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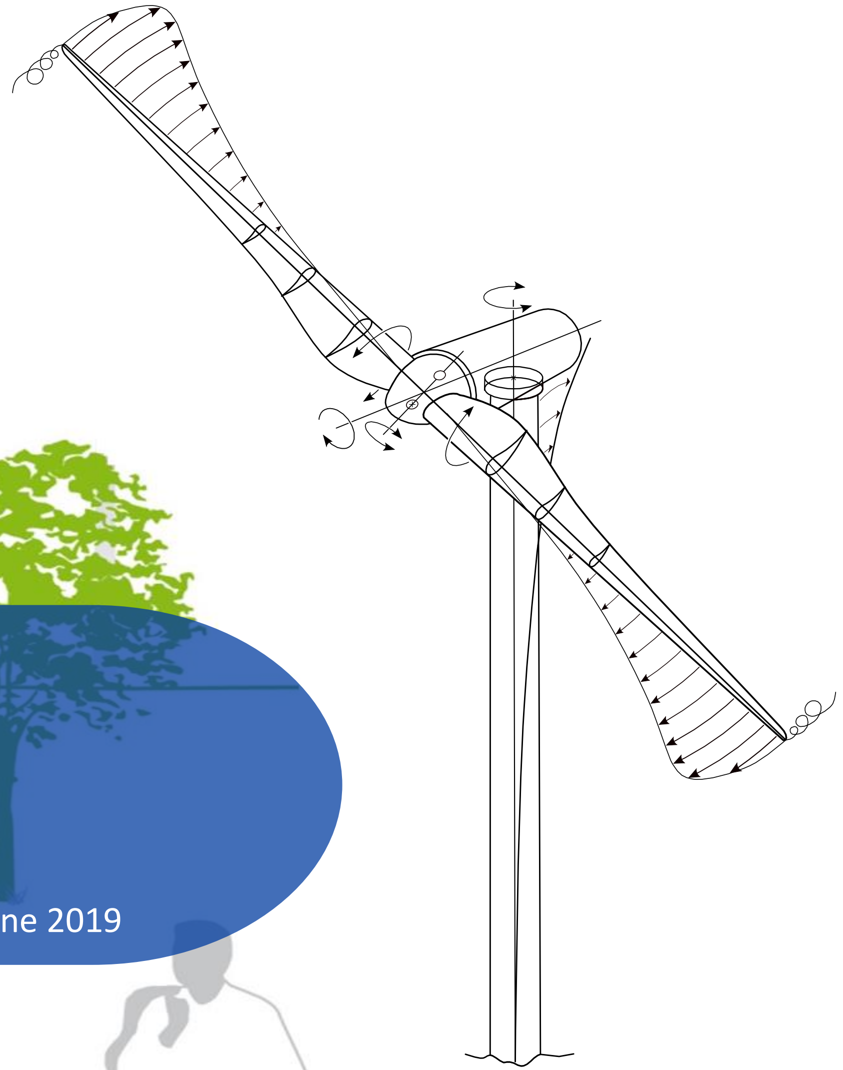

Hub design potentials for two-bladed 20 MW offshore wind turbines

M. Schütt, F. Anstock and V. Schorbach

Wind Energy Science Conference, Cork, 17th June 2019

Who are we?

Cooperation project:

“X-Rotor – two-bladed wind turbines”

20 MW turbines of the next generation

Between HAW HAMBURG | CC4E

and SIEMENS Gamesa RENEWABLE ENERGY

Funded by Federal Ministry of Education and Research


Source: Levin Schilling


Source: HAW Hamburg

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Motivation: Hub design potentials for two-bladed 20 MW wind turbines

Focus on:

Continuous hubs, oval blade connections, and partial pitch:

- No new idea
- MOD-2 from 1982 with 2.5 MW
- MOD-5B form 1987 with 3.2 MW

Questions:

1) Why could be an oval shape be beneficial?
2) Has such a design, as in the case of the MOD-Turbines, any advantages?

➔ Design study of different shaped blade connections

Source: Boeing, available: https://www.boeing.com/history/products/mod-2-mod-5b-wind-turbine.page, accessed 27 May 2019

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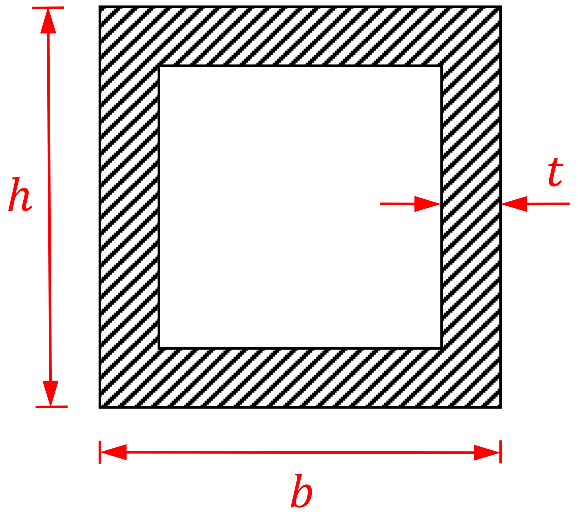
Estimation of section modulus and stresses

<u>Use of method of stress equality between 3B- and 2B-cross section[1]</u>

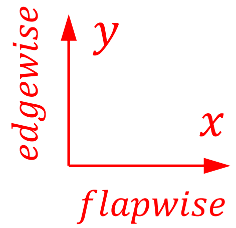
- One procedure of “redesigning” blades from a 3B-turbine to a 2B-turbine
- Basis is the increase of the chord by 50 % to maintain the same solidity
- Relate to the entire rotor blade, at each blade section



<u>Adaptions for the present work</u>

- Use of square cross sections instead of an circular cross section for simplicity: The results are identical!
- Application of the method to the first blade section as part of the entire rotor blade (blade connection)
- Look at x- and y-direction, not only at x-direction
- Look at different shapes for 2B-cross sections, no comparison between 3B- and 2B-turbines

$$\sigma = \frac{M}{S} \qquad S \approx bht + \frac{1}{3} h^2 t$$



$$\sigma_{edge} = \frac{M_{edge}}{S_x}$$

$$\sigma_{flap} = \frac{M_{flap}}{S_y}$$

[1]Source: Larsen TJ, Madsen HA, Thomson K, Rasmussen F. Reduction of teeter angle excursions for a two-bladed downwind rotor using cycling pitch control. EWEC Conference. 2007

Comparison of different shaped blade connections

Square / Circle

h = b

vs.

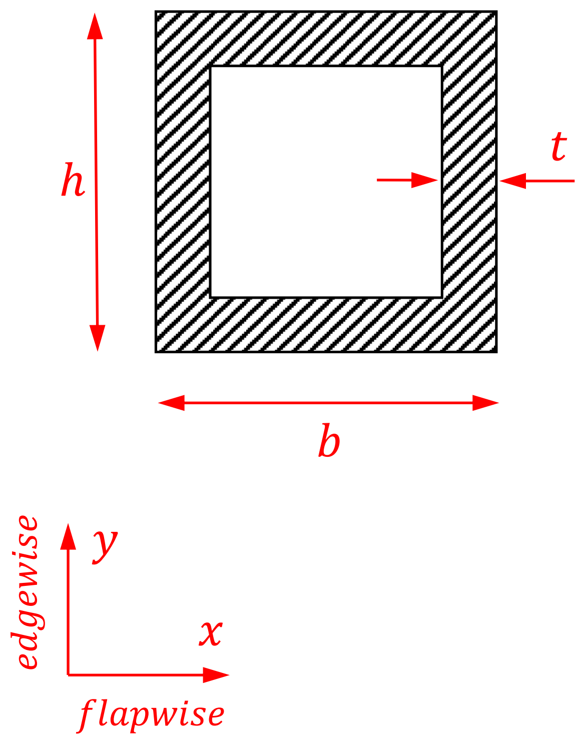
Rectangle / Oval

h = 2b

Reference:

$\sigma_{edge\ square} = 1$

$\sigma_{flap\ square} = 1$



$$thickness = const.$$

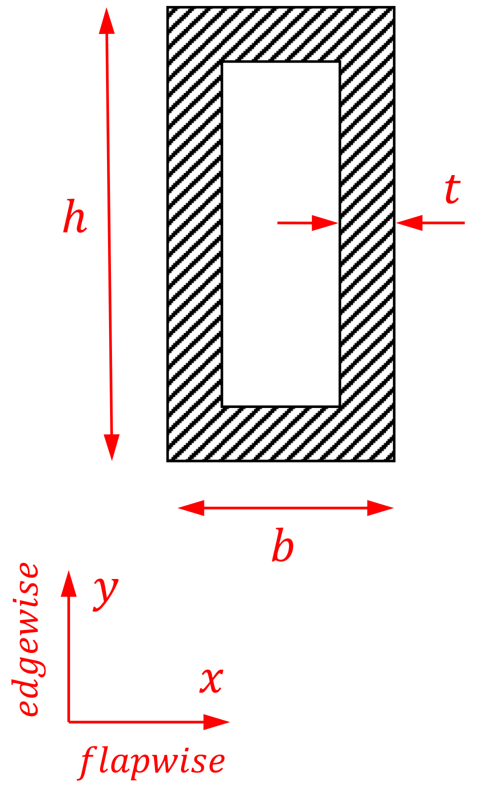
$$area = const.$$

$$material = const.$$

$$perimeter = const.$$

$$\Rightarrow h_{rect.} = \frac{4}{3} \cdot h_{square}$$

$$\Rightarrow b_{rect.} = \frac{2}{3} \cdot b_{square}$$



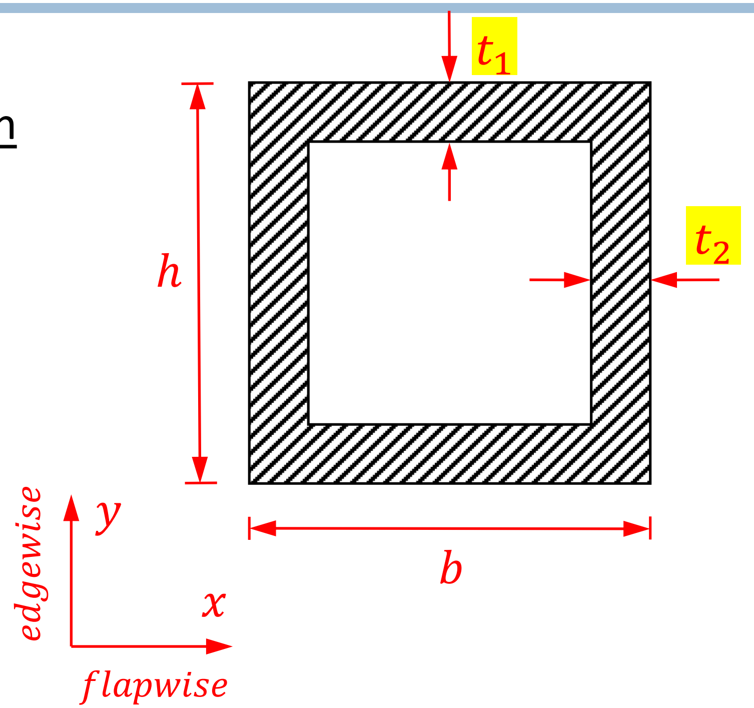
$\sigma_{edge\ Rect.}$
$= 0.9 \cdot \sigma_{edge\ square}$

$\sigma_{flap\ Rect.}$
$= 1.285 \cdot \sigma_{flap\ square}$

→Oval geometry (like MOD-Turbine hubs) is useful if edgewise and flapwise loads are unequal

→Reduction of material by design is possible

Study of different shaped blade connections for different loads



Material reduction by design due to different loads in edgewise and flapwise direction

- Use t_1 and t_2, instead of thickness t for the whole cross section
- Use of load factor f

Load factor f

$$f = \frac{M_{edge}}{M_{flap}}$$

Different settings:

Reference (Square / Circle)

$h = b$ and $t_1 = t_2$

$\Rightarrow\ S_x = S_y$

$\Rightarrow\ \sigma_{edge} = f \cdot \sigma_{flap}$

Optimized Square / Circle

$h = b$ and $t_1 \neq t_2$

$S_x \stackrel{\text{def}}{=} f \cdot S_y$

$\Rightarrow\ \sigma_{edge} = \sigma_{flap}$

Optimized Rectangle / Oval

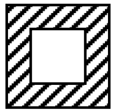
$h \neq b$, same perimeter, and $t_1 = t_2$

$S_x \stackrel{\text{def}}{=} f \cdot S_y$

$\Rightarrow\ \sigma_{edge} = \sigma_{flap}$

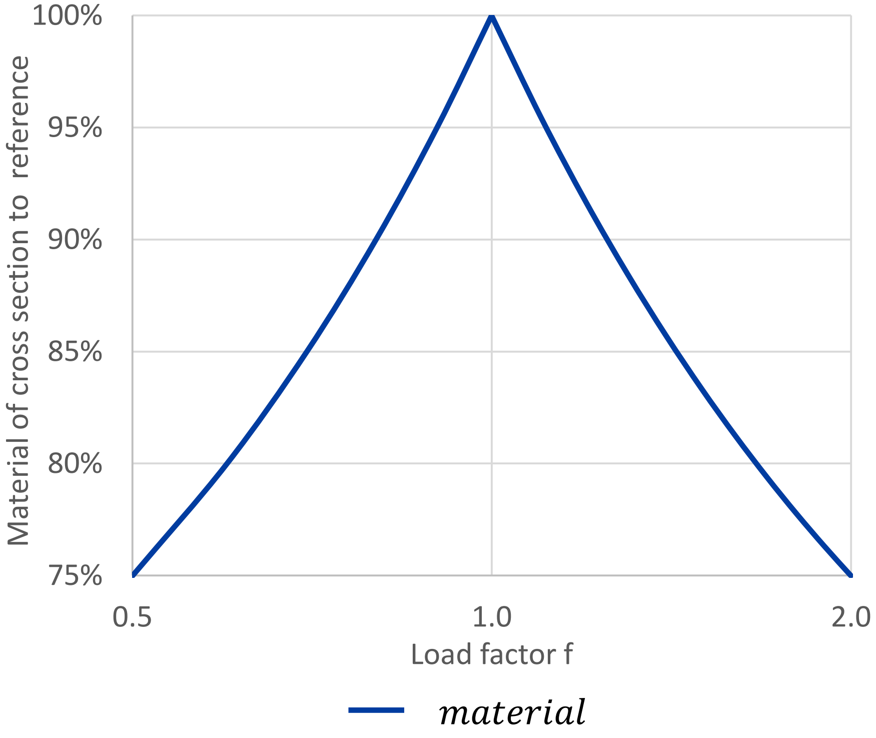
Study of different shaped blade connections for different loads

$h = b$
$t_1 \neq t_2$



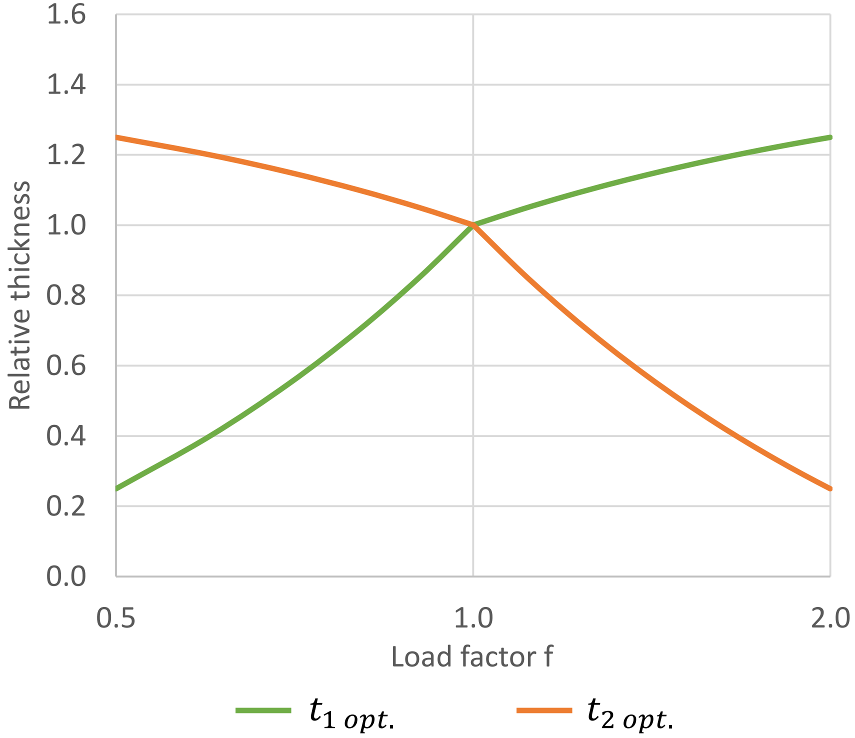
<u>Square / Circle:</u> $h = b$ and $t_1 \neq t_2$ are to be calculated for different load factors f

<u>Material reduction:</u>



$$\Rightarrow \frac{m_{square}}{m_{ref.}} \sim \frac{A_{square}}{A_{ref.}} \Rightarrow \frac{function_{square}\left(\frac{t_1}{t_2}\right)}{function_{ref.}\left(\frac{t_1}{t_2}\right)}$$

<u>Thickness ratio</u>



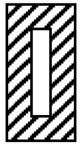
both for $\sigma = \sigma_{Ref}$ *and* $m < m_{Ref.}$

→ Maximum reduction by adapting t_1 and t_2 simulataneously

→ Depending on the load factor the thicknesses t_1 and t_2 are relatively low, strength and stability properties are not considered

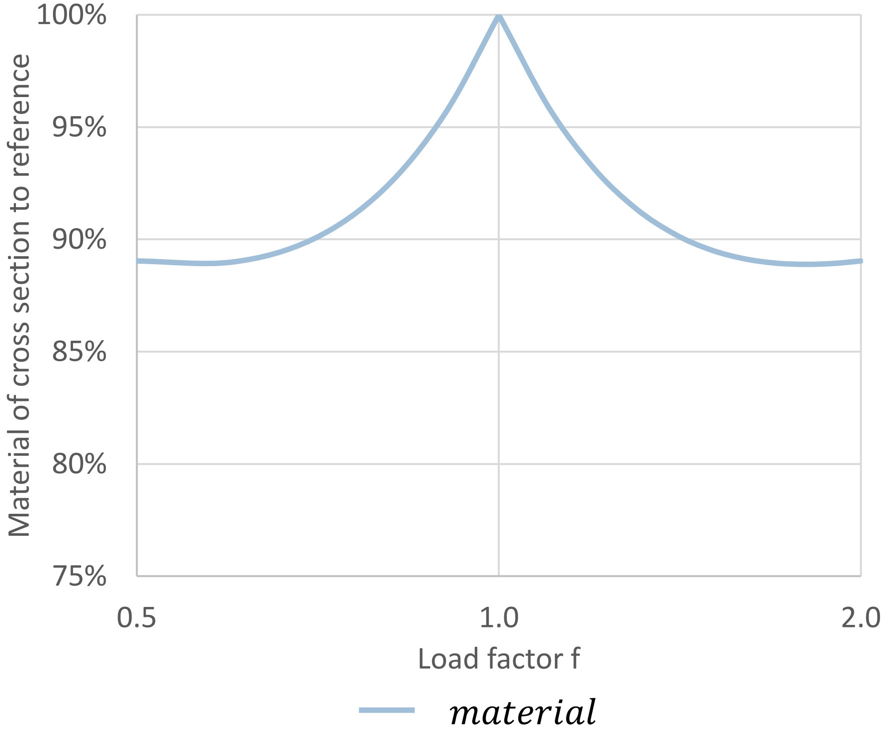
Study of different shaped blade connections for different loads

$h \neq b$
$t_1 = t_2$



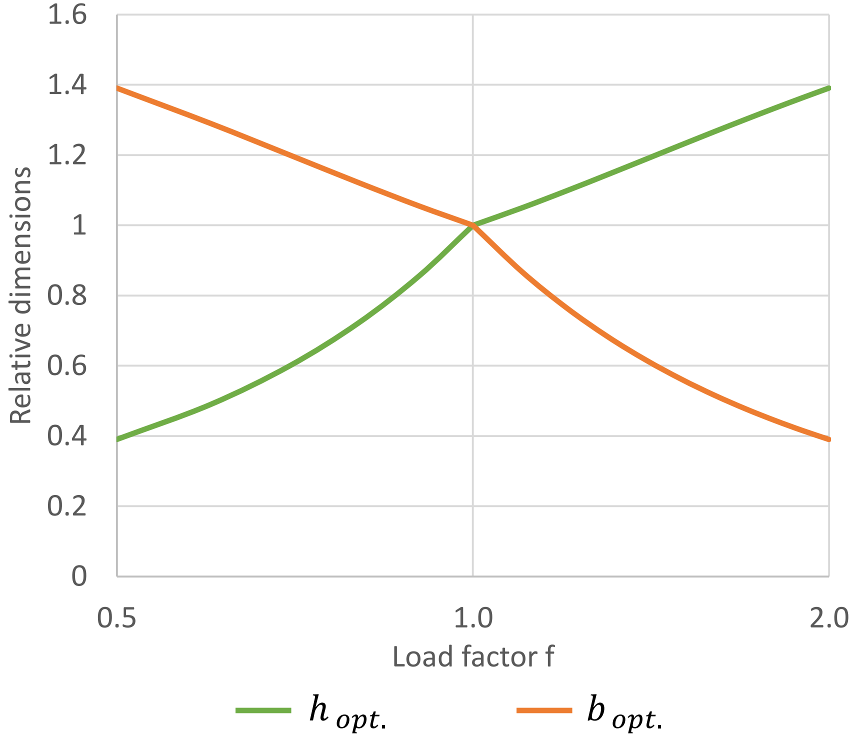
Rectangle / Oval: $t_1 = t_2$ and $h \neq b$ are to be calculated for different load factors f

Material reduction:



$$\Rightarrow \frac{m_{rect.}}{m_{ref.}} \sim \frac{A_{rect.}}{A_{ref.}} \Rightarrow \frac{function_{rect.}\left(\frac{h}{b}\right)}{function_{ref.}\left(\frac{h}{b}\right)}$$

Ratio of height and width



both for $\sigma = \sigma_{Ref}$ and $m < m_{Ref.}$

→ Maximum reduction by adapting h and b simultaneously

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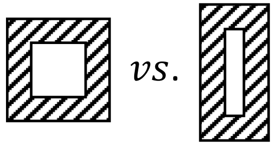
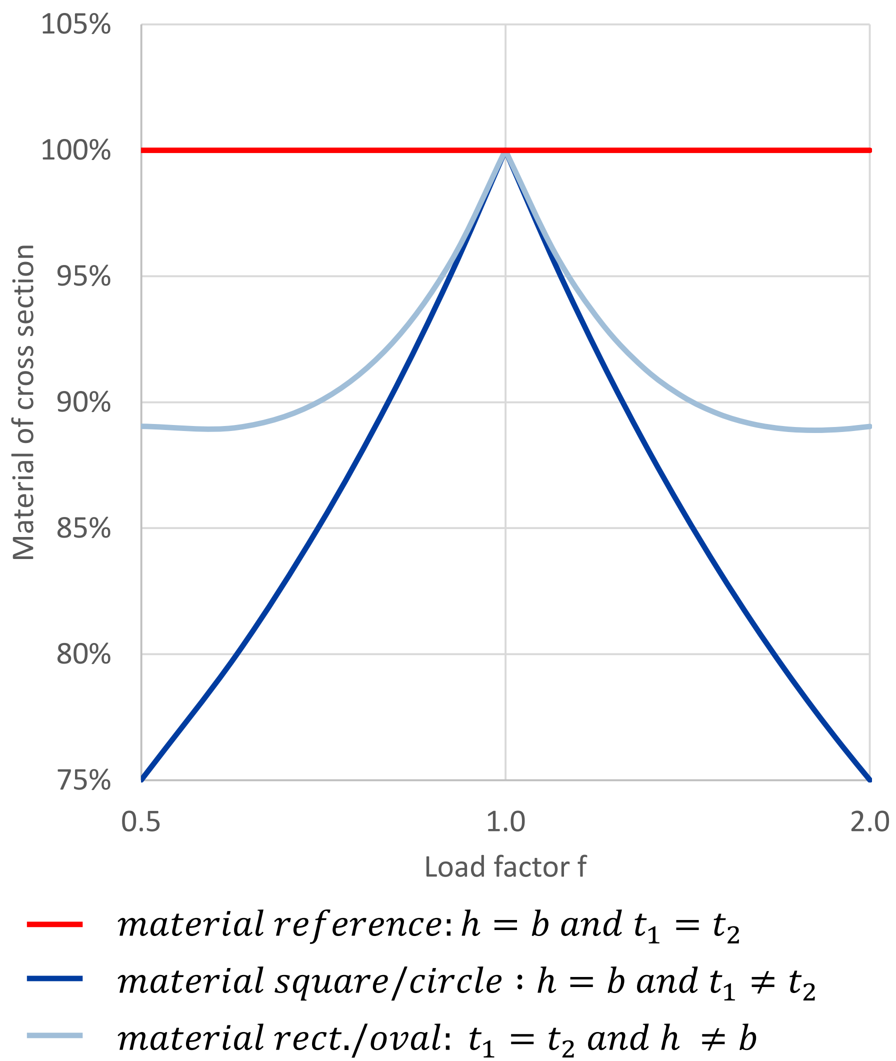
Conclusions



Material reduction

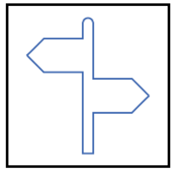


- The approach shows analytically the maximum possible material reduction potentials for different load conditions

- If a constant wall thickness is mandatory an oval blade connection is basically useful if edgewise and flapwise loads are unequal
- For optimized blade connections the adaption of the thickness is more beneficial than the adaption of height and width

- The idea to use an oval shaped blade connection was a first intuitive approach for different load conditions
- By maintaining the same perimeter, a circular blade connection has higher material reduction potentials
- Studies using other basic conditions could change the results

Outlook



1. Calculate material reduction for other basic conditions to understand advantages and disadvantages even better
2. Analyze the strength and stability properties of the cross section

- Not considered in this study
- Problems could result due to small wall thicknesses
- Especially buckling could be problematic
- High importance for two-bladed turbines:

→ To maintain the same solidity when redesigning a three-bladed turbine into a two-bladed turbine, a reduction of the thickness by $^1/_3$ is required[1]

➔ Finite Element Analysis (FEA) is necessary!

[1]Source: Larsen TJ, Madsen HA, Thomson K, Rasmussen F. Reduction of teeter angle excursions for a two-bladed downwind rotor using cycling pitch control. EWEC Conference. 2007

Thank you for your attention!

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Source: Levin Schilling