On the tip vortex moving inboard before wake expansion drives it outboard

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Several SPIV experiments on model wind turbine rotors[1,2,3] focussing on the flow around the tip have shown that after being released the tip vortex first moves to a lower radius. This is in contrast to what is generally assumed, namely that the wake expansion starts immediately. A detailed analysis of one of these experiments, the 2m Ø TUDelft-B rotor tested in the TUD 3m Ø Open Jet Facility, is combined with CFD calculations and a vortex panel code using the full blade geometry. Figure 1 shows the tip of the rotor, the coordinate system and the contour of the flow analysis. For 6 chordwise positions of this contour the spanwise and chordwise vorticity, the associated circulation and the Kutta-Joukowsky loads acting on the chordwise vorticity have been determined. Figure 2 shows the results as a function of the chordwise position. The squares show the CFD data, the diamond marker indicates the experimental data and the triangles present the results of a momentum balance applied to the experimental data.

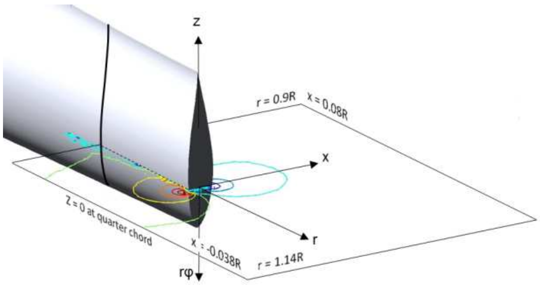

Figure 1: the tip of the TUD Rotor B

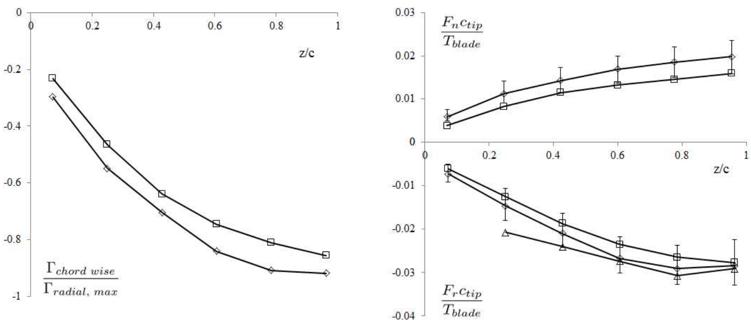

Figure 2: $\Gamma_{chordwise}$, F_{normal} and F_{radial} as function of chordwise position

The ratio of the integrated normal force $\mathcal{N}$ and radial force $\mathcal{R}$ to the thrust of the blade is 1 to 2%, so the contribution of the tip loads on chordwise vorticity to the overall rotor load is very small. However, when $\mathcal{N}$ and $\mathcal{R}$ are normalized by the thrust at the blade for r > 0.9R, the order of magnitude changes to 10%. $\mathcal{N}$ and $\mathcal{R}$ are the components of the conservative load on chordwise vorticity. It is conservative as it does not convert power and does not generate vorticity, in contrast to the non-conservative load on radial vorticity. Analyses methods based on the true blade surface, like full CFD or vortex panel codes, automatically take account of the conservative tip load as part of the pressure distribution. However, analyses methods in which chordwise information is discarded, like lifting line and actuator line methods, cannot include the conservative load as part of the solution. The impact of this is shown in figure 3, showing the tip vortex evolution as experimentally observed, as a result from a full (blade) CFD as well as vortex panel code and as an actuator line CFD (AL) result. Indeed the blade CFD predicts the inboard motion reasonably well, whereas the AL misses it. If this higher order tip effect has to be modelled, the conservative force tip load should be included.

An extensive treatment of this topic is to be published[4]. This contains a part on conservative loads on actuator discs, reported in a previous Euromech seminar[5].

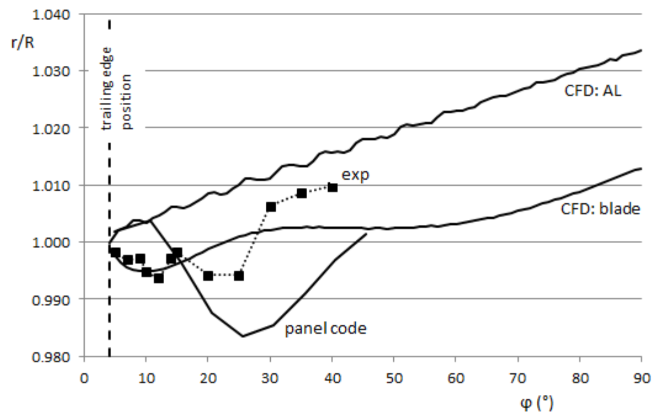

Figure 3: the trajectory of the tip vortex as function of the azimuthal angle after the c/4 position.

[1] Schepers *et al.*, conf. proc. Science Making Torque from Wind 2012
[2] Micallef *et al.*, conf. proc. Science Making Torque from Wind 2012
[3] Xiao *et al., Appl. Math. Mech. -Engl.*, **32**, (6) 729-738
[4] van Kuik *et al.* submitted to JFM
[5] van Kuik & van Zuylen. 2009 Euromech Symp.**508** 26-28

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