Dynamic Formulation of the Double Multiple Stream Tube Model of Offshore Vertical Axis Wind Turbines

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MOTIVATION

Suitability of VAWTs for floating offshore applications

Lack of experimental-numerical validation for floating VAWTs

Performance and detailed wake measurements on floating VAWT model

- Design of laboratory scaled model
- Platform motion analysis

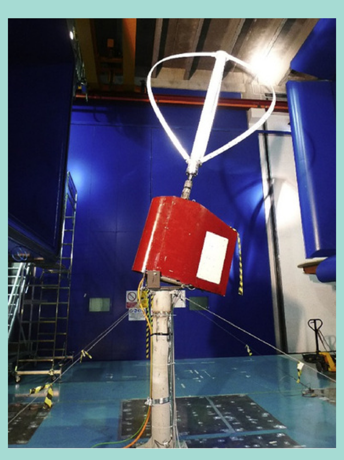
Development of multi fidelity tools for floating VAWTs

- **Double Multiple Stream Tube (DMST)**
- Medium-fidelity: Actuator Line Model
- Blade-resolved CFD

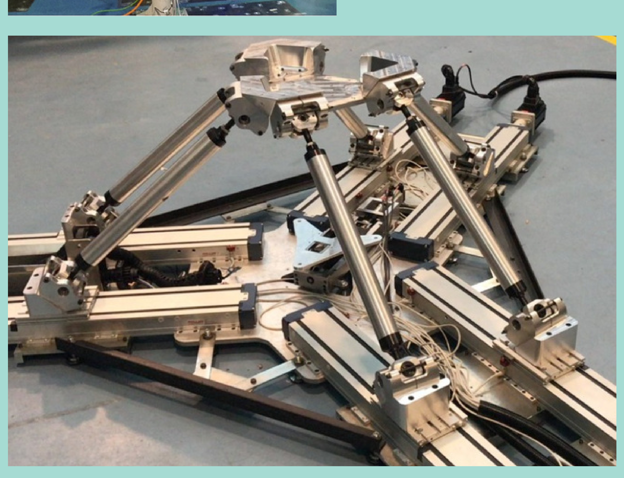
RESEARCH QUESTION

What is the potential impact on the solution when transitioning from a steady DMST model to a **dynamic formulation of the DMST** in the context of **floating VAWTs**?

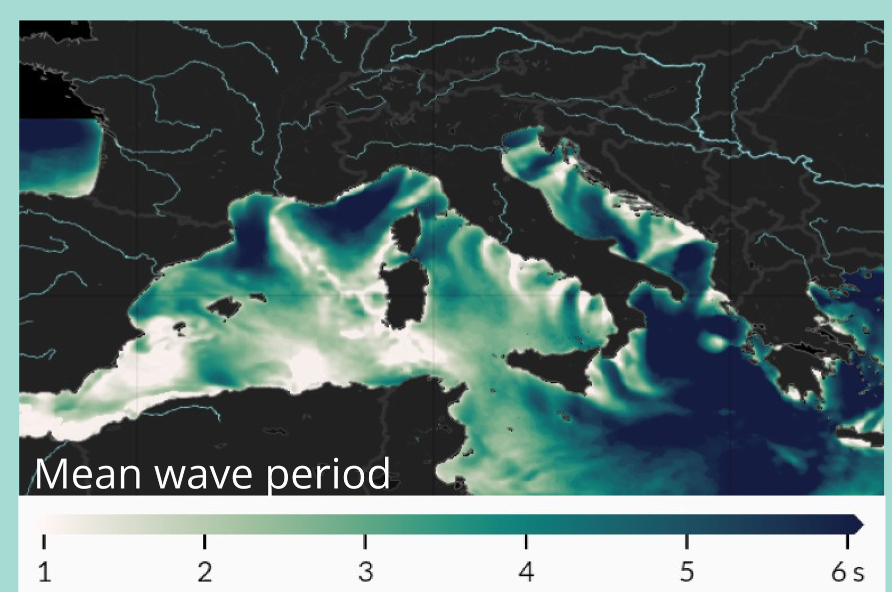
DESIGN OF EXPERIMENTAL SETUP



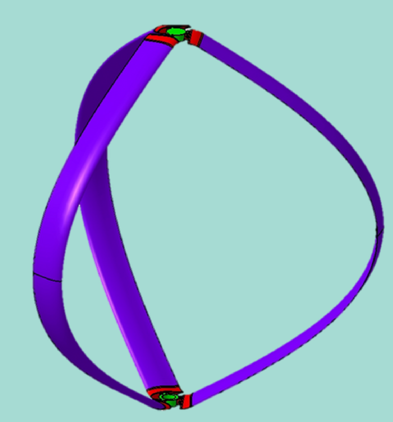
Experiments on Troposkein DeepWind Demonstrator in upright and tilted layouts. Rotor performance and wake measurements in [1].



HexaFloat 6 d.o.f. floating motions tested on scaled HAWTs (LIFES50+ [2,3], OC6 Phase III [4]).



Wave parameters extracted by database of the Mediterranean sea [5]. Mediterranean mean wave periods between 5-15 s. Mean wave frequencies equal or higher than VAWT rotor frequency.



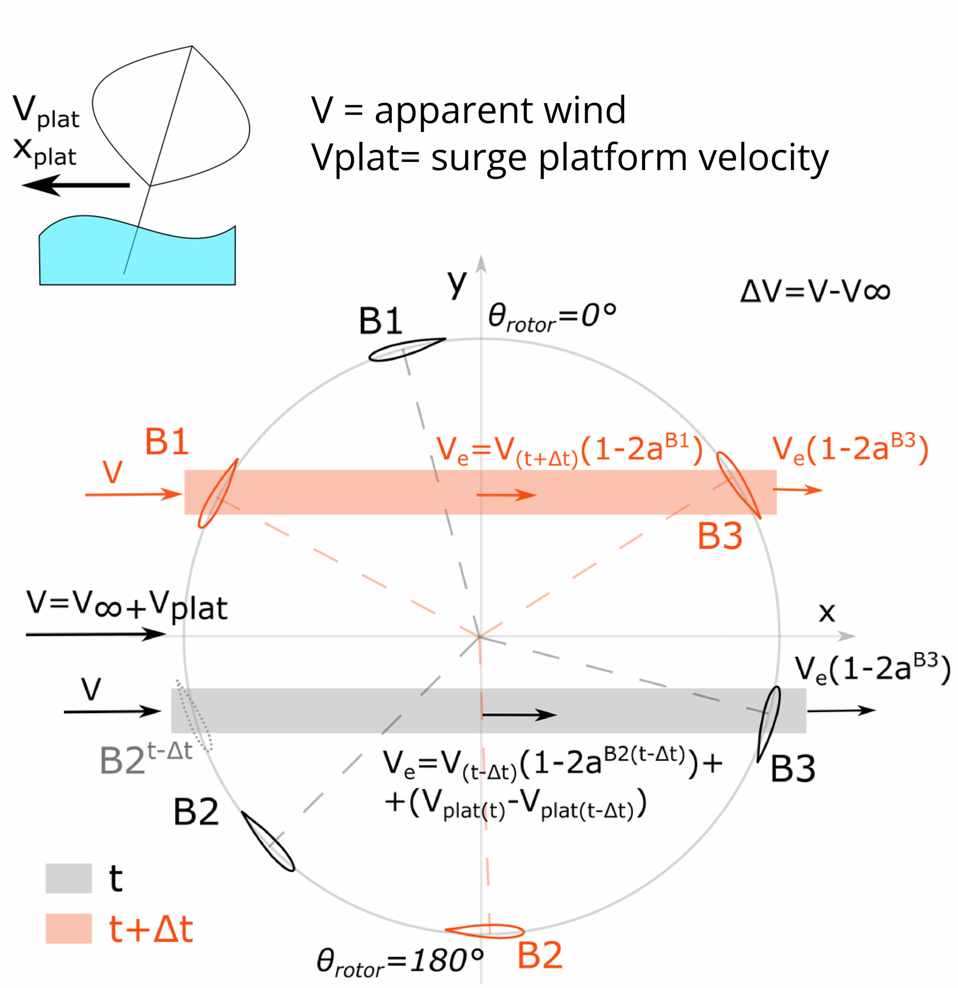
Design of new optimised Troposkein Rotor for wind tunnel tests in surge motion (scaled from 150 m-dimeter size application). Floating operations with scaled wave frequency and amplitude of the Mediterranean sea.

Diameter [m]	1.51
Tip Speed Ratio [-]	2.85
Angular speed [rpm]	360
Rated wind speed [m/s]	10
Chord [m]	0.126
Airfoil shape	DU06W200

METHODS AND RESULTS

Standard DMST is a steady state model [6]. It has limitations when the rotor blades undergo apparent velocities varying over the wave period.

Dynamic 3D DMST formulation

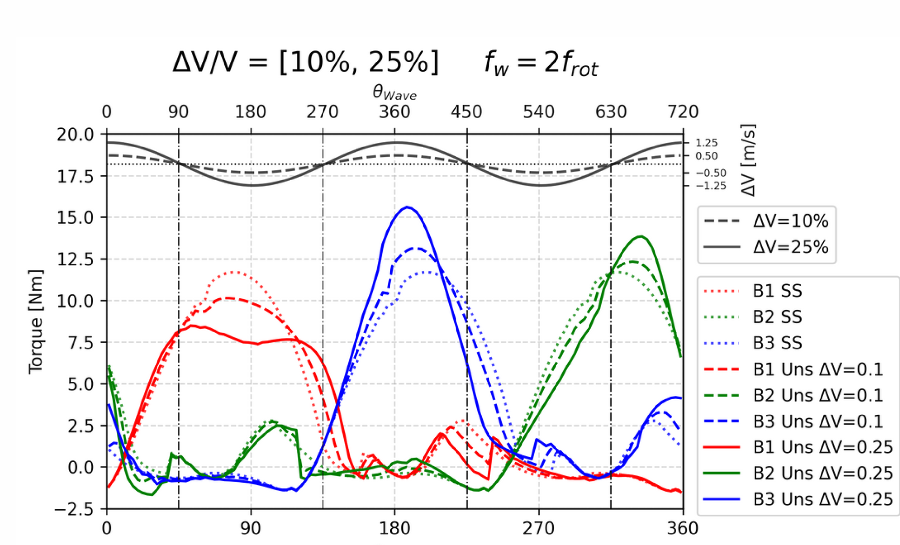


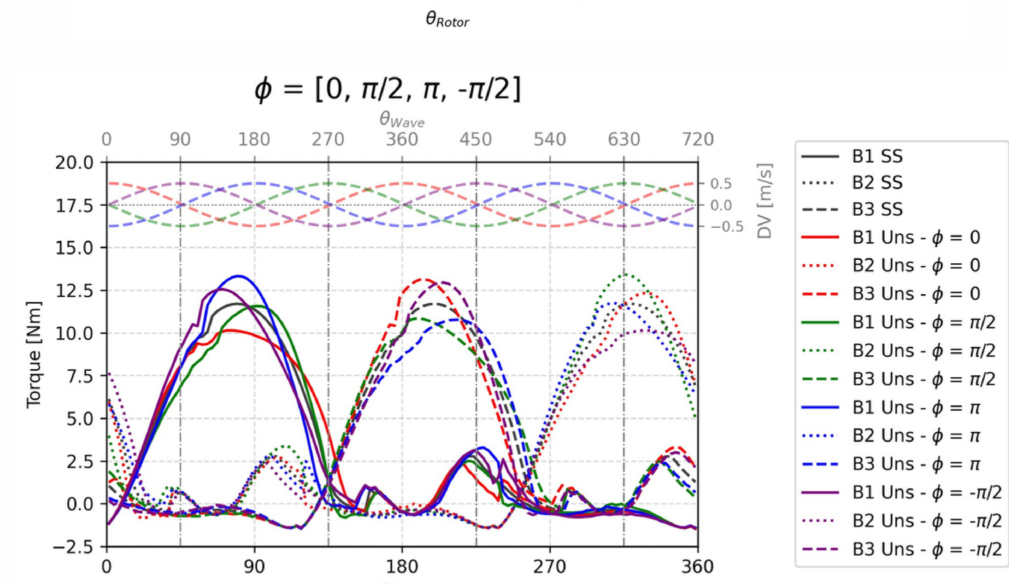
- Blade position and wave motion require a time- dependent approach: no spatial-temporal link as SS model.
- Downstream blades experience the induction caused by the last blade passage.
- Downstream wind speed corrected by local apparent wind.

Comparison for each rotor blade for the DMST models:

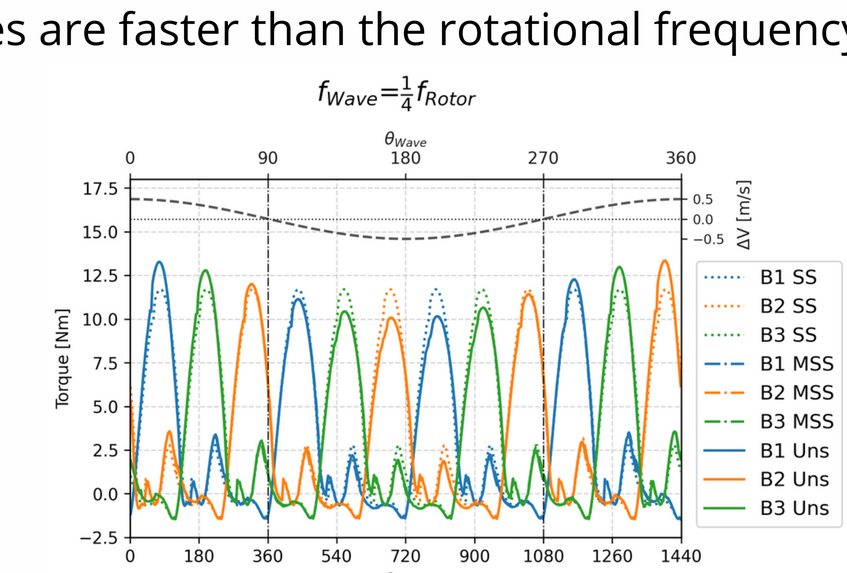
- **Steady:** standard steady state DMST formulation with average wind speed, fixed-bottom VAWT.
- **Multiple Steady State (MSS)**: quasi-steady solution of the rotor with variation of the apparent wind.
- **Unsteady (Uns):** time resolved approach for each blade with the induction of the 'last blade passage'.

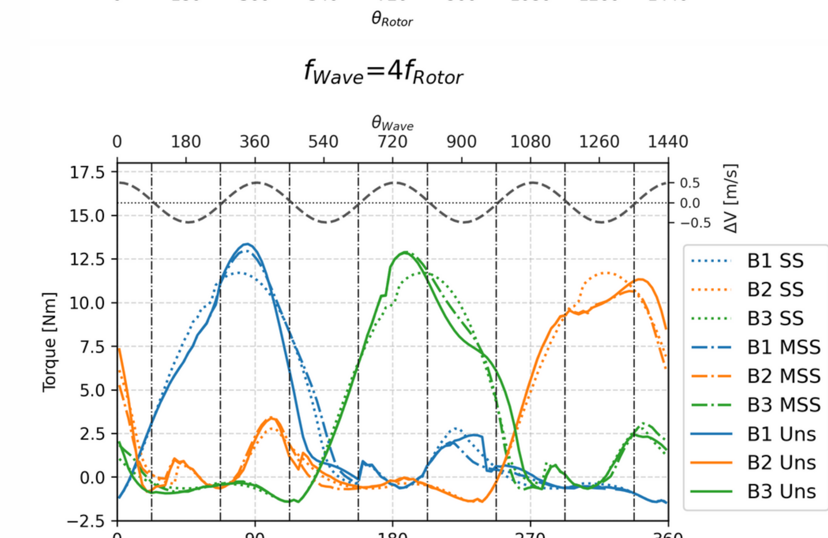
Effect of the **apparent wind amplitude (ΔV/V)** and **motion phase shift (ϕ)** on the torque over rotor angle.





Time-resolved torque at different **wave-rotor frequency** ratio. Torque differences between quasi-steady (MSS) and unsteady (Uns) are higher when waves are faster than the rotational frequency.





CONCLUSION

The impact of the **Dynamic DMST formulation** becomes relevant for wave frequencies multiples of the turbine rotational frequency and high apparent winds.

REFERENCES

[1] L. Battisti et al. Wind tunnel testing of the DeepWind demonstrator in design and tilted operating conditions, 2016.

[2] I. Bayati et al. A wind tunnel/HIL setup for integrated tests of Floating Offshore Wind Turbines, 2018.

[3] M. Belloli et al. A hybrid methodology for wind tunnel testing of floating offshore wind turbines, 2020.

[4] R. Bergua et al. OC6 project Phase III: validation of the aerodynamic loading on a wind turbine rotor undergoing large motion by a floating support structure, 2023.

[5] MEDSEA_MULTIYEAR_WAV_006_012, HCMR (Greece), 30 November 2023.

[6] A.G. Sanvito et al. Formulation, Validation, and Application of a Novel 3D BEM Tool for Vertical Axis Wind Turbines of General Shape and Size, 2021

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