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Project Condor: Early numerical study of bio-inspired winglets in wind turbine applications

Khashayar RahnamayBahambary[1], Brian A. Fleck[2], Alexandra Komrakova[3],
Ryan Church[4], Evan Chou[5]

[1] *University of Alberta, Edmonton, Canada, Krahnma@ualberta.ca*
[2] *University of Alberta, Edmonton, Canada, bfleck@ualberta.ca*
[3] *University of Alberta, Edmonton, Canada, komrakov@ualberta.ca*
[4] *Biome Renewables, Toronto, Canada, rchurch@biome-renewables.com*
[5] *Biome Renewables, Toronto, Canada, echou@biome-renewables.com*

SUMMARY:
A steady-state Reynolds averaged Navier-Stokes simulation of a bio-inspired winglet (Project Condor) designed by Biome Renewables (Biome) has been conducted to demonstrate the applicability of this innovation on the DTU 10 MW reference wind turbine model. The addition of this novel retrofit will increase the annual energy production of a wind turbine while requiring only a modest capital investment. The multiple reference frame approach applied in this study shows agreement with the previous studies; the simulated power curve of the turbine retrofitted with this winglet indicates that such a modification can lead to an average power increase of 8.21 % across a range of wind speeds tested in the partial load regime through to rated power.

Keywords: CFD, Wind turbine, Winglet

1. INTRODUCTION

Renewable energy plays a crucial role in the electricity market of Canada, accounting for 68% of the energy production (Agency, 2022). Given the increasing demand for clean and renewable energies, even a slight increase in energy production can lead to a larger return on investment. A method of increasing the efficiency of the rotary machinery is to decrease the drag. Surprisingly, wing tip modification is among the less implemented methods of achieving this increase in wind turbine applications in spite of its proven effectiveness in fixed-wing applications. Wing tip vortices that originate from the lift-generating bound vortices result in an increase in the induced drag. By making use of winglets, the effects of the wingtip vortices are minimized, and as a result, the lift-to-drag ratio increases.

Sørensen et al. (2006) was among the first to study the implementation of winglets in wind turbines using fully resolved CFD simulations. By conducting a Reynolds averaged Navier-Stokes (RANS) simulation using the $k-\omega$ SST turbulence model, Sørensen et al. showed that the addition of the winglet caused 0.6% to 1.4% increase in the power output of the wind turbine. Chattot (2009) used the vortex model to investigate the effects of a wind turbine winglet's sweep and dihedral, and the results indicated that these additions enhance the performance of wind turbines. By developing a free wake-lifting line code, Gaunaa and Johansen (2007) showed that downwind-facing winglets are preferable to upwind. The investigation of the effects of a winglet on a small-scale stall-regulated turbine demonstrated that this modification could lead to a 9.4% increase in peak power (Maniaci and Maughmer, 2012).

To account for the addition of winglets, vortex-based methods have been extensively used in the literature due to their low-cost implementation, but with advancing computational technology, rotor-resolved modeling has become more accessible in recent years. By conducting a steady-state simulation of the NREL VI blade and coupling it with a multi-point optimization scheme, Elfarra et al. (2014) optimized the cant and the twist angle of the winglet that resulted in a 9% increase in power output. To investigate the accuracy of wind turbine modeling methods, the well-known lifting line method, blade element momentum (BEM) method, and the vortex-based method were validated using a blade-resolved Navier-Stokes equation by Horcas et al. (2022). The results showed that the lifting line method provides the best match to CFD results, while the BEM method showed the least similarity.

2. METHODOLOGY

For Project Condor, Biome's winglet is used to study the aerodynamics of the 10 MW DTU Turbine (Bak et al., 2013). Firstly, the numerical simulation of the baseline model (without the winglet) is validated. The baseline model results are then compared to the winglet data, followed by a discussion of the findings. To account for the rotation of the blades in a non-transient simulation, the multiple reference frame (MRF) approach was used.

2.1. Winglet

The Biome's novel wind turbine blade tip retrofits were inspired by the shape of the wings of the Andean and California condors. A condor's wings allow them to glide and cover distances as large as 150 miles in a day without flapping its wings (Cohn, 1993), taking a circuitous route comparable to the aerodynamics of a wind turbine. The Biome's winglet, shown in Fig. 1, is retrofitted to the

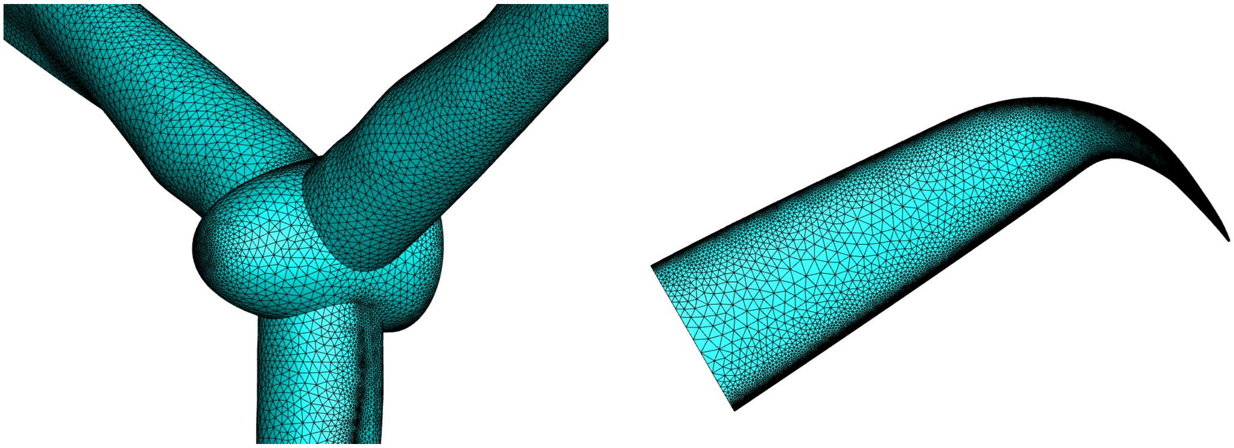

Figure 1. The hub and winglet mesh

tip of the wind turbine and increases the rotor radius by 1.02%. The length of the winglet itself is 5.35 m.

2.2. Blade and Winglet Mesh

The blade has a span of 89.60 m and 91.35 m in the baseline and winglet cases, respectively. Assuming that the tower and nacelle would not affect the differential change in efficiency with and without the wingtip, neither were incorporated in this simulation. The simulation domain was a $400m \times 400m \times 1000m$ rectangular box. The baseline mesh consisted of 12 million cells, while approximately 36 million cells were used to fully capture the physics of the flow near the wingtip region. The mesh at the hub and the winglet are shown in Fig. 1. An initial cell height of 0.5 cm and 0.01 cm was used to resolve the boundary layer at the ground and the blades, respectively.

3. RESULTS

Five different inflow conditions were used to investigate the validity of the baseline model. A comparison of results can be seen in Fig. 2. As can be seen, the results generally agree with Bak et al. (2013) data, and the difference between the current study and the published baseline DTU 10 MW data is limited to 10% at V=8 m/s. The same inlet velocities were then used to investigate the effects of the winglet. A summary of the winglet data is shown in Table 1. The results show that the efficiency of the winglet is a function of the velocity, with the peak improvement of 9.53% taking place at the velocity of 10 m/s. More importantly, the winglet increases the output of the turbine by 6.54% at the rated speed of 11 m/s. This increase in the turbine's power production is

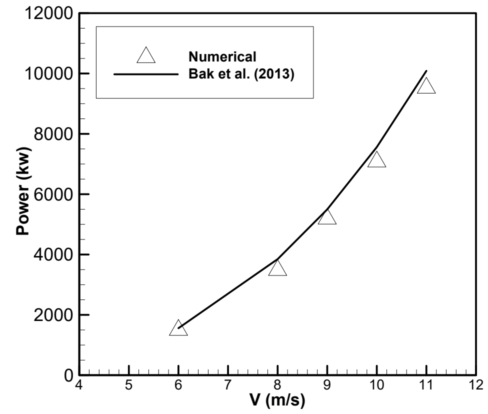

Figure 2. Power results of different inflow conditions.

Table 1. Power production in the baseline and winglet case.

V (m/s)	RPM	Baseline power (kW)	Winglet power (kW)	% Increase in power
6	6	1495	1611	7.75%
8	6.426	3480	3762	8.10%
9	7.229	4939	5395	9.24%
10	8.032	6802	7451	9.53%
11	8.836	9521	10183	6.45%

not due to the blade's surface area, given that the total increase in the surface area of the blade is less than 1%. As seen from Fig. 3, the presence of the winglet drastically affects the flow field in the vicinity of the tip region, increasing the axial velocity. This undoubtedly forms part of the reason for the power gains that are seen in this study.

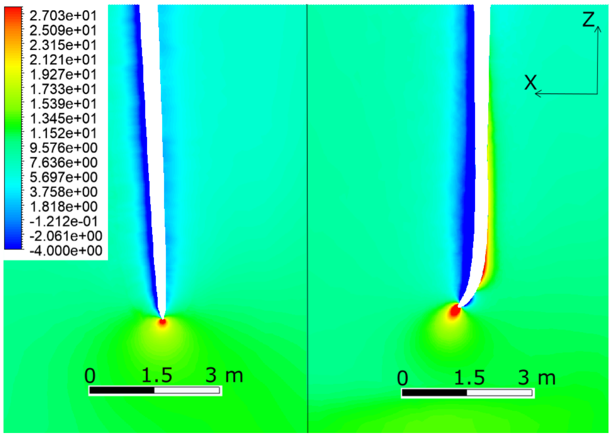

Figure 3. Axial velocity at the wingtip

4. CONCLUSION

In this study, a numerical investigation of the newly designed Biome winglet was conducted. The results showed that the implementation of the winglet can help increase the power output by 8.21 % on average. Future work will aim to tackle the following: How can this increase in power be further explained? How does the winglet affect the wake recovery? What is the impact of unsteady flow conditions using unsteady RANS, and what is the magnitude of the impact of blade length extension versus the geometry of the winglet itself? Finally, can the simulated flow morphologies be incorporated into Biome's next generation of winglet design?

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