Design of wind energy systems
SS 2016

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

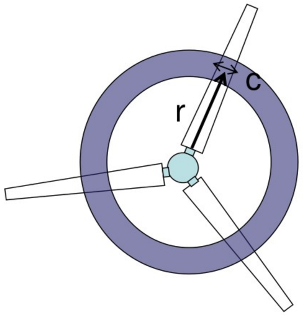
Task

- 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

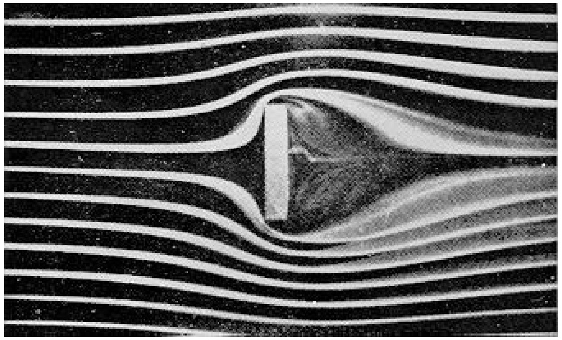


r = (rout+rin) / 2

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

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CThrust increases

- Spera (1994) empirical correction

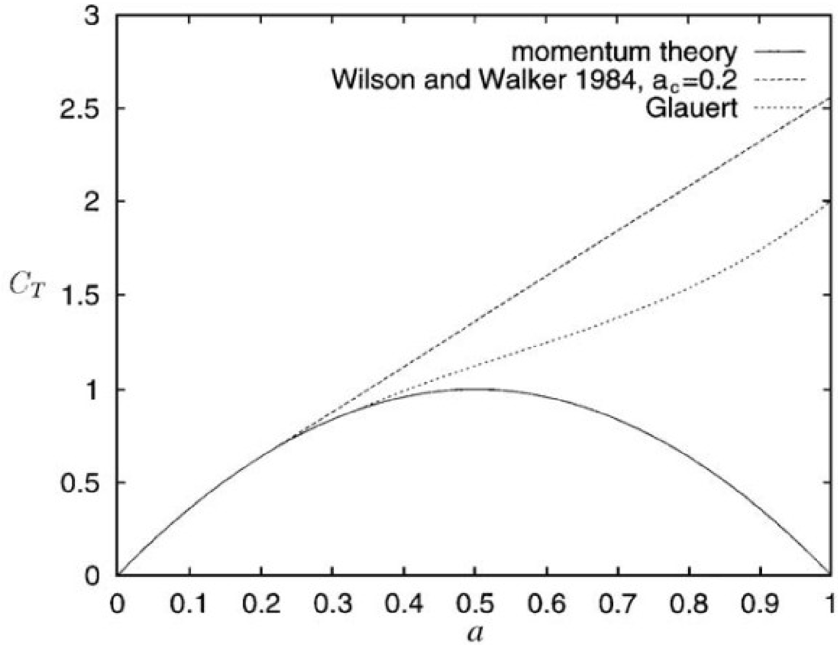


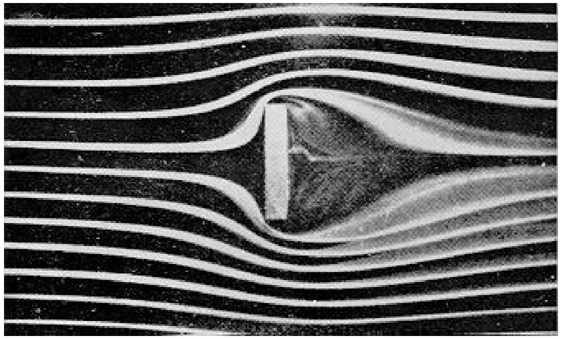
Fig. Hansen

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

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

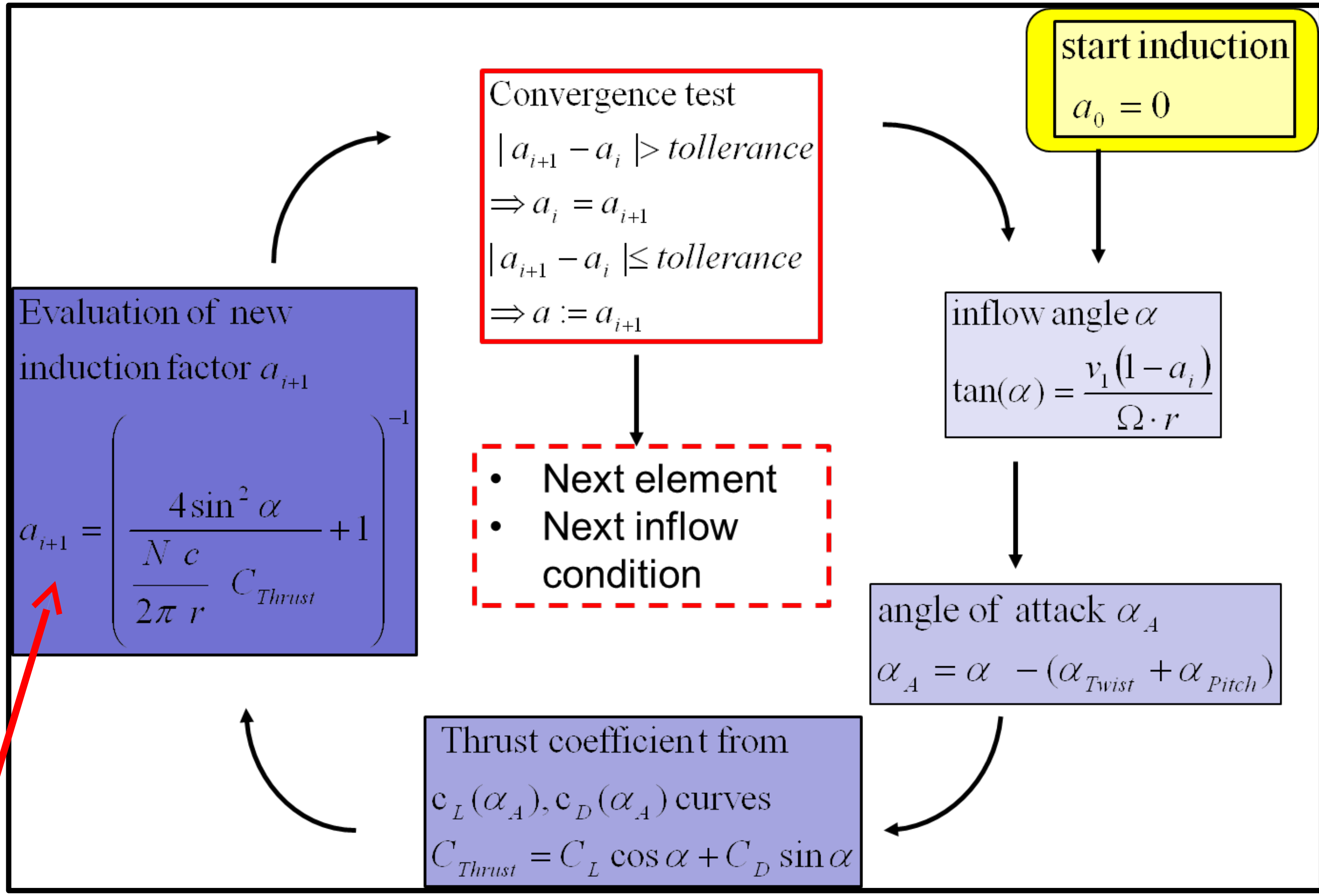
$$a_c \approx 0.2\,;\sigma = \frac{Nc}{2\pi r}$$

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



BEM Algorithm

- CD=0
- if ai+1>ac
  ai+1 according to Spera



[from lecture 02, slide 13]

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

$$a_c \approx 0.2$$

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

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

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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°,180°
- Linear approximation of $C_L(\alpha_A)$
  - $\alpha_A \geq -20°$, $C_L = -0.98 + 0.056\,\alpha_A$
  - $\alpha_A \geq -10°$, $C_L = 0.2 + 0.062\,\alpha_A$
  - $\alpha_A \geq 0°$, $C_L = 0.2 + 0.095\,\alpha_A$
  - $\alpha_A \geq 15°$, $C_L = 1.6$
  - $\alpha_A \geq 22°$, $C_L = 2 - 0.02\,\alpha_A$