Quantification of the Effects of Using Slats on the Inner Part of a 10MW Rotor

Gaunaa, Mac; Zahle, Frederik; Sørensen, Niels N.; Bak, Christian

Publication date: 2012

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit


General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.
Quantification of the Effects of Using Slats on the Inner Part of a 10MW Rotor
Mac Gaunaa, Frederik Zahle, Niels N. Sørensen, Christian Bak
Wind Energy Department, DTU, DK-4000 Roskilde, Denmark

Abstract
The present work attempts at quantifying the effects of using slats on the thick airfoils [4-7] of inner part of a modern multi-MW rotor [1] as a post-fix to increase power production.

In the process of doing this, the main behavior of the underlying physics is illuminated using a simplified BEM approach, and the effect of the lift and drag forces on local and integral power production and thrust is shown in a clear way.

Two different methods (a BEM based and a free wake lifting line method) for determining design angles of attack and lift coefficients corresponding to a specific loading on the inner part of the rotor are shown, and the results are compared.

For the design of the slats, a 2D CFD based optimization approach is shown, and the final results from the algorithm for four specific inner airfoil sections on the multi-MW rotor is shown.

Finally, the impact of the alteration of the airfoil section force characteristics are shown in the design point using both a BEM based and a free wake lifting line method, and BEM based results are used to assess the effects of the addition of the slats on the annual energy production.

Simplified BEM approach
A simplified version of the BEM equations is derived in the paper for use in the early stages of the design of the loading on the inner part of the rotor. By specifying the axial induction, lift speed ratio and chordlength along the rotor, the required lift coefficient can be obtained without iteration. Furthermore, the separate effect of lift and drag on power production are shown clearly, illuminating the driving mechanisms and drag penalty for power production along the rotor.

\[
C_P \simeq C_{P,inviscid} + C_{P,drag} \\
C_{P,inviscid} = \int_0^\infty \frac{2C_{l,loc}}{1 + \epsilon^2} \frac{1}{r^2} dr \\
C_{P,drag} = -\int_0^\infty \frac{2C_{l,loc}}{1 + \epsilon^2} \frac{1}{r^2} \frac{C_{l,loc}}{C_l} dr.
\]

Design angles and lift coefficients
In the paper, design angles and design lift coefficients obtained with the simplified BEM model and a lifting line method [2,3] is compared. It is found that even though the values of the predicted power production differ somewhat between the methods, the design points with respect to angle of attack and lift coefficient are in qualitative agreement. Since the uncertainties due to stall delay effects on the inner part of the rotor are likely to be very high, it is concluded that the design point supplied by the simplified method is of good enough accuracy to be used for initial design studies for additions of slats to the inner part of wind turbine rotors.

2D CFD based optimization tool
In order to be able to design the slats for the rotor, a 2D CFD based optimization tool was used. In the current work, the slit profile is obtained by adding extra camber to an existing airfoil. The location of the slat airfoil relative to the main airfoil is given by three parameters: a surface distance from the leading edge, a normal distance, and a slat angle, as shown below.

The optimization algorithm adjusts the slat parameters to optimize the performance of the combined configuration at the design angle of attack.

Conclusions
The article-counterpart of this poster have:
- Described a new CFD based tool for optimization of slats for thick airfoils
- Described a BEM-based simplified theory to aid in the design of slatted rotors
- Found that the power production potential by fitting slats on the inner part of design iteration 1 of the (quite heavily loaded) 10MW reference turbine is likely to be more than 1% AEP
- Stated that the beneficial effects of using slats may be larger if the slats and the main rotor blade are designed simultaneously
- Found that further work is needed to determine the AEP increase more accurately due to uncertainties in rotational effects/stall-delay
- Suggested that 3D CFD should be used to investigate a rotor with slats on to dig into these interesting issues

Acknowledgements
It is gratefully acknowledged that this work was partly funded by the Danish Energy Agency by the EUDP2010-I Light Rotor project. Furthermore, any work of this character would not have been possible without the patience of our loving wives and girlfriends.

References
5. Gaunaa, M. & Sørensen, N. N. Thick multiple element airfoils for use on the inner part of wind turbine rotors In The Science of Making Torque from Wind, Crete, Greece, June 2010.