Scalability of the CRAFT turbine

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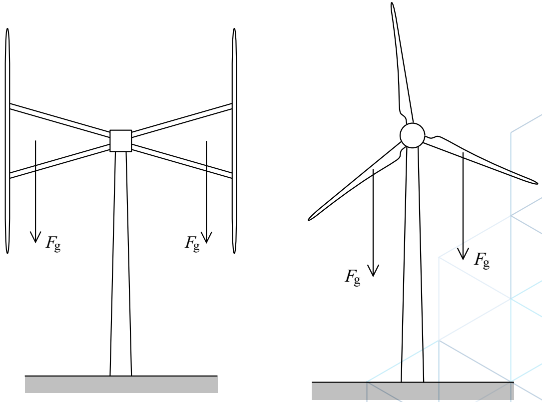
Introduction

- Trend in offshore wind: Increased scales!
- VAWTs probably well suited for really large scales:
  - Aerodynamic force F_a scales as area (i.e., L^2).
  - Gravitational force F_g scales as volume (i.e., L^3).
  - For HAWT blades: Gravity implies cyclic load – fatigue



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The CRAFT turbine

The CRAFT (Counter-Rotating Axis Floating Tilted) turbine:

- In between HAWT and VAWT.
- Developed by the company World Wide Wind.
- Proposed 8-MW version – baseline in this study:

Tip-speed ratio	6.0
Blade length	86 m
Blade mass	10 ton

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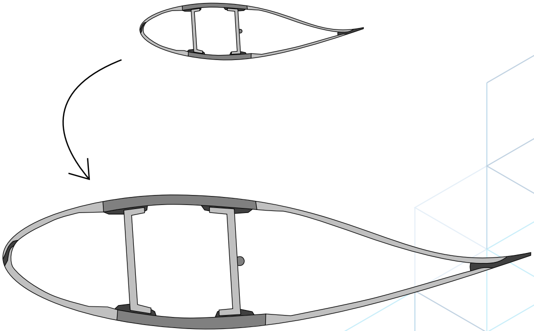
Scaling model

Similar scaling:

- All proportions preserved.
- Tip-speed ratio kept unchanged.
- Scaling parameter β:
  - Lengths: $\tilde{L} = \beta L$
  - Areas: $\tilde{A} = \beta^2 A$
  - Aerodynamic force: $\tilde{F}_a = \beta^2 F_a$



Material stress: $\sigma = F/A$

- As long as F_a dominates
  – then σ unchanged...

Scaling model

Similar scaling with slight modification:

- Wind profile:

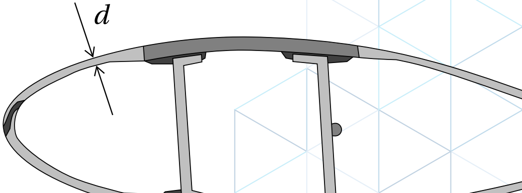
$$U_2 = U_1 \left(\frac{h_2}{h_1} \right)^{\alpha}, \qquad \alpha = 0.08 \quad \left(z_0 = 0.5 \text{ mm} \right). \tag{1}$$

- So... $\tilde{U} = \beta^{\alpha} U$
- This implies:

$$\tilde{F}_a = \beta^{2+2\alpha} F_a, \qquad \tilde{P} = \beta^{2+3\alpha} P \tag{2}$$

We want unchanged material stress...

- Impose that wall thickness scales as: $\tilde{d} = \beta^{1+2\alpha} d$.
- Then: $\tilde{m} = \beta^{3+2\alpha} m$
  and $\tilde{F}_g = \beta^{3+2\alpha} F_g$.



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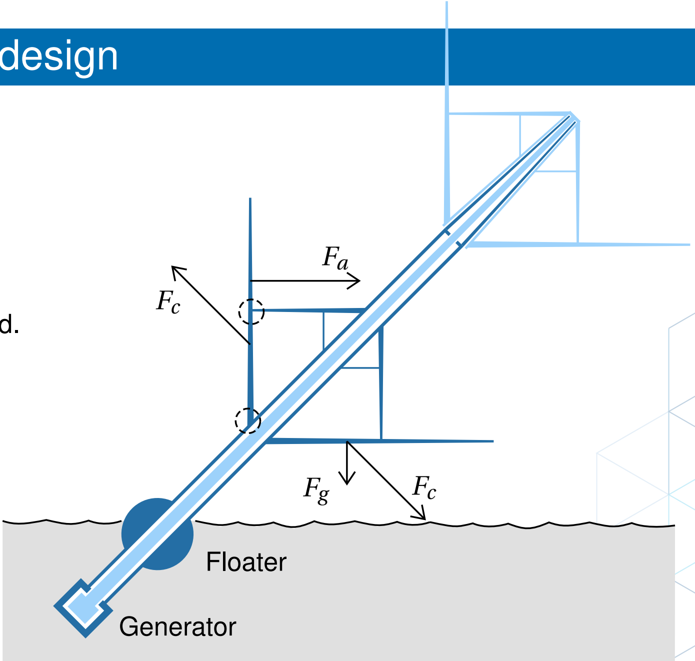
The CRAFT design

Forces on the blade indicated.

The cyclic nature of the blade load is clear.

Two critical areas highlighted.



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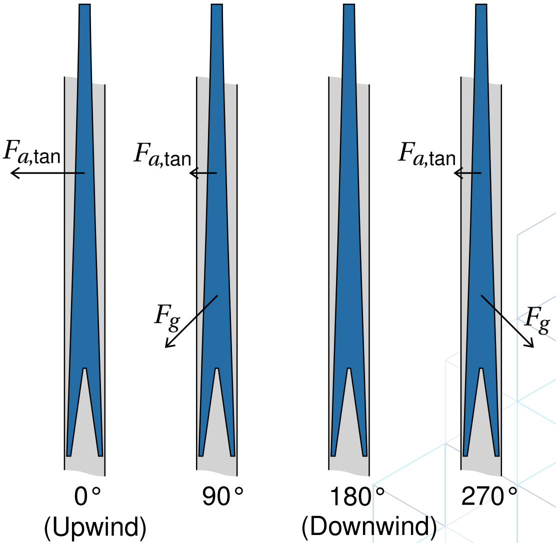
Blade attachment to tower

Forces that gives rise to a moment between the attachment points:

- Large forces at the attachment points due to short lever arm.
- Blade chord and $F_{a,\tan}$ from BEM analysis with $a = 0.2$.
- This is the most critical point. . .



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Fatigue analysis

Design ultimate stress – Goodman's rule:

$$\sigma_u = k\sigma_a + |\sigma_m| \tag{3}$$

mean

amplitude

Assumption:

- Fiberglass
- 10^8 cycles
- Then: $k = 7$

Now: Plug in the forces – amplitude and mean – then observe at which scale gravity starts to dominate σ_u...

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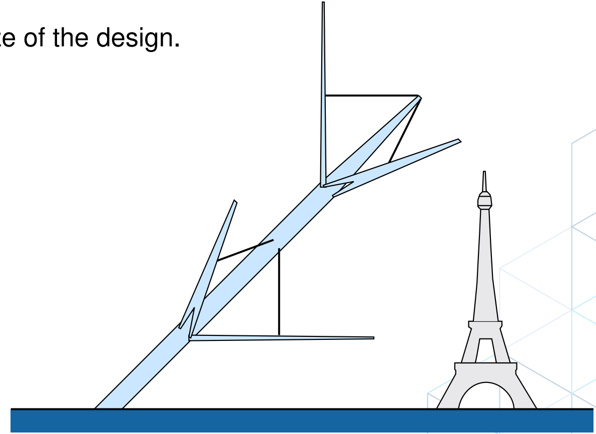
Results

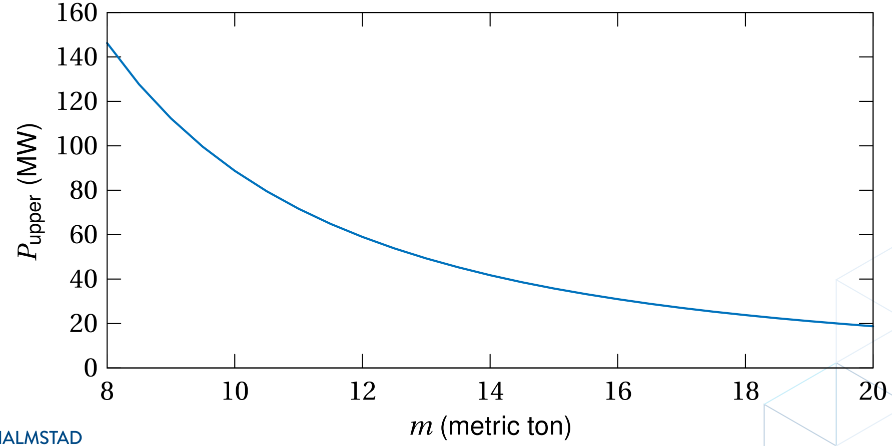
- Gravity starts to dominate the design work at scale $\beta = 2.9$, with reference to the 8-MW baseline.
- This becomes a likely upper size of the design.
- $\beta = 2.9$ translates into:

Rated power	90 MW
Blade length	250 m
Mass per blade	300 ton



Results

- The result is sensitive to the assumed blade mass of the 8-MW baseline.



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Conclusions

General conclusions:

- The CRAFT design seems to allow for large scales.
- Result dependent on the blade mass

This study does not address...

- ...if the 8-MW baseline is simple or difficult to design.
- ...if the upper scale is practical or economical.

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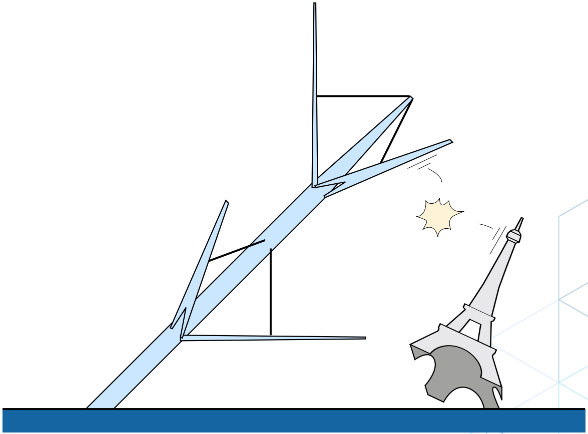
Thank you!



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