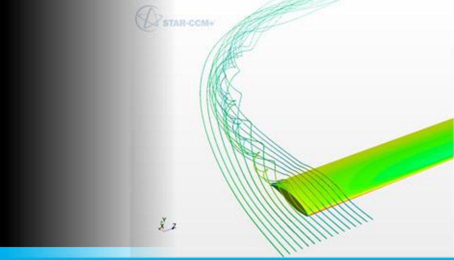
NTNU

A computational fluid dynamics investigation of the performance of tip winglets for horizontal axis wind turbine blades



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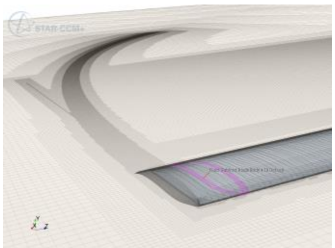
Introduction

- Both in offshore and onshore wind turbine installations limitations may arise for wind turbine blade radii due to for example either structural loading or noise issues. In such a case, in order to achieve a higher maximum power output from a single wind turbine it becomes a natural goal to increase its maximum power coefficient. This study aims to shed some light on the aerodynamic effects induced by the addition of turbine blade tip winglets by use of both steady state and transient computational fluid dynamics (CFD) approaches.
- A substantial amount of work exists on the topic of winglets, with respect to the development of wings on airplanes and race-cars, but the research is less extensive with respect to use in wind turbine blades. Many studies however, seem to agree that the addition of winglets may substantially improve the efficiency of the turbine, though more so in cases with high aspect ratio blades and relatively low Reynolds numbers (1).
- A recent study, by Y. Ostavan (2) further suggested that the addition of winglets on blades on a up-stream turbine may be beneficial for the total power output of two in-line HAWT's, such as could be the case in wind turbine farms.

Methods

- The first part of the study concerns the effects of simple tip vanes/end-plates, similar to MIE-vanes (1) on isolated blades and utilizes steady state RANS simulations, with turbulence modelled with the Realizable k-epsilon formulation.
- Two types of situations are investigated; straight flow and planar rotational flow implemented by introducing a rotating reference frame.
- The isolated wing is rectangular, with a span to chord ratio of ~15, similar to the blades of the test turbines used in experimental studies at NTNU (5). The profile of the wing is the NREL S826.
- The wing is split into several segments for analyzing lift and drag distribution, analogous to analyzing techniques used in blade element momentum (BEM) codes.

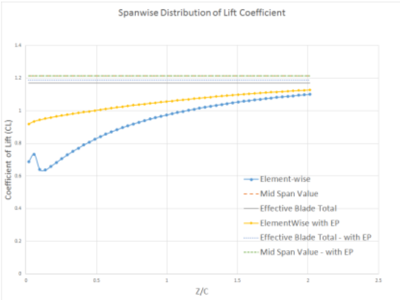
Curved and straight domains. Z axis is aligned with the span of the blades, X along the streamwise velocity for the straight tunnel.



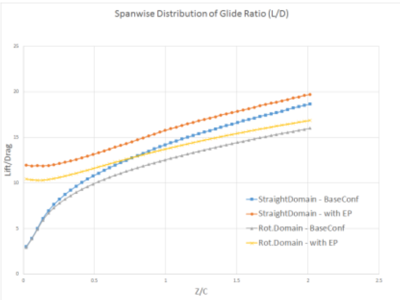
Mesh of the curved domain, with one element highlighted. Each connected blade element is 1 mm wide or ~1/25 Chord legths.

Results

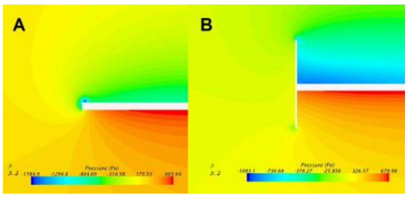
- In presented order; lift coefficients and glide ratio span wise distributions for an isolated wing, pressure distribution for cases A and B (without and with end plates (EP), respectively), and finally a path line illustration of the pair of vortexes generated in the cases with EP's. Note that only glide ratio distribution is calculated for the blade experiencing rotational flow.



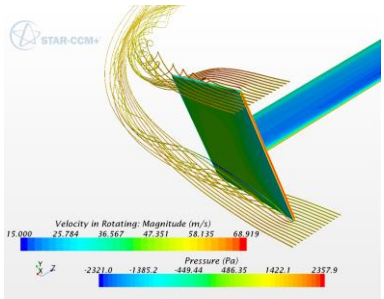
Span-wise lift coefficients for blade with and witout end-plates. The end-plate is one chordlength high, and extends slighty beyond the wing tip dimensions in the streamwise direction. For the case without an end-plate it's interesting to note the small local peak in lift at the tip, where the vortex roll-up creates a local low pressure zone on the suction side, at the cost of large values of drag. Wing tip is located at Z=0.



Glide ratio distributions along blade falling off toward tips; Z=0. Note the excellent agreement between the rotational and straight flow cases without end plates attached towards the tip of the blades where Reynolds numbers are matched.



Side by side comparison of static pressure distributions for cases with A; no tip-vane, and B; with rectangular tip vane. Plane is perpendicular to flow direction, looking downstream at position 0.64 chordlengths downstream of leading egde. Note that full formation of the vortex core is delayed in the wingletted case.



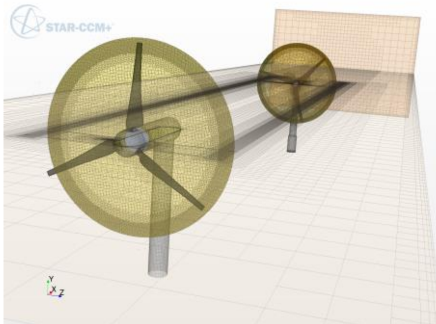
Blade with rectangular tip-vane. Surfaces are colored according to static pressure distribution. Pathlines colored according to velocity. On the suction side of the wing (top here) air is sucked (pushed) toward the inside of the vane, while the opposite happens on the pressure side causing vortex cores to align on opposite sides of the plate, as can also be seen in B.

Observations

- In the case of a wing or turbine blade of limited length, with rectangular shaped tips, the addition of simple end-plate structures can greatly improve the span-wise distribution of glide-ratio several chord-lengths into the blade.
- The study suggest that the addition of a winglet type add-on for a wing works much in the same way for a rotating blade as for a blade gliding along a straight path.
- By creating a physical barrier for the circulation of air at the tip, circulation is shifted and lift is increased along the span of the blade. This is along the same observation made by Gaunaa and Johansen (5).

Ongoing and Future Work

- Simulations using URANS and DES numerical schemes are currently under way investigating a winglet's effect on velocity deficits and turbulent kinetic energy in the wake of a turbine, as well as blade loads. Two in-line turbine geometries are modelled to help understand how the combined power-output can be optimized.
- Investigate the feasibility of developing an empirical model of the effect of simple winglet-type add-ons to turbine blades for use in BEM-theory design codes.



Computational domain modelling two interacting turbines to assess the effects of winglets mounted on an upstream HAWT turbine on it's wake and the performance of a downstream turbine. The blind-test experiment performed at NTNU presented in (5) serves as the reference case for validation of the simulations.

Acknowledgements

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References

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