

Design of wind energy systems

SS 2015

Tutorial 2: Blade Element Momentum Theory

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ForWind – Wind Energy Systems

Outline

- Class exercise
 - Blade design
 - BEM (partial load)
- Home exercise
 - Distributed soon

Assignment

Data

- Consider the turbine defined in the table as an actuator disk
- Consider the disk evenly subdivided in 10 annular rings

Task

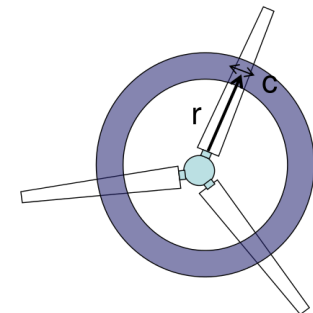
- Design a blade following Schmitz and using a NACA 63-215 profile (see C_L in tables of CIP-Tutorial)
- Evaluate the axial induction factor of the designed blade by means of BEM for an inflow speed 10 m/s

Turbine specification

Rotor diameter [m]	100
Number of blade [-]	3
Electrical conversion efficiency [-]	0.95
Design wind speed [m/s]	10
Design tip-speed-ratio [-]	7
Design lift coefficient * [-]	0.65

Air density [kg/m³] 1.225

* Based on max. gliding factor

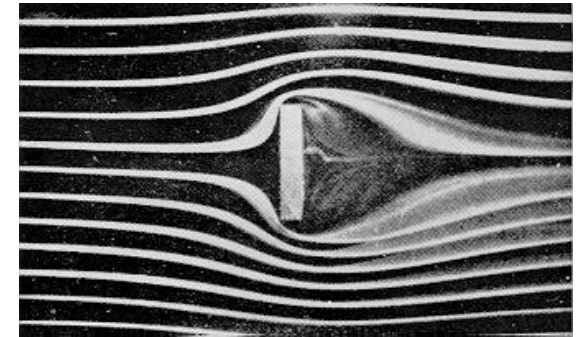


$$r = (r_{out} + r_{in}) / 2$$

BEM approximation/extension

During this tutorial the following assumptions are taken in order to implement the blade element momentum method

- No wake rotation
- No drag on blade element
- No tip-loss correction
- Wake separation, turbulent wake state (see next slide)



[Fig.: www.windpower.org]

Wake separation

- Turbulent wake state:

high tip-speed-ratio/induction-factor



rotor ~ impermeable disk



CThrust increases

- Spera (1994) empirical correction

$$a = \frac{1}{2} \left(2 + K(1 - 2a_c) - \sqrt{((K(1 - 2a_c) + 2))^2 + 4(Ka_c^2 - 1)} \right)$$

$$K = \frac{4\sin^2(\alpha)}{\sigma C_{Thrust}} \quad a_c \approx 0.2 ; \sigma = \frac{Nc}{2\pi r}$$

$$C_T = C_L \cos(\alpha) + C_D \sin(\alpha)$$

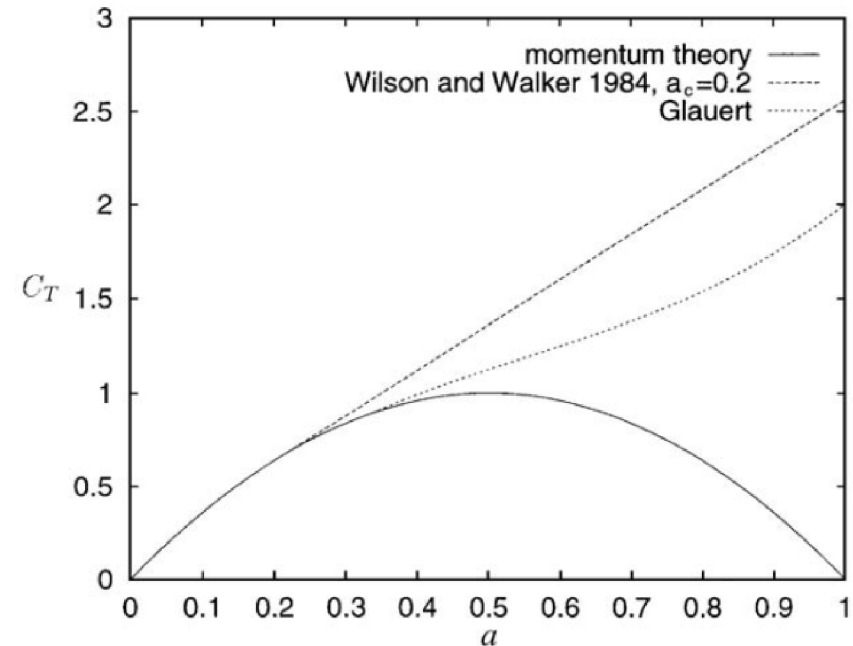
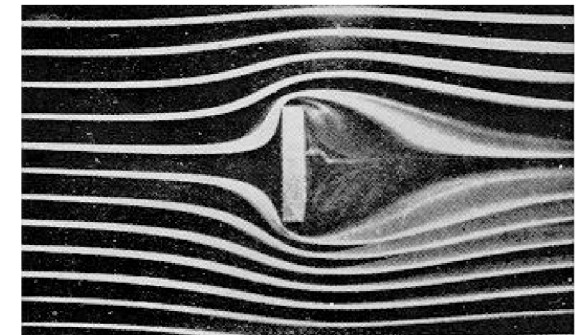


Fig. Hansen



BEM Algorithm

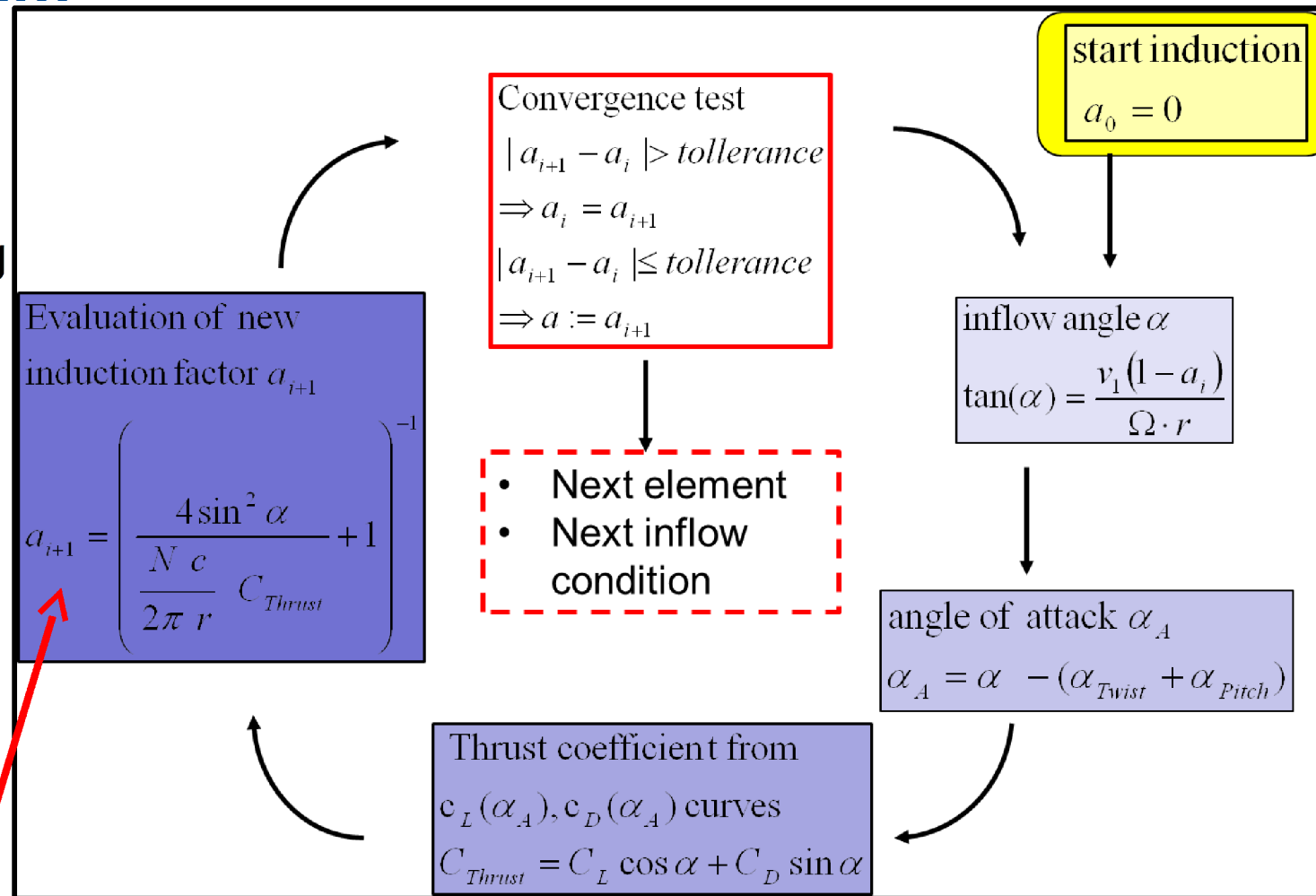
- $CD=0$
- if $a_{i+1} > a_c$
 a_{i+1} according to Spera

$$K = \frac{4 \sin^2(\alpha)}{\sigma C_{Thrust}}$$

$$a_c \approx 0.2$$

$$\sigma = \frac{Nc}{2\pi r}$$

$$a = \frac{1}{2} \left(2 + K(1 - 2a_c) - \sqrt{(K(1 - 2a_c) + 2)^2 + 4(Ka_c^2 - 1)} \right)$$



[from lecture 02, slide 13]

Aerodynamic profile (NACA 63-215)

- Use C_L table in Excel-sheet of CIP-Tutorial or use the approximations below to interpolate data for BEM
- C_L, C_D curve extended to α_A $-180^\circ, 180^\circ$
- Linear approximation of $C_L(\alpha_A)$
 - $\alpha_A \geq -20^\circ$, $C_L = -0.98 + 0.056 \alpha_A$
 - $\alpha_A \geq -10^\circ$, $C_L = 0.2 + 0.062 \alpha_A$
 - $\alpha_A \geq 0^\circ$, $C_L = 0.2 + 0.095 \alpha_A$
 - $\alpha_A \geq 15^\circ$, $C_L = 1.6$
 - $\alpha_A \geq 22^\circ$, $C_L = 2 - 0.02 \alpha_A$

