen to be 20% of the chord. To determine the coefficient of lift and moment, 54 surface pressure taps were located on an aluminum airfoil section. Differential pressure transducers were mounted on a custom printed circuit board (PCB) to sense the pressure difference between the suction and pressure side of the airfoil. Two strain gage groups were used to measure the strain in both directions at the airfoil support. A miniature 8 mm diameter Maxon motor comprising a gearbox, motor, and an encoder was used to actuate the TEF. The most complex and most novel part about the experimental setup was the custom designed and 3D printed airfoil that housed all the pressure transducers, TEF actuator, and controller. The data acquisition system (DAQ) was designed and built in a way to communicate to a computer wirelessly. This is especially useful once the airfoil section is mounted on the wind turbine blade. The DAQ will be placed in the hub and could transfer data to the computer in real time.

The airfoil section was designed to be tested on an existing 3.4 diameter wind turbine [5]. Initial base loading and testing of control authority will be completed in a wind tunnel. Figure 1 shows the pressure transducers and flap motor mounted in the blade. The strain gages measure the strain at the root of the blade in both directions. A stepper motor is used to control the angle of attack of the airfoil.

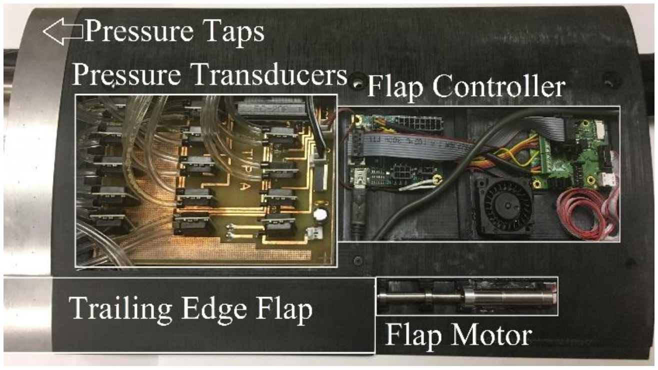

Figure 1 In-blade surface pressure measurements and flap actuation and control

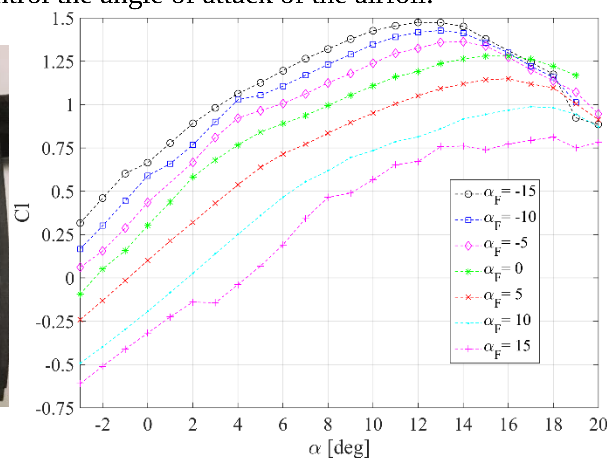

Figure 2 C_l versus α for different flap angles (simulation results)

Results

Initially, XFoil was used to simulate the aerodynamic characteristics of the S833 airfoil for different flap angles (α_F). The airfoil geometry was imported to XFoil with a Reynolds number of 450,000. The angle of attack (α) was varied between -3° to 20° in steps of 1° while the α_F was varied between -15° to 15° in steps of 5° (+α_F is defined when the flap is deflected to the suction side of the airfoil). C_l is plotted against α for different α_F in Figure 2. The different C_l curves clearly show that for different α_F, C_l is shifted to the left or right depending on the flap angle direction. ΔC_l is larger for positive α_F and smaller for negative angles. This is due to the fact that the simulated airfoil is non-symmetric. Increasing the camber in the same direction (negative α_F) will not have the same influence as changing the camber in the opposite direction (positive α_F). Experimental data will confirm these results.

Conclusion and Future Work

Based on previous work by various groups and the results of simulations it is concluded that the TEF is fully capable of controlling the load on the blades and power output of the wind turbine. By the conference, the experimental setup will be tested and the C_l for different α_F and α will be analyzed. This would be the first step to show the airfoil section is capable of load manipulation and will be installed on the wind turbine in the future.

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