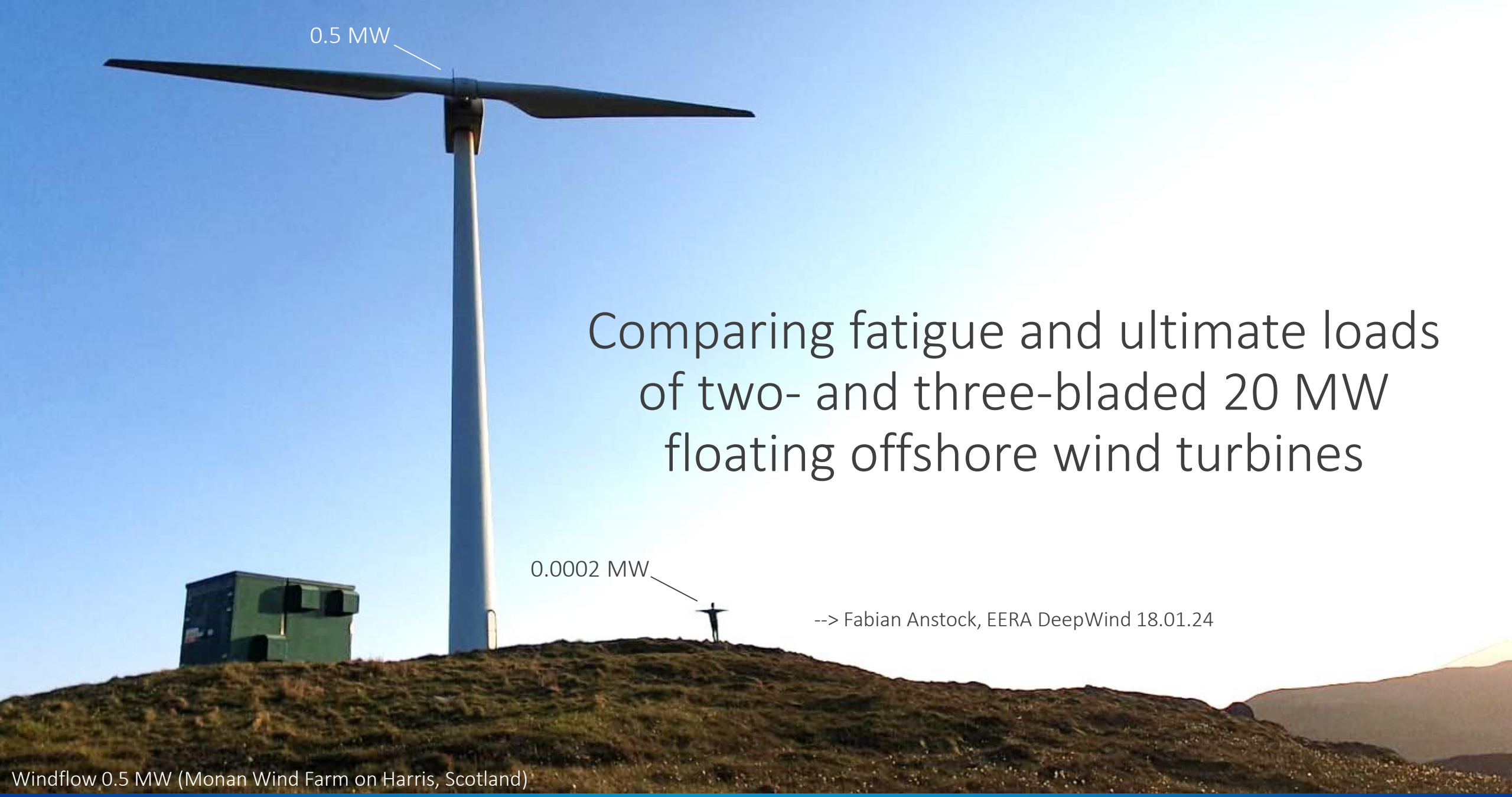


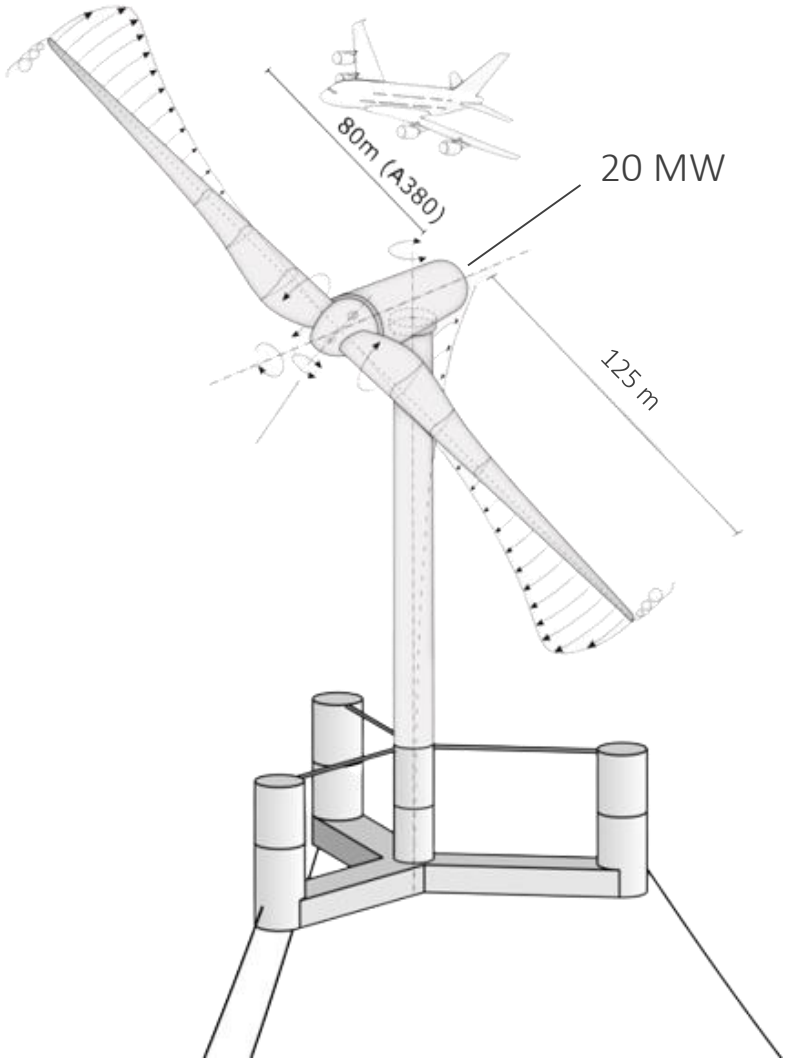
Comparing fatigue and ultimate loads of two- and three-bladed 20 MW floating offshore wind turbines

--> Fabian Anstock, EERA DeepWind 18.01.24

Windflow 0.5 MW (Monan Wind Farm on Harris, Scotland)

Agenda

1. Two-bladed reference turbine and floater design
2. Change of tower eigenfrequency (fixed vs. floating)
3. FLS and ULS load comparison
4. Summary

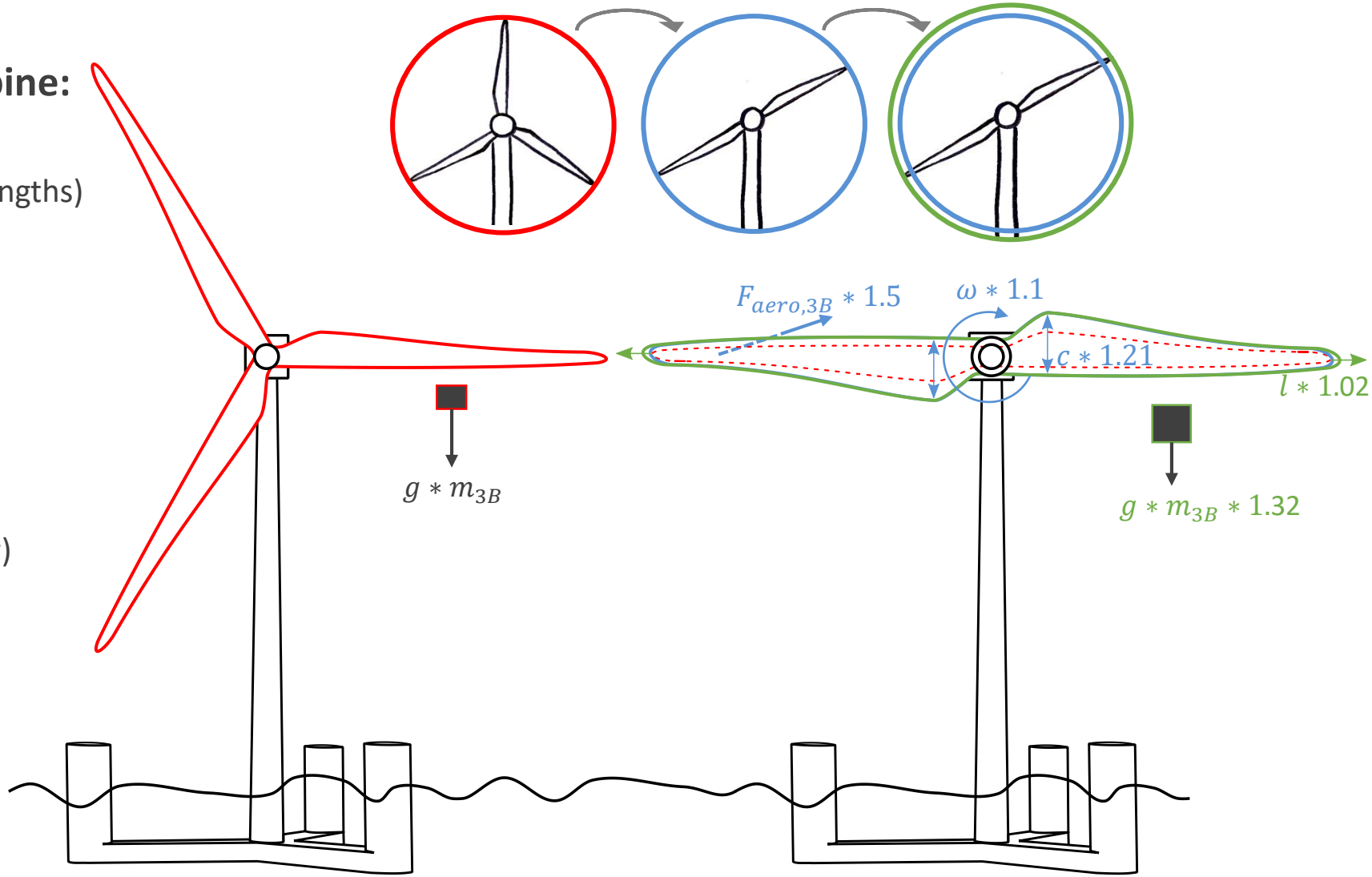


1) Two-bladed turbine from a three-bladed reference (20MW INNWIND)

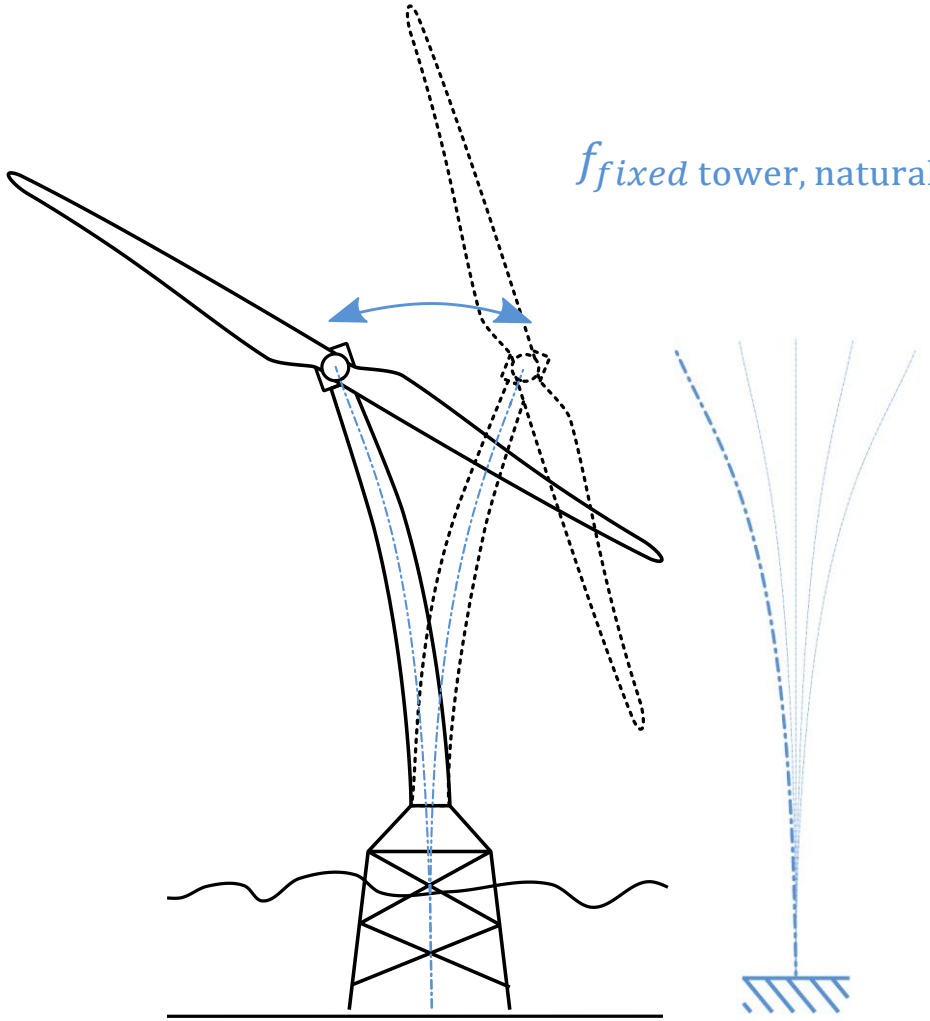
Most comparable two-bladed turbine:

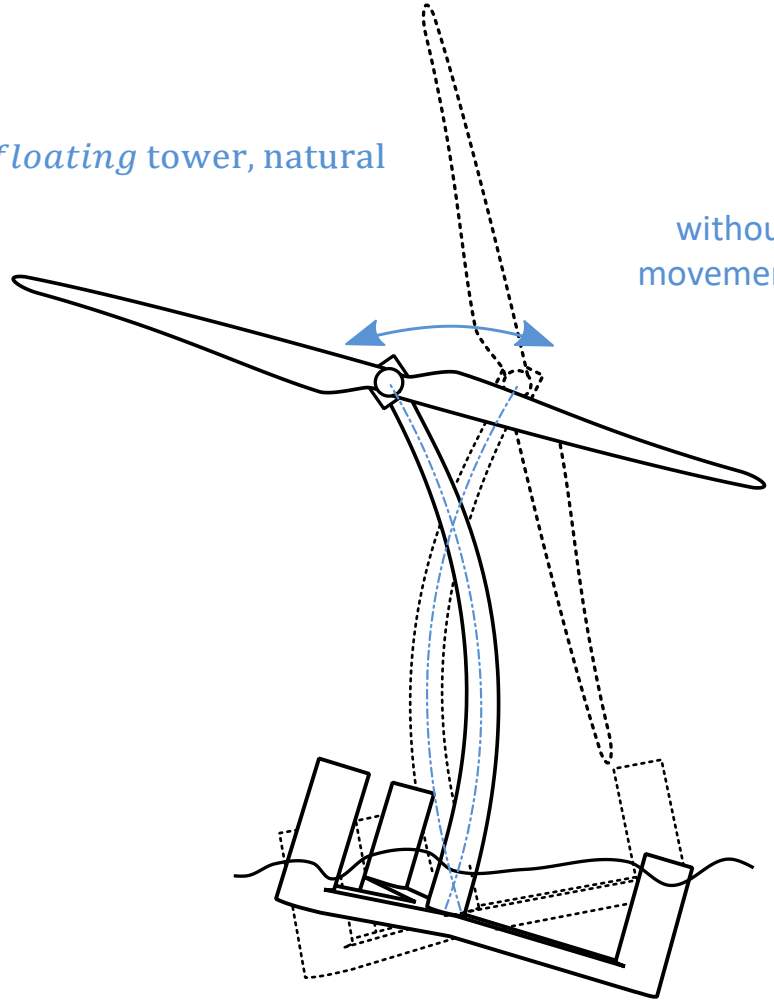
- **Equal aerodynamics[1]**
  (same airfoils, AoA, and relative chord lengths)
- **Equal structural design[2,3]**
  (same strength and stability limits)
- **Equal absolute power curve[1]**
  (2B blade ~2% longer)
- **Equal controller[4,5]**
  (standard PI; parameters tuned
  by objective control cost criterion,
  values reduced to avoid pitch instability)
- **Equal floater platform pitch of 5° at rated conditions[6]**

(size scaled proportionally)



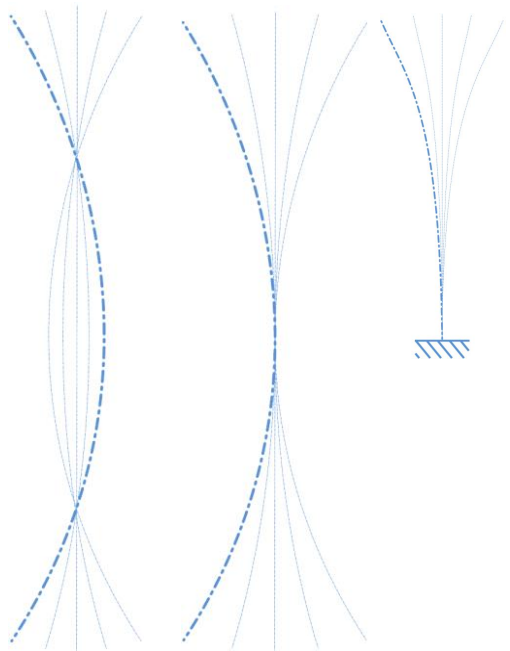
$$f_{fixed\ \text{tower, natural}} \approx 2 * f_{floating\ \text{tower, natural}}$$





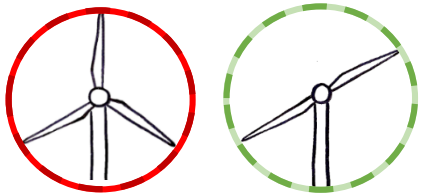
without lateral movement at center

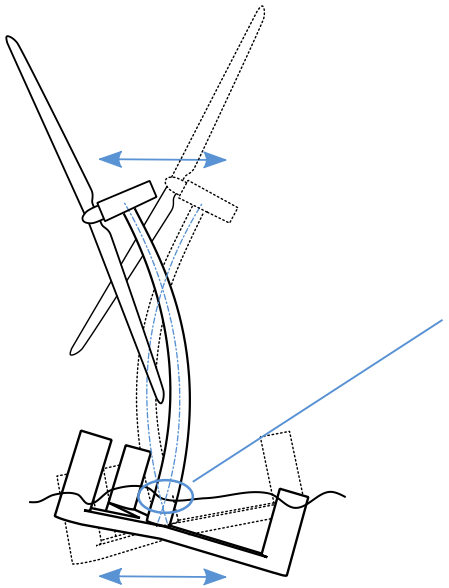
similar to a shorter bottom-fixed tower



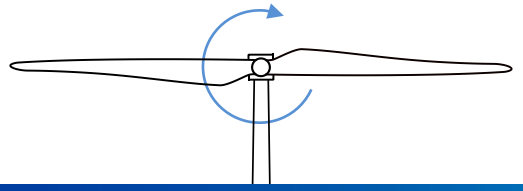
Effect of changing tower eigenfrequencies[6]

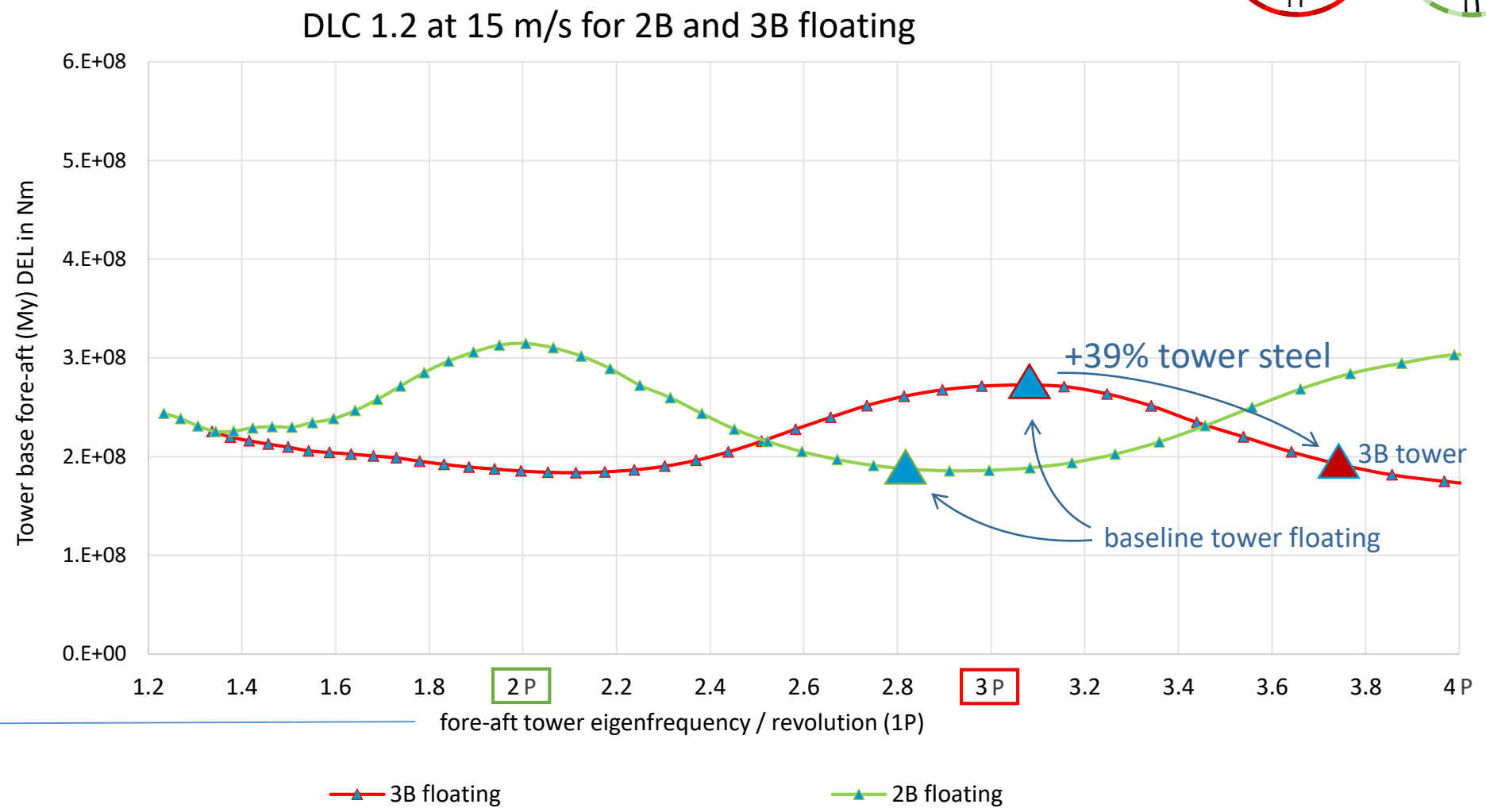
2) Tower's Young's modulus iteration





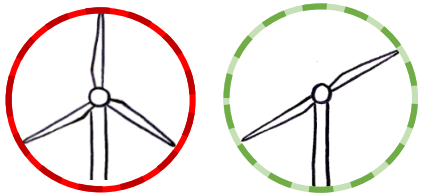
$$\frac{f_{\text{tower, natural}}}{f_{\text{rotation}}}$$

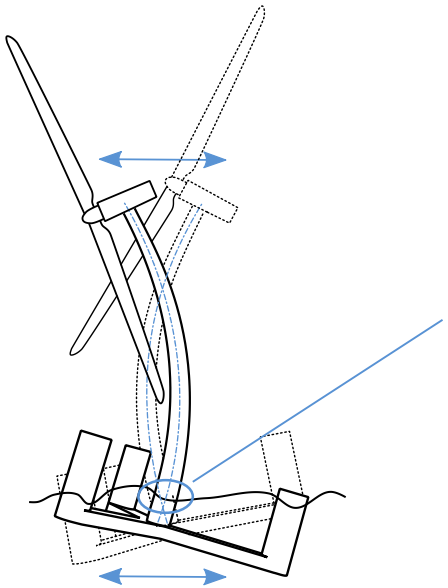




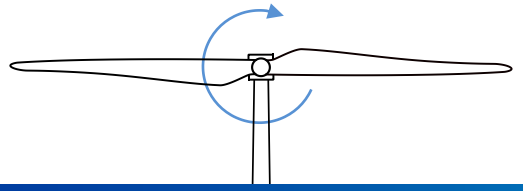
1P, 2P and 3P => once, twice or thrice per revolution

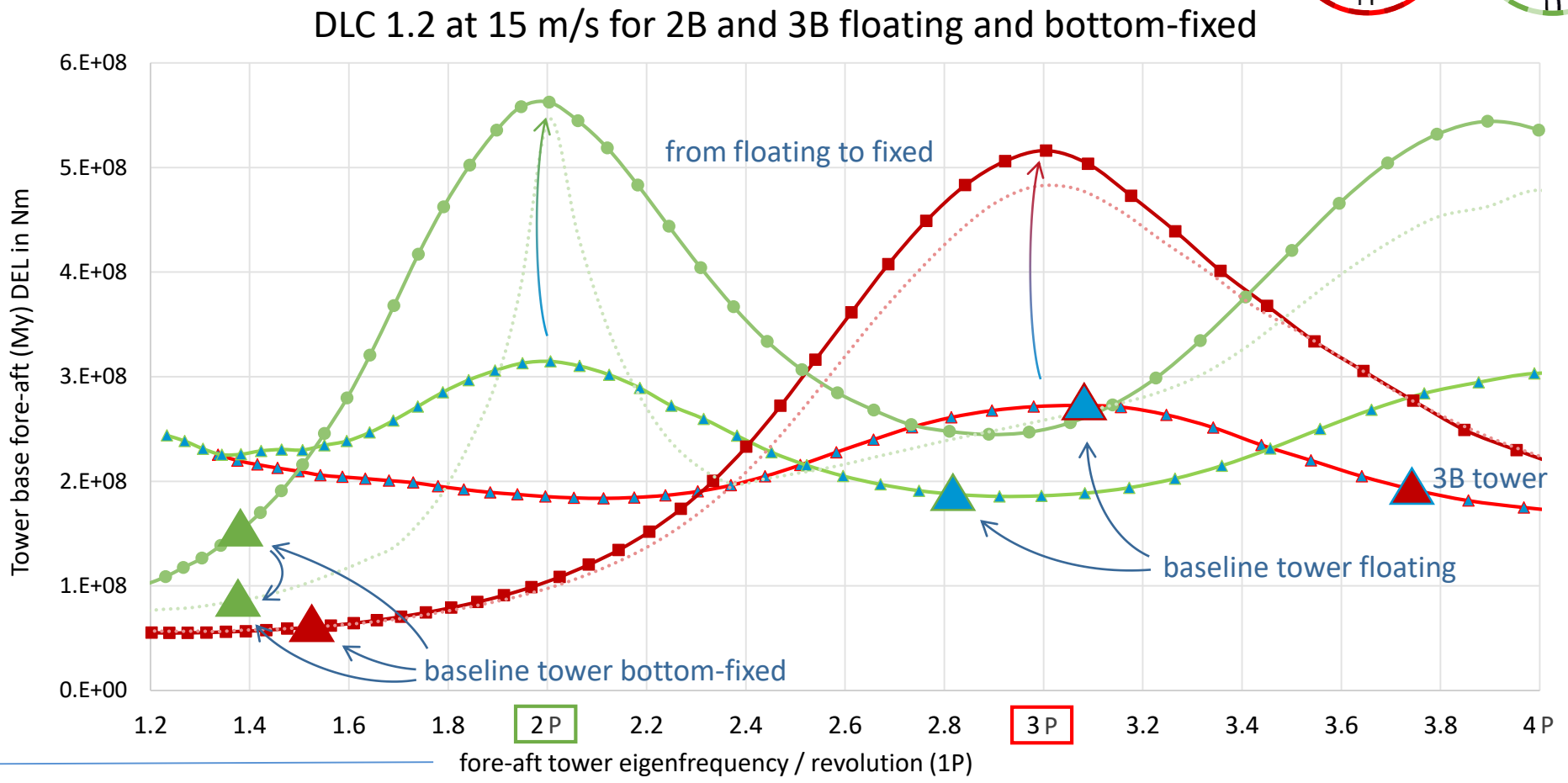
2) Tower's Young's modulus iteration



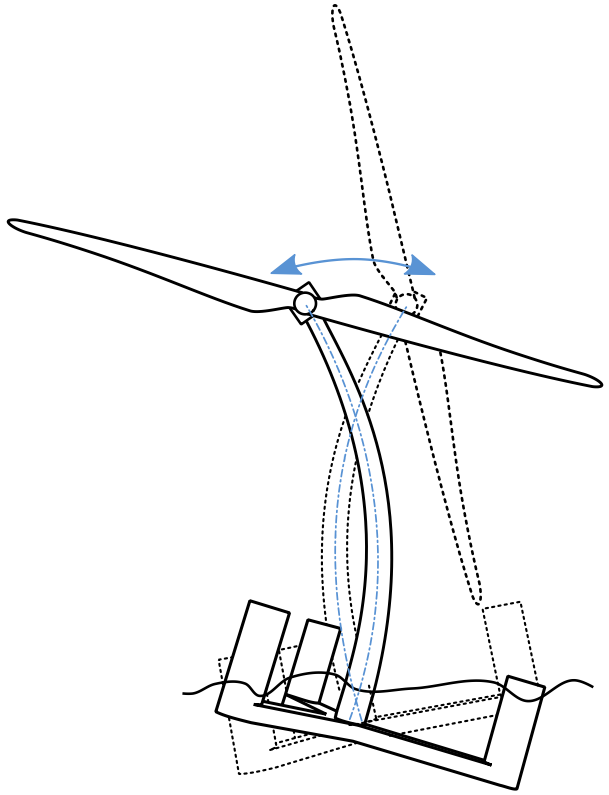


$$\frac{f_{\text{tower, natural}}}{f_{\text{rotation}}}$$





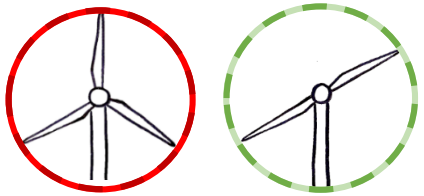
1P, 2P and 3P => once, twice or thrice per revolution

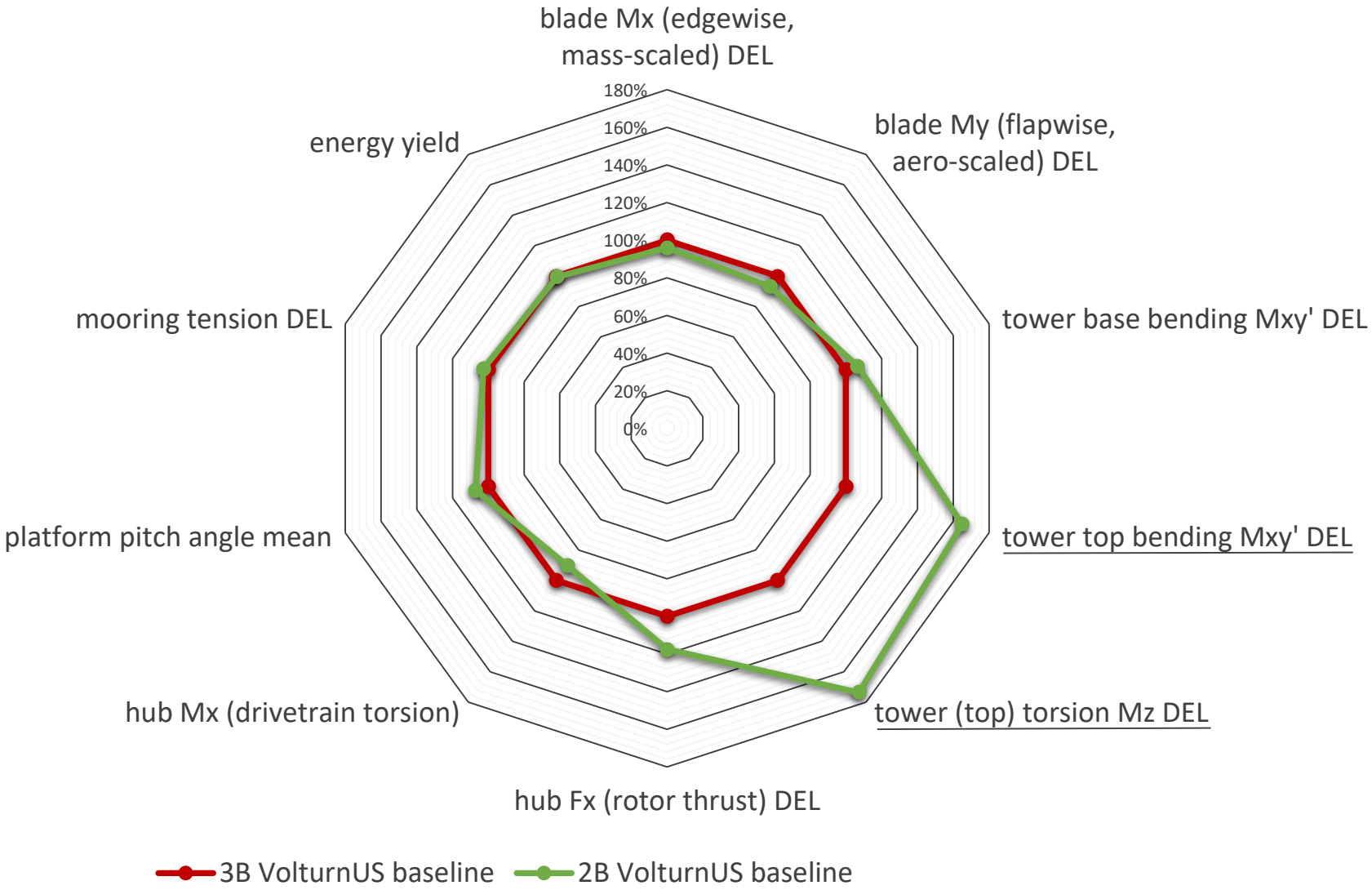


fatigue and ultimate load comparison loads

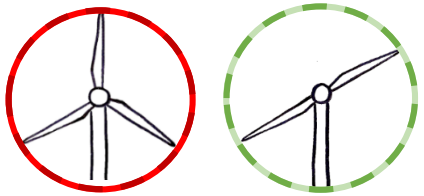
Simulations performed in Bladed with hydrodynamics from SESAM

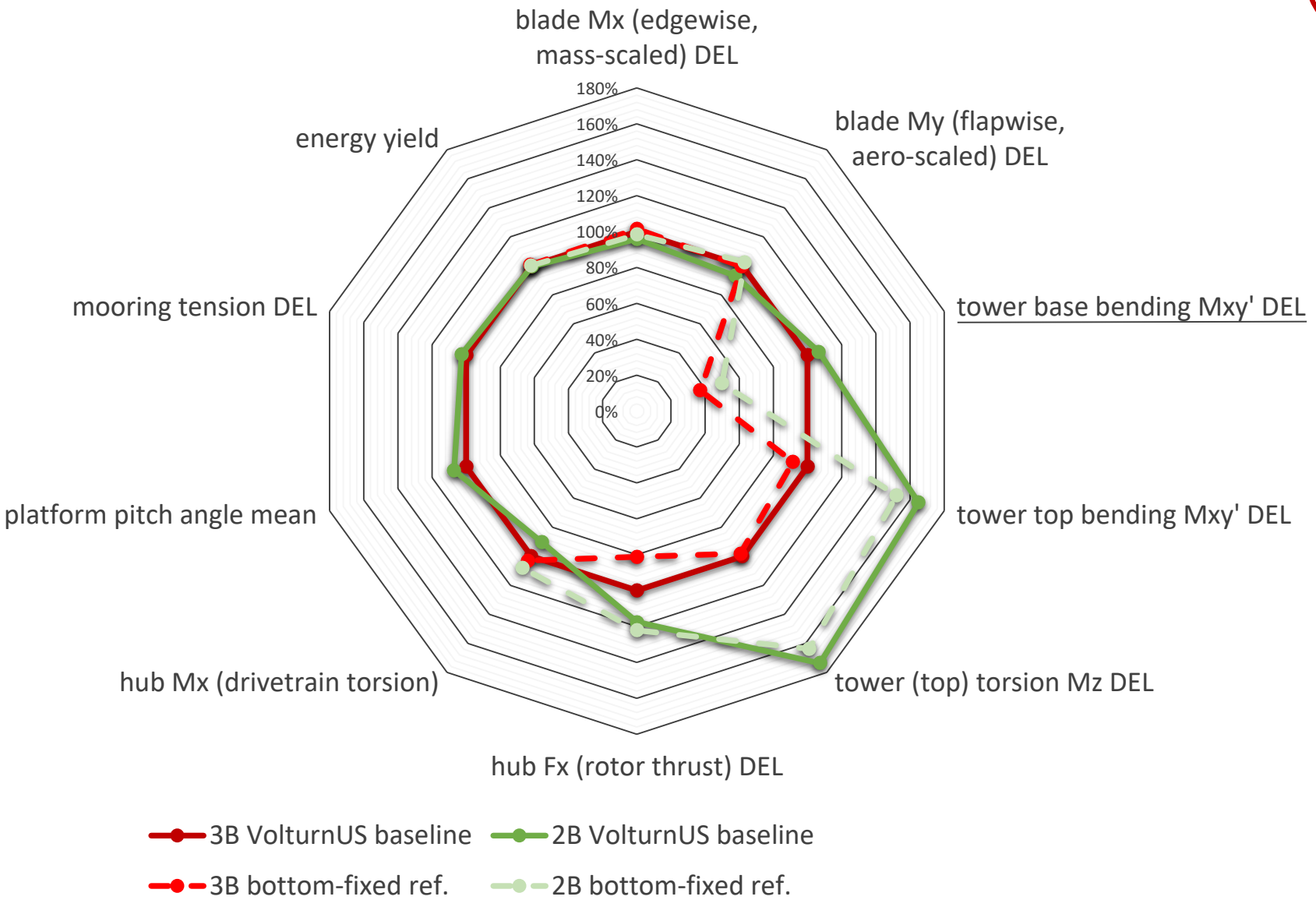
3) Fatigue load comparison (floating)



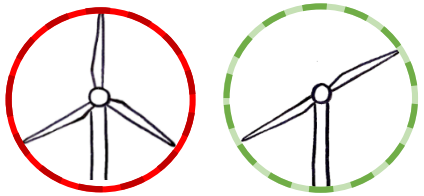


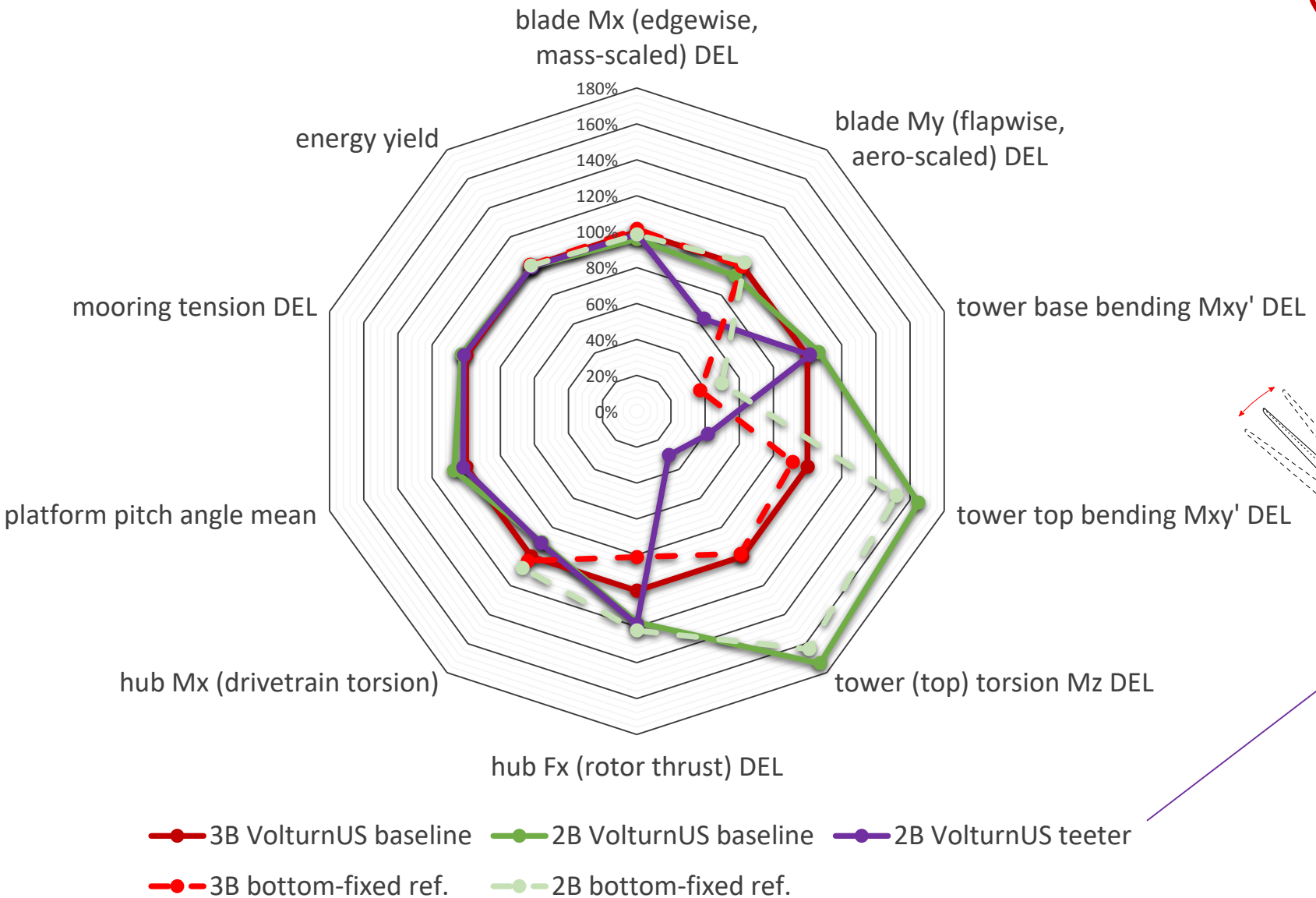
3) Fatigue load comparison (floating vs. bottom-fixed)

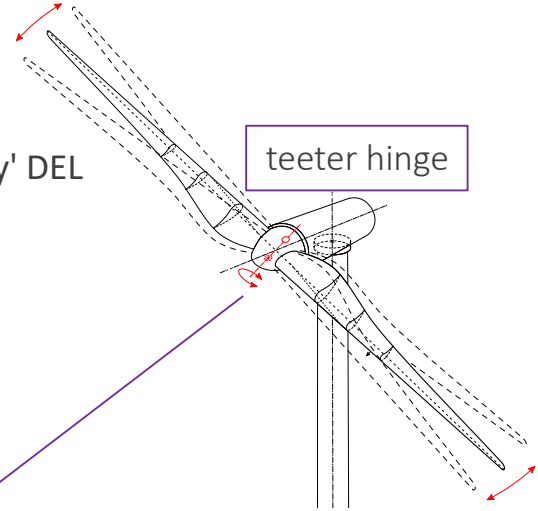




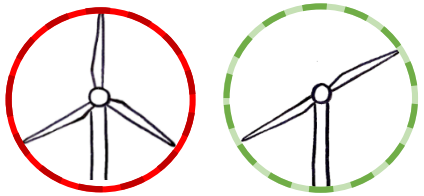
3) Fatigue load comparison (floating vs. bottom-fixed)

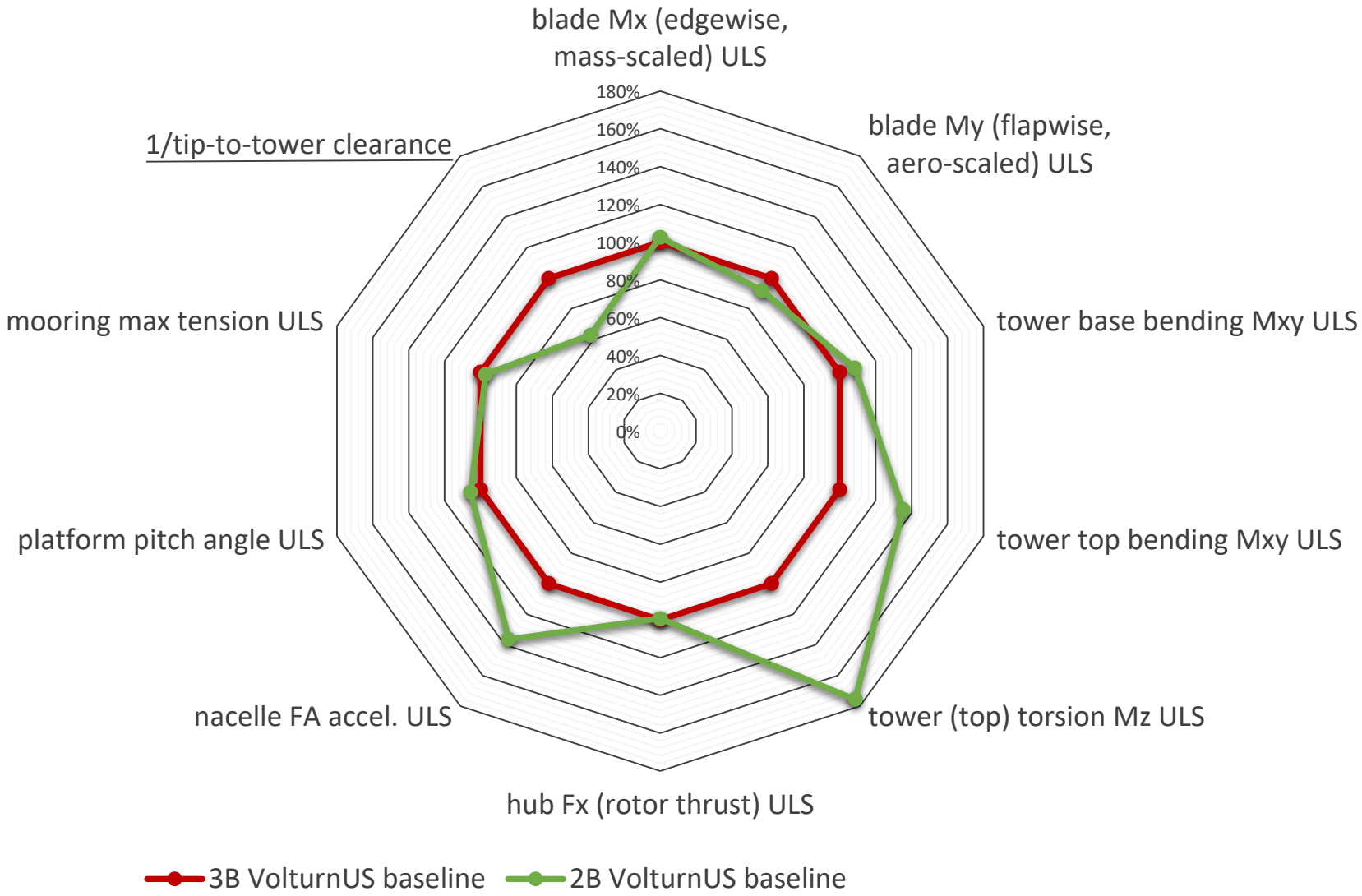




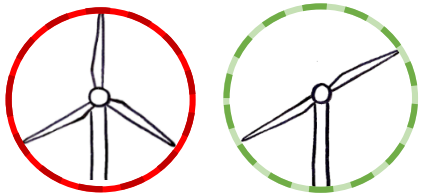


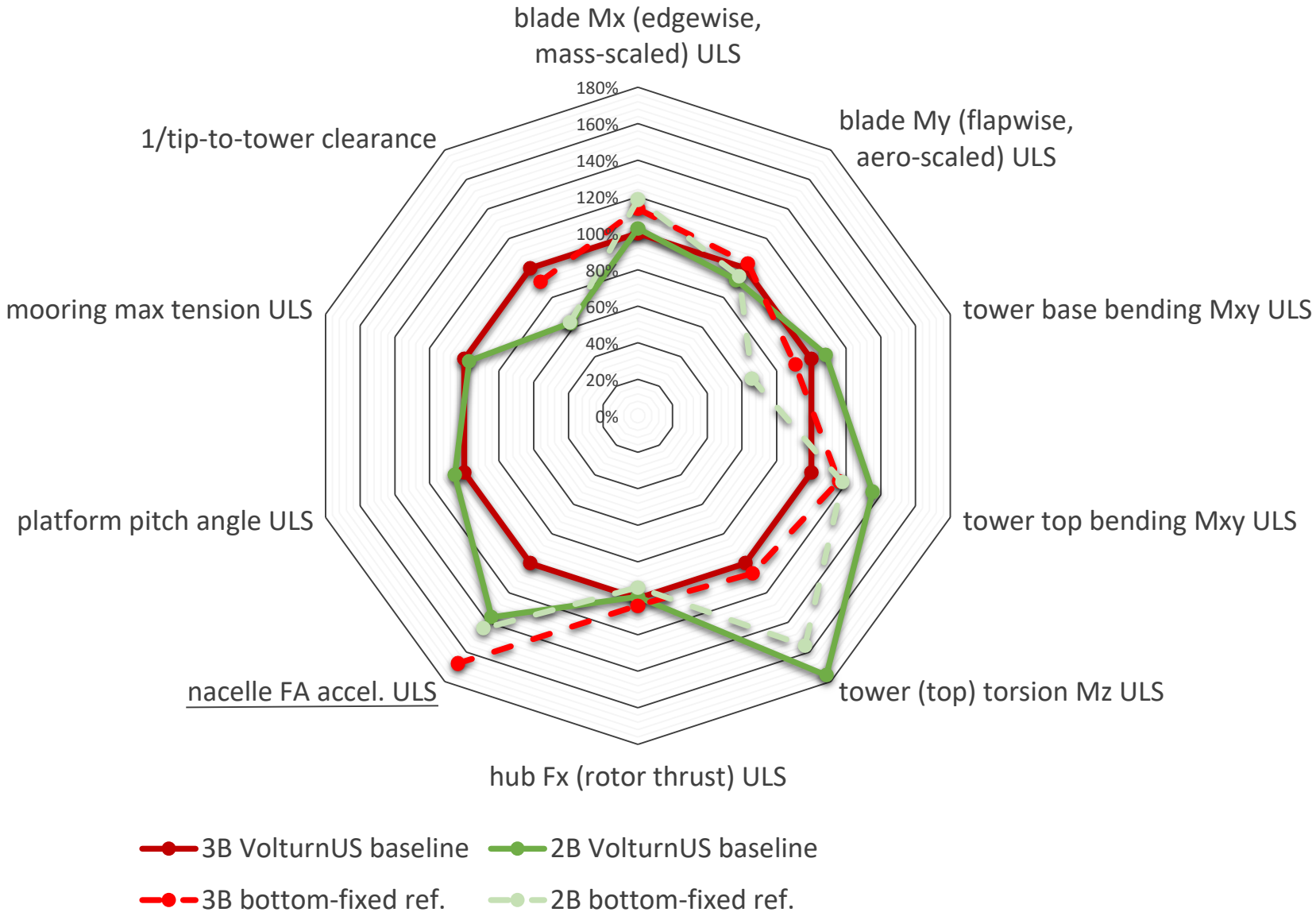
3) Ultimate limit state (ULS) comparison (floating)





3) Ultimate limit state (ULS) comparison (floating vs. bottom-fixed)





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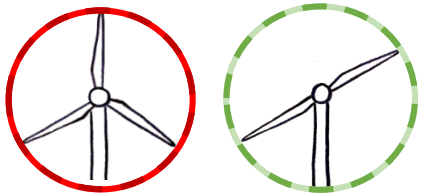
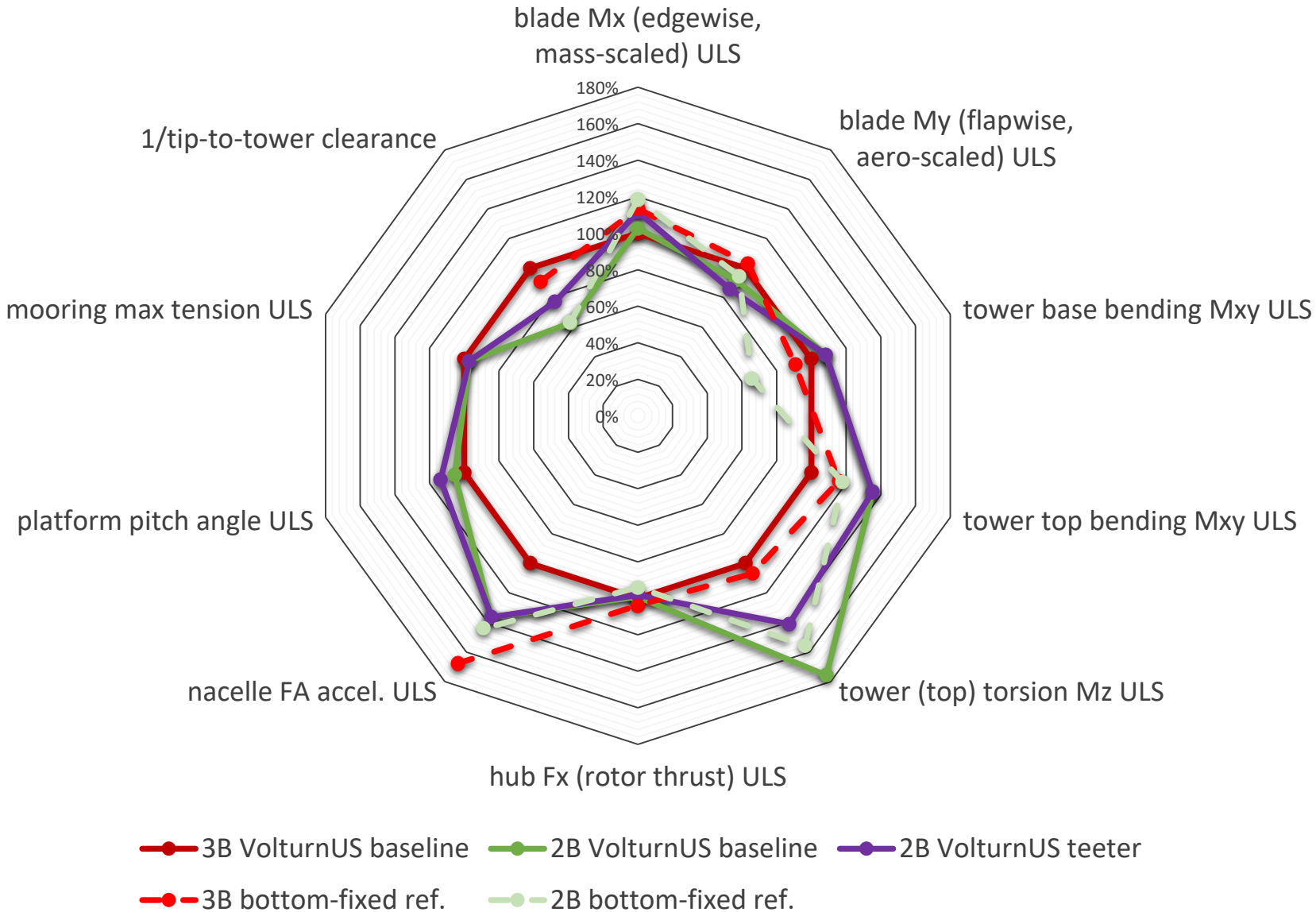
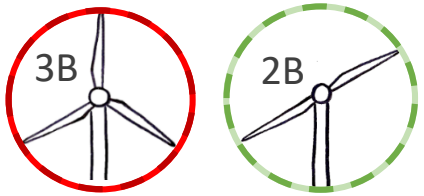




4) Summary (Case specific for the 20MW VolturnUS)

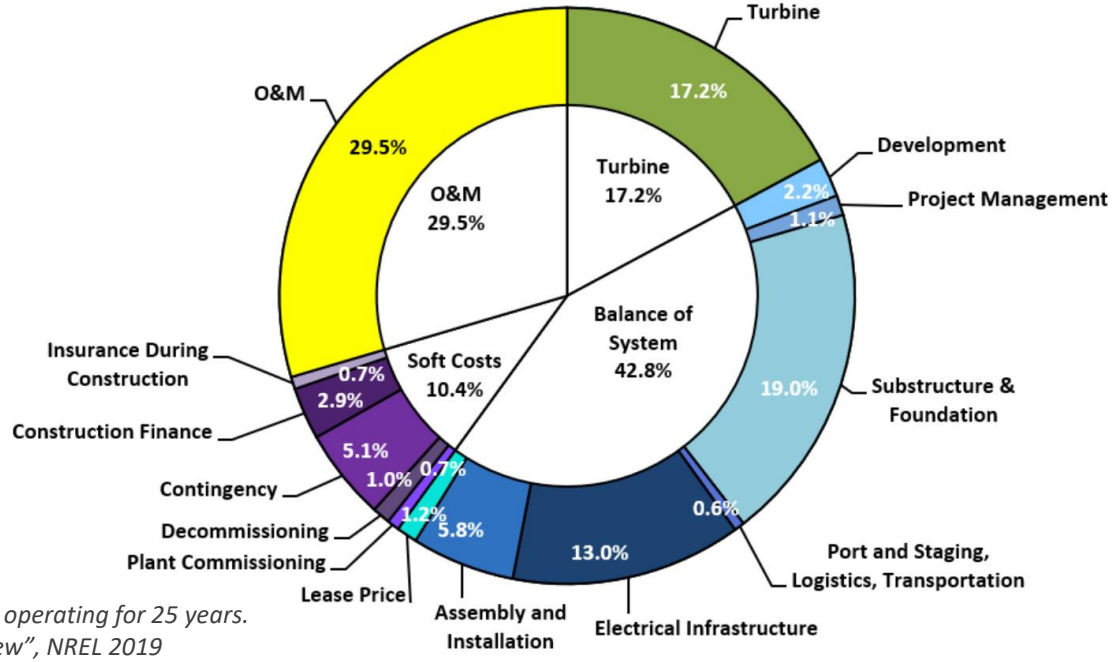


What to take away?

- Tower resonance is less problematic for floating turbines
- Tower base bending moments are larger for floating turbines, but most other loads are similar
- Two-bladed (rigid-hub and rigid-yaw) turbines possess higher dynamic loads between hub and tower top
- Tower base bending, mooring line loads and platform pitch are very similar for 2B and 3B!

Why two-bladed?

- Potentially still even better economics!
  Due to less costs in manufacturing, transport, erection, maintenance and decommissioning.



Component-level LCOE contribution for the 2019 floating offshore wind reference project operating for 25 years.
source: Tyler Stehly, Philipp Beiter, and Patrick Duffy. „Cost of Wind Energy Review", NREL 2019

Own references

[1] Anstock F., Schütt M., and Schorbach V. *A new approach for comparability of two- and three-bladed 20 MW offshore wind turbines.* JoP: Conf. Series, 2019.

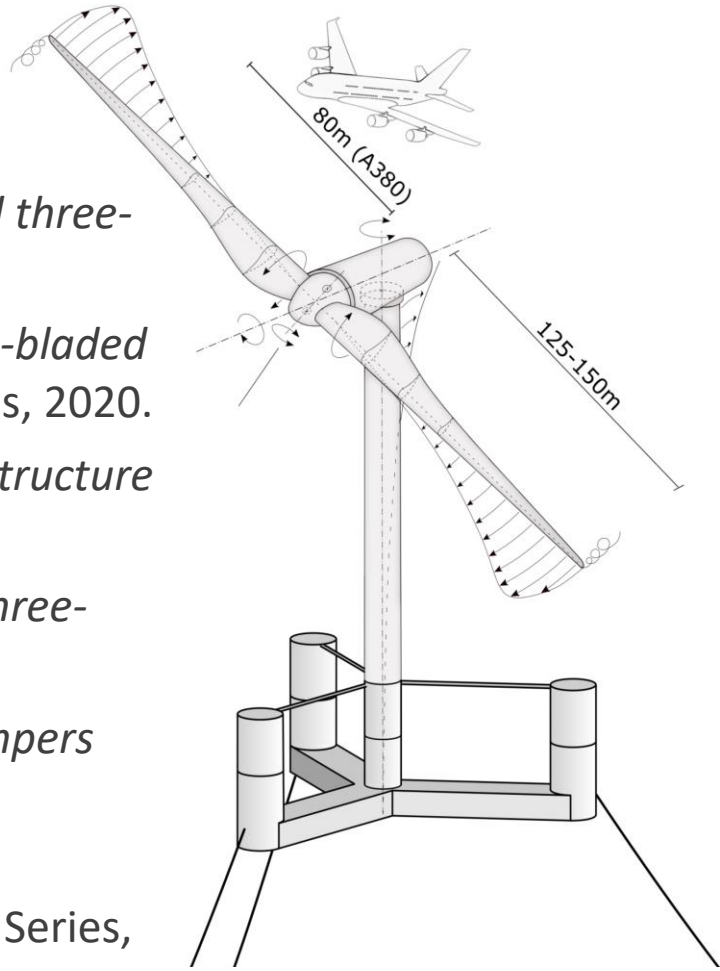
[2] Schütt M., Anstock F., and Schorbach V. *Progressive structural scaling of a 20 MW two-bladed offshore wind turbine rotor blade examined by finite element analyses.* JoP: Conf. Series, 2020.

[3] Schütt M., Anstock F., and Schorbach V. *A procedure to redesign a comparable blade structure of a two-bladed turbine based on a three-bladed reference.* JoP: Conf. Series, 2021.

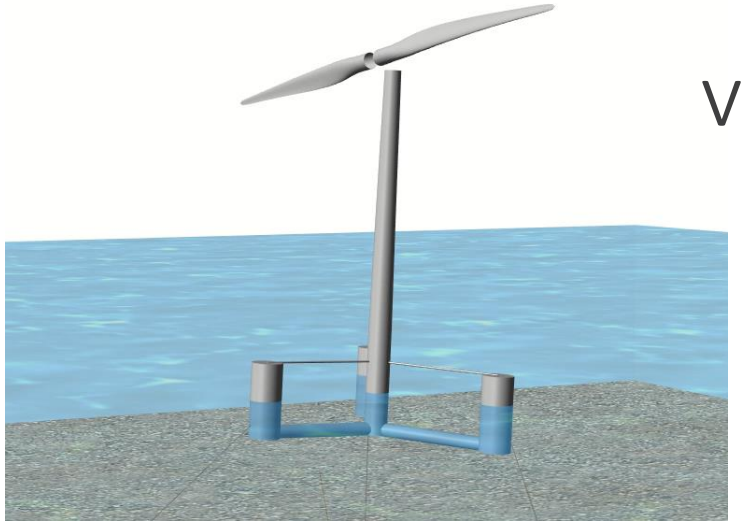
[4] Anstock F. and Schorbach V. *A control cost criterion for controller tuning of two- and three-bladed 20MW offshore wind turbines.* JoP: Conf. Series, 2020.

[5] Anstock F. and Schorbach V. *The effect of a speed exclusion zone and active tower dampers on an upwind fixed-hub two-bladed 20 MW wind turbine.* JoP: Conf. Series, 2021.

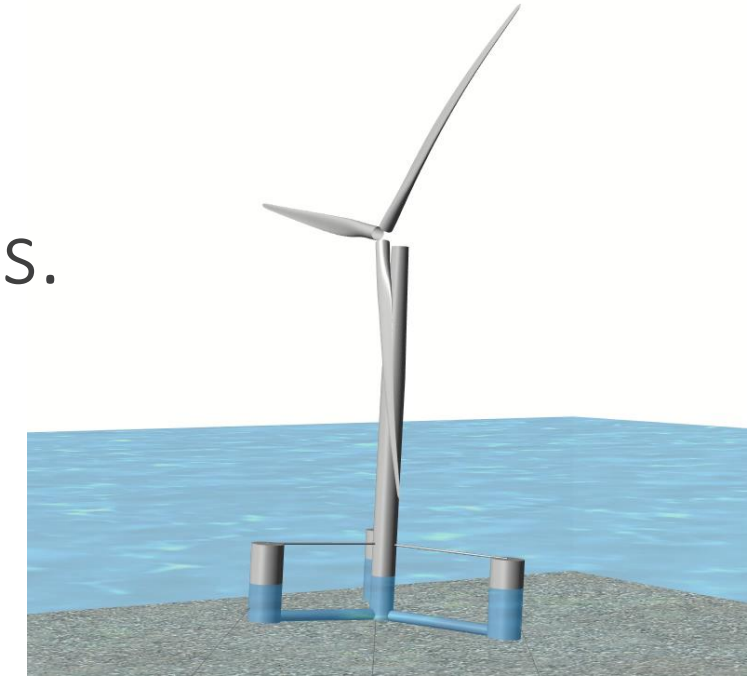
[6] Anstock F., Kessler A., and Schorbach V. *Increased tower eigenfrequencies on floating foundations and their implications for large two- and three-bladed turbines.* JoP: Conf. Series, 2023, in review.



Thank you for your time



vs.



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EnBW

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