Analysis of Modifications on Wind Turbine Blade

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Abstract

This project looks into the combination of upper surface dimples and trailing edge serrations of a 3D thin airfoil and their effect on aerodynamic performance. Dimples are known to reduce the drag while a serrated trailing edge is known to reduce noise. A flatback design is also studied to see if its properties also apply to a thin airfoil. The airfoil in the present study is NREL S825, to be 3D-printed with six combinations of the proposed modifications and tested in a wind tunnel. This study has found that the combination of dimples, flatback, and serrations has increased the maximum lift coefficient by 9.85%; however the maximum lift-to-drag ratio has been reduced by 14.4%.

Introduction

There is a need to improve how we generate the electricity we use. Renewable energy such as solar and wind are two solutions being implemented worldwide. However, these methods are not as efficient as they can be. The present research searches for a way to improve wind energy production by improving the shape a wind turbine blade.

Background

Previous studies looked into the aerodynamic effects of a variety of trailing edge modifications such as sawtooth, sinusoidal, and slotted sawtooth serrations, flatback, and splitter plates. The serrations have shown to reduce noise generated by the blade; however they trade performance to do so[1]. Flatback reduce the sensitivity of surface soiling which improves maximum lift performance but introduces a cavity that increases drag[2]. Splitter plates alleviates the drag penalties by breaking up the vortex generated by the flatback shape[3]. Vortex generators, such as surface dimples, on the upper surface of a wing or blade are a solution that recirculate the air flow and forcing it to stick to the surface, delaying separation and reducing overall drag.

Problem

The objective of this work is to study the behavior of a wind turbine blade when it is modified with upper surface dimples, flatback trailing edge, and trailing edge serrations. These modifications should help improve the performance of a blade by reducing the drag wake. The dimples should act as vortex generators, delaying boundary layer separation. The flatback shape should reduce the pressure gradient along the surface of the blade, and the serrations should break up vortices behind the blade by forcing the wake to dissipate energy.

Methodology

Work began with selecting a wind turbine airfoil to be tested. The Flatback conversion was done by applying a distribution function that evenly adds thickness to the trailing edge of the airfoil without altering the camberline. The M-shape serration geometry and upper surface dimples were chosen for their drag reduction characteristics. The models were generated in CAD by combining the different permutations of the geometries in question.

The selected airfoil and its modifications were 3D printed with PLA into a 6" chord by 12" span blade. Figure 1 shows a few of the blades designed for this work. To test the blades, a wind tunnel with a force balance beam was used. A threaded aluminum insert is introduced to attach the blades to the force balance beam. Lift and Drag was measure for a wide range of angles at a Reynolds Number of 296,000.

Figure 1: Model Blades (Left to Right): Flatback, Serrated Dimple, Control

Results and Discussion

The data obtained from the experiments was analyzed to find the difference of each model with respect to the control model. Each dimple variant was also compared with its smooth counterpart and the serrated variants compared with the flatback design.

The present Table 1 contains the most relevant parameters of this study, namely the maximum lift coefficient and the maximum lift-to-drag ratio, with their respective angle of attack. The maximum lift for each of the modifications, except for the Control Dimple, increased while maintaining the angle of attack of maximum lift somewhat constant.

All variations managed to reduce the zero-lift angle, meaning that each variation managed to improve the lift in the linear region of the control blade. Due to the relative increase in drag forces measured, the maximum lift-to-drag ratio worsened. A lower angle of attack for this ratio would have meant less twist on a real turbine blade.

The dimple design used seems to have been most effective on the Flatback design, having the highest relative increase in lift with lowest increase in drag. The serrations also seem to improve lift characteristics of the flatback design but did not manage to reduce drag as expected. Figure 2 is a comparison of trendlines of lift and drag based on the acquired data during the experiment. They show how the dimples have little effect on the lift of the blades tested and how each modification increases drag on the baseline blade.

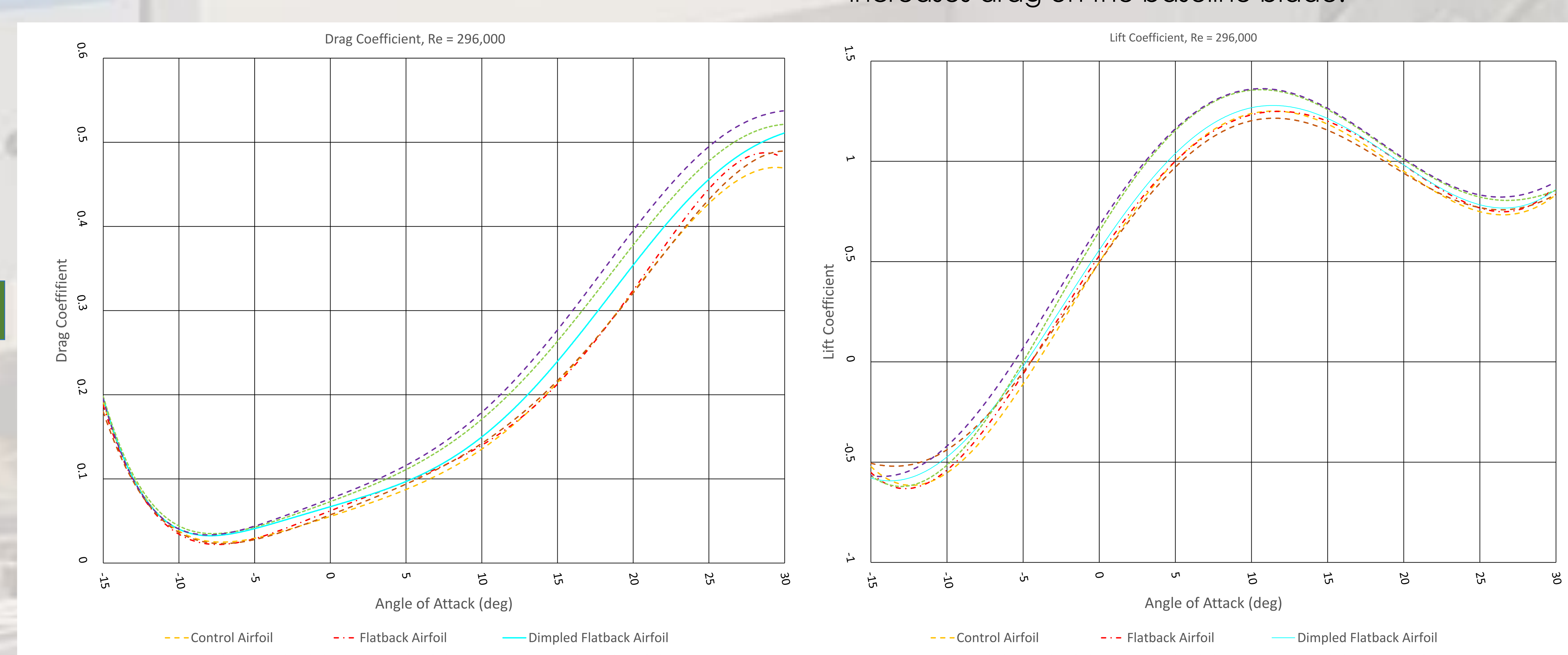

Figure 2: Comparison of drag coefficient (left) and lift coefficient (right) of the model blades, Re = 2.96E5

Conclusions

All models possess similar aerodynamic behavior. The M-shape serrations improved the overall lift performance of the blade by 7.43%, but drag also increased by 22.62%. The upper surface dimple design did not have a substantial effect on the blades. The flatback design does not seem to be suitable for the selected airfoil as lift was unchanged while increasing drag. The combination of serrations, dimples, and flatback shape increased the maximum lift coefficient by 9.85%; however the maximum lift-to-drag ratio has been reduced by 14.4%. All variations generated more drag than the control model, without an equal increase of lift.

Table1: Aerodynamic Characteristics of Experimented Blades

Model / Characteristic	Cl_{max}	α_{Clmax}	$\alpha_{CL=0}$	CL/CD_{max}	α_{CL/CD_max}
Control	1.32	12.00	-4.45	10.42	2.00
Control Dimple	1.24	13.00	-4.63	9.65	3.00
Flatback	1.33	13.00	-4.57	9.65	5.00
Flatback Dimple	1.39	13.00	-5.15	9.15	5.00
Serrated	1.44	12.00	-5.17	9.35	1.00
Serrated Dimple	1.45	10.31	-6.15	8.92	4.16

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References

1. X. Liu, M. Azarpeyvand and R. Theunissen, "On The Aerodynamic Performance of Serrated Airfoils," in *The 22nd International Congress on Sound and Vibration*, Florence, Italy, 2015.
2. E. S. Ferry, "Estudio aerodinámico y optimización de perfiles flatback aplicado a aerogeneradores.," Universitat Politècnica de Catalunya, 2014.
3. J. P. Baker and C. v. Dam, "Drag Reduction of Blunt Trailing-Edge Airfoils," *Bluff Bodies Aerodynamics & Applications*, 20-24 July 2008.