Wind Energy Institute
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Design of a two-bladed teetering downwind rotor for wind tunnel testing of wake mixing techniques

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Motivation

Increased interest in 2-bladed downwind rotors for offshore applications.

- Due to lower mass, they are cheaper than 3-bladed rotors.
- Increased noise emissions and unappealing visual appearance have only a reduced relevance offshore.
- A teetering hinge has the potential to relieve hub loads.

Goals

The goal of this work is:

- Develop a scaled two-bladed downwind rotor to be used in wind tunnel tests to experimentally investigate wake control techniques for application in offshore wind farms. In doing so, re-use as much as possible from existing 3-bladed G2 model wind turbines to save costs.
- Experimentally investigate wake control techniques with a focus on wake-mixing techniques (e.g. Helix [1]) for a 2-bladed downwind rotor.
- Analyse if the teetering hub can help with reducing loads of 2-bladed rotors.

Design

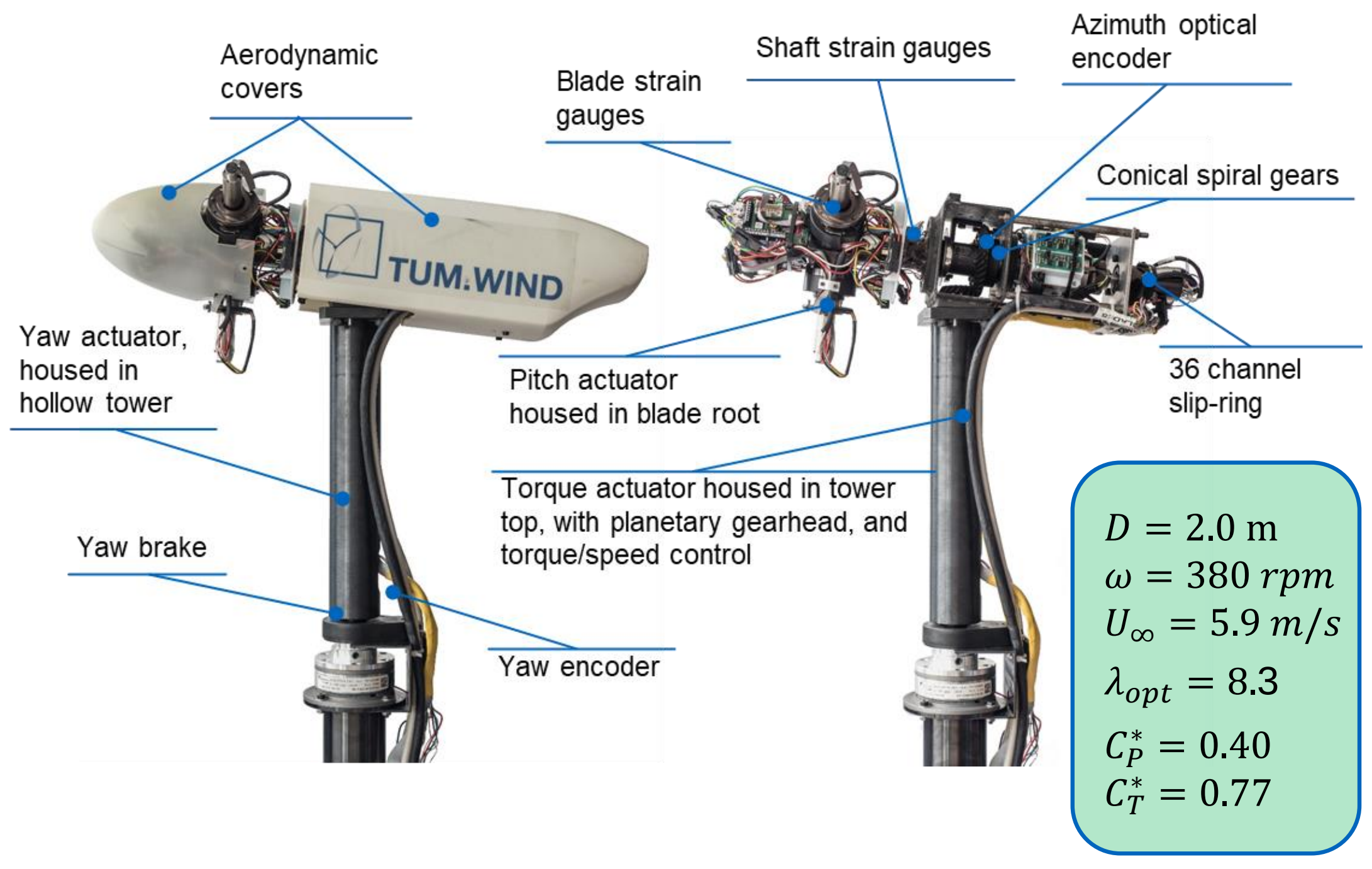
Reference turbine

There are various 2-blade rotors that are used for research purposes, but also commercially.

The selection came to the SUMR 13i turbine, which is a two-bladed, single-rotor wind turbine with an output of 13.2 MW. [2][3].

Existing G2 turbine

The G2 wind turbine model is a 2 m diameter machine, developed at the TUM Wind Energy Institute. Details about the design process and applications are explained in [4][5].



$D = 2.0$ m
$\omega = 380\ rpm$
$U_\infty = 5.9\ m/s$
$\lambda_{opt} = 8.3$
$C_P^* = 0.40$
$C_T^* = 0.77$

The turbine is equipped with actuators allowing active real-time control of: individual pitch, torque and yaw.

It features extensive onboard sensorization, including tower, shaft- and hub-loads.

The real-time control and monitoring system is implemented on a Bachmann PLC.

The tower, nacelle, sensors, actuators and blades of the G2 were re-used in the new model turbine, named D2. Only the hub and generator were newly designed and manufactured.

Scaling

The scaling of the model wind turbine was based on Buckingham π-Theorem.

The geometrical scaling factors are given by the existing G2 model turbine:

$$n_L = \frac{L_{G2}}{L_{SUMR}} = \frac{2.0\ m}{213.7\ m} = \frac{1}{107}$$

Based on the tip Tip-speed ratio similarity and the selected generator, the time scaling factor is:

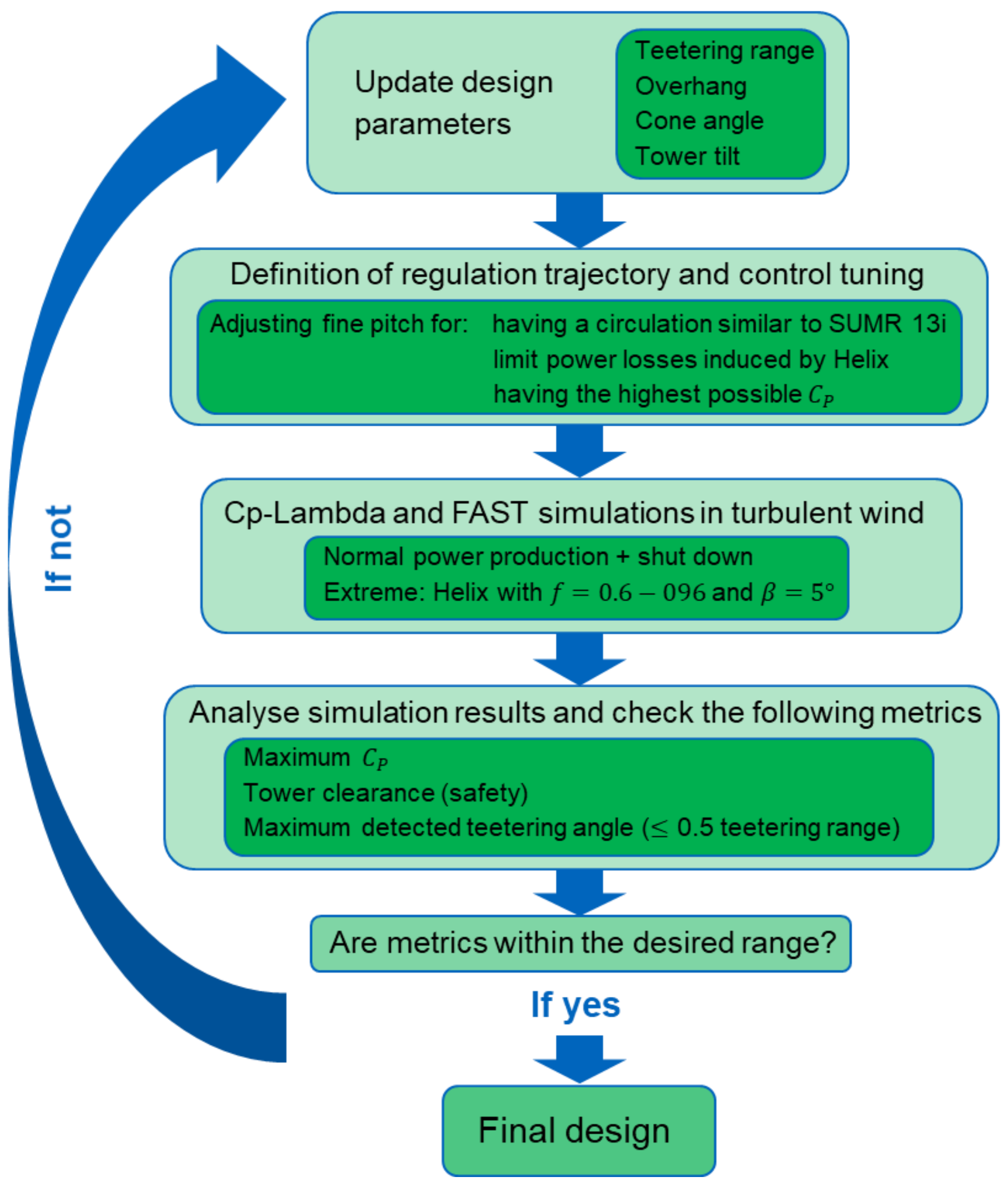
$$n_T = \frac{\omega_{G2}}{\omega_{SUMR}} = \frac{450\ rpm}{9.54\ rpm} = \frac{47}{1}$$

Turbine	TSR	Blade number	ω_R [min^{-1}]	P_R [W]	V_R [m/s]	D [m]	H_{Hub} [m]
SUMR 13i	9.5	2	9.54	13.2*10^6	11.3	213.7	142.4
G2	8.3	3	380	127	5.9	2.0	1.34
D2	9.5	2	450	111	5.7	2.0	1.32

Design parameters

The D2 was designed with the purpose of investigating a 2-bladeded downwind turbine concept with a focus on testing the effect of the teetering hub on load reduction and evaluating wake mixing techniques.

In the design process, the design parameters were determined iteratively.



Update design parameters
Teetering range
Overhang
Cone angle
Tower tilt

Definition of regulation trajectory and control tuning
Adjusting fine pitch for: having a circulation similar to SUMR 13i
limit power losses induced by Helix
having the highest possible C_P

Cp-Lambda and FAST simulations in turbulent wind
Normal power production + shut down
Extreme: Helix with $f = 0.6 - 096$ and $\beta = 5°$

Analyse simulation results and check the following metrics
Maximum C_P
Tower clearance (safety)
Maximum detected teetering angle ($\leq$ 0.5 teetering range)

Are metrics within the desired range?

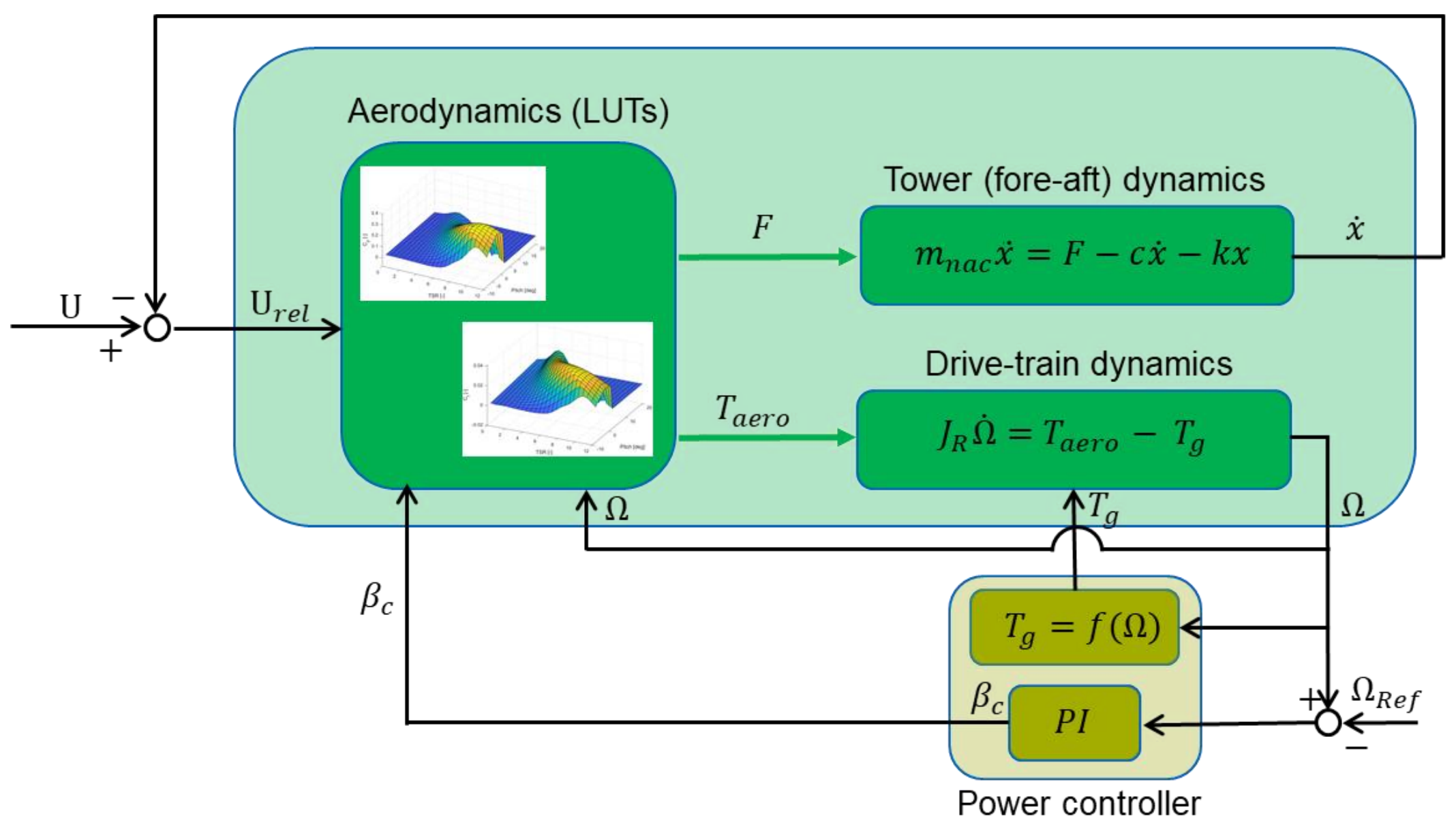
If not

If yes

Final design

Controls

The controller for the normal operation consists of PI loops for both the pitch and torque control. A simplified model in Simulink consisting of tower and drive-train dynamics is used for tuning the gains of the controllers.



Results

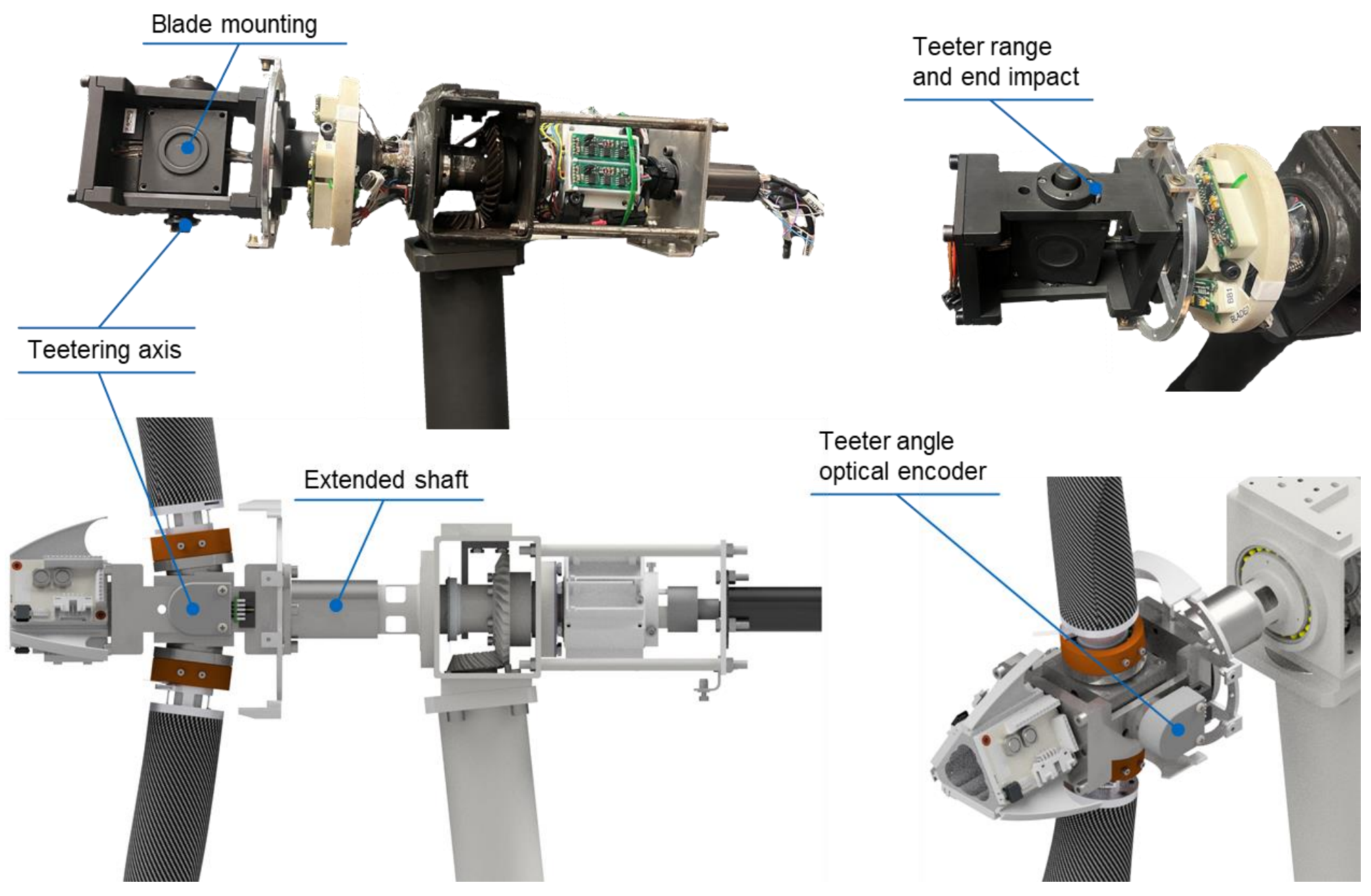
Hub design

The nacelle of the turbine is rotated 180° for the downwind configuration

For higher tower clearance, the G2 tilt is removed with a wedge at the tower bottom, to have more margin in the teetering degree of freedom (11° instead of 5°).

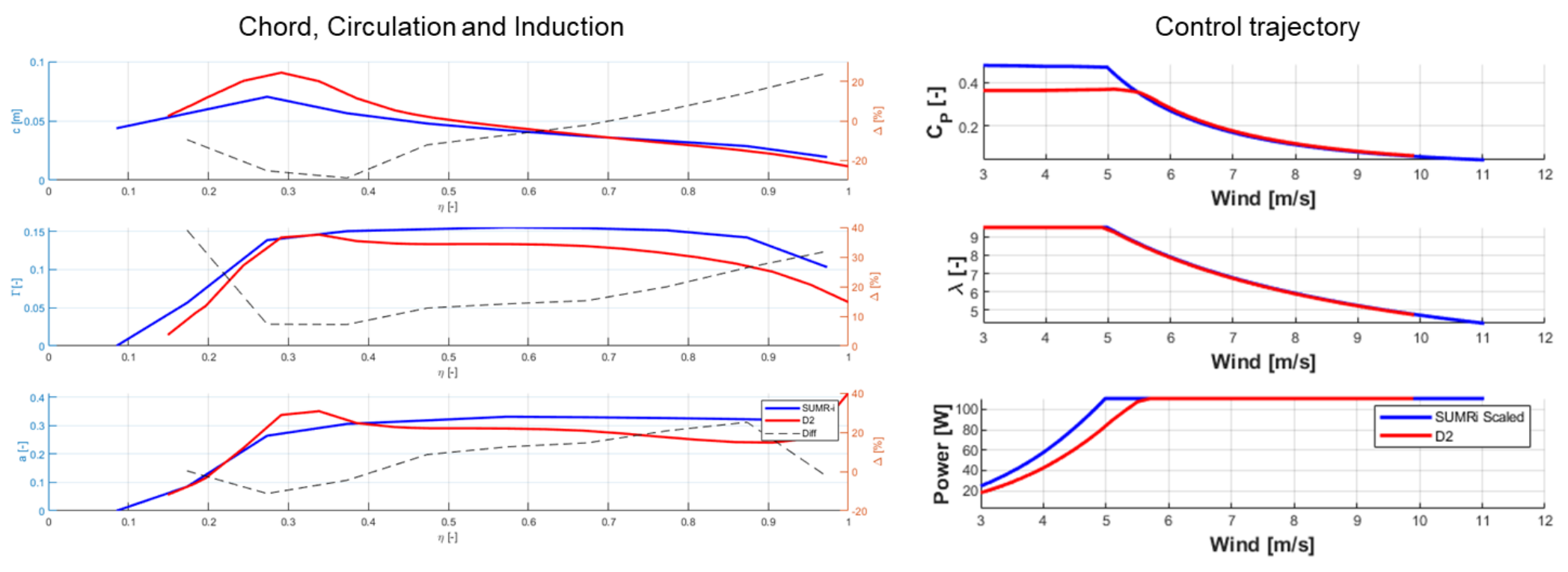
The teetering was designed based on finding from [6]

- Same blade root to rotor axis distance as G2.
- Teetering axis with encoder for teeter angle readings.
- Free teetering range until 11° without additional damping.
- Soft stop at 11° and hard stop at 12°.



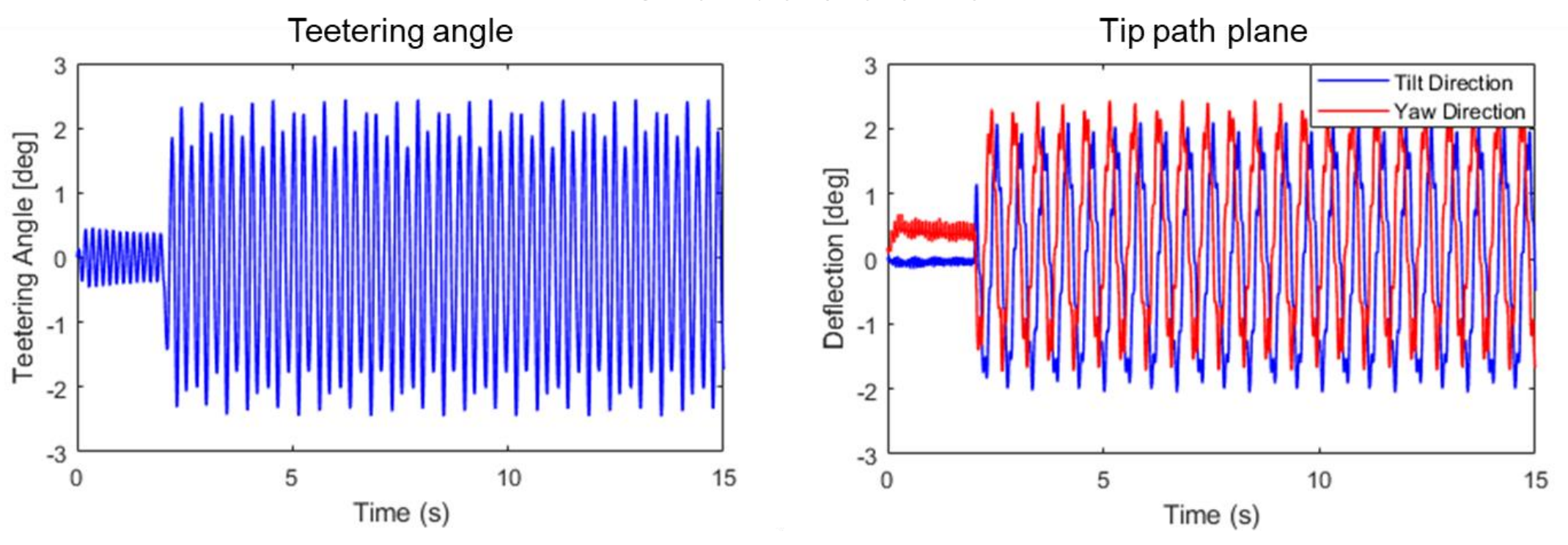
Comparison D2 and SUMR 13i

The comparison of the 2-bladed rotor and the SUMR 13i show good agreement.

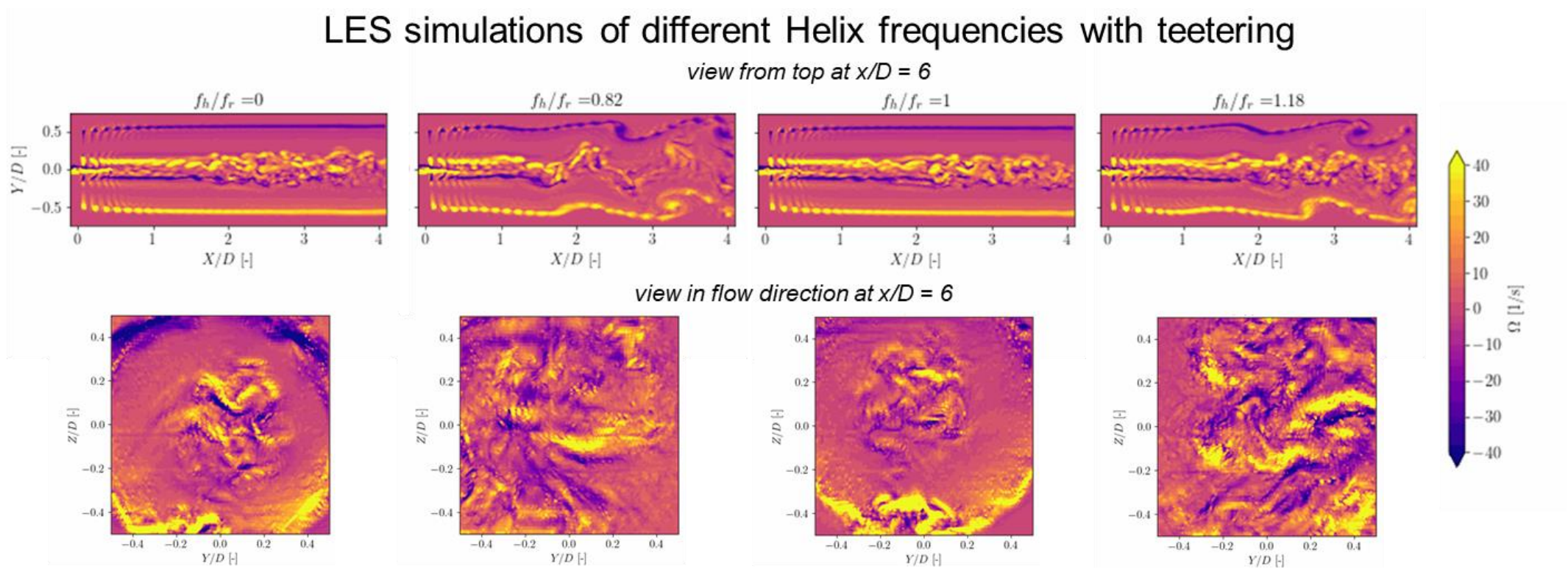


Simulation output

Simulation results of the teetering angle and the tip path plane show that the rotor is operating smoothly in the teetering range.


FAST simulations of Helix

LES simulations confirm the capability of the 2-bladed downwind turbine to operate in normal and individually pitch actuated conditions.


LES simulations of different Helix frequencies with teetering

Conclusions and Outlook

Most parts of the existing G2 model turbine could be re-used.

The rotor has fairly similar circulation and thrust as the reference rotor.

The rotor has a sufficient teetering range and runs smoothly with the extra degree of freedom.

Simulation results show that the rotor performs as expected in normal and individually pitch actuated conditions.

Next steps

Measure performance of rotor and teetering hub in wind tunnel experiments.

Wake measurements for different wake mixing techniques.

Literature

[1] F. V. Mühle et al. 2024, [2] G. Ananda et al., 2018., [3] S. Yao et al., 2020. [4] F. Campagnolo, 2013, [5] C. L. Bottasso et al., 2014, [6] V. Schorbach et al., 2018.

Wind Energy Institute

Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

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EERA DeepWind CONFERENCE 2025