Wind turbine rotors in surge motion: Relevance of the returning wake effect for large-scale FOWT

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TUHH
Hamburg
University of
Technology

Fluid Dynamics and Ship Theory

Maritime Systems

Motivation:

Are there unsteady contributions to the aerodynamic loads of FOWT?

If yes: Do we need to enhance our simulation models?

Preprint

eawe european academy of wind energy

Wind Energy Science

Wind turbine rotors in surge motion: New insights into unsteady aerodynamics of FOWT from experiments and simulations

Christian W. Schulz, Stefan Netzband, Umut Özinan, Po Wen Cheng, and Moustafa Abdel-Maksoud

Abstract. An accurate prediction of the unsteady loads acting on floating offshore wind turbines (FOWT) under consideration of wave excitation is crucial for a resource-efficient turbine design. Despite a considerable number of simulation studies in this area,

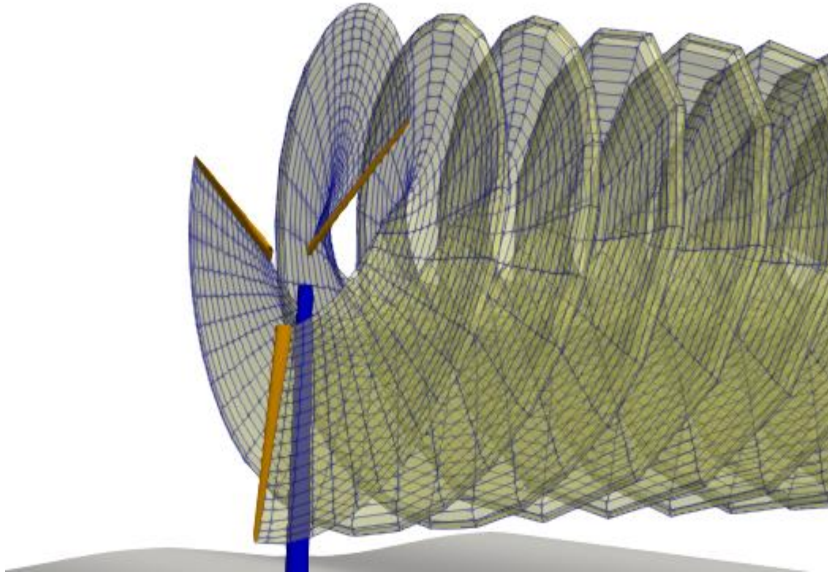
- Recent simulation study on surging rotors revealed

→ **strong unsteady contributions** at high motion frequencies

→ **returning wake effect** becomes relevant

Next step: **Check practical relevance of returning wake effect and other unsteady phenomena for a large scale FOWT rotor**

Relevance of the returning wake effect for large-scale FOWT

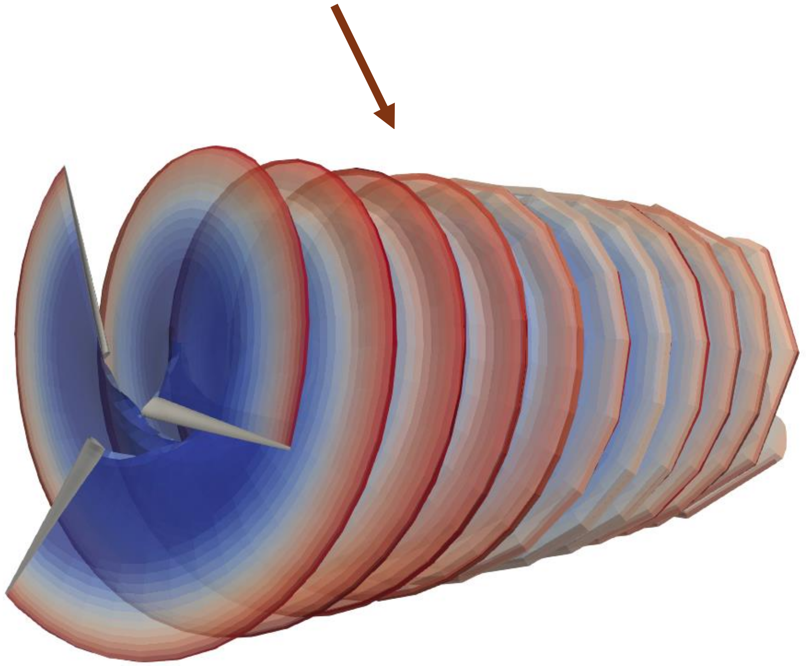


Relevant unsteady phenomena for surging wind turbines

Dynamic wake effect

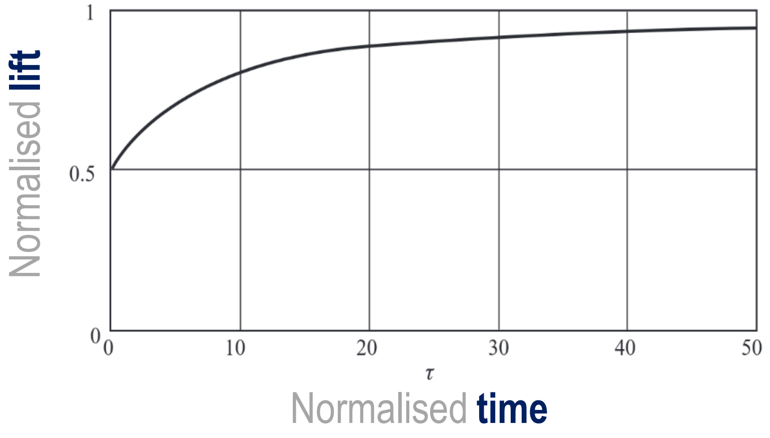
- Also called dynamic inflow effect
- Changes of **the inflow situation in the past** act on **actual** induced velocity
- Only **gradual** changes of axial induced velocity
- **Low pass filter** effect
- Characterised by **rotor reduced frequency**

$$f_r = \frac{f\,D}{v_0}$$



Equation: Schepers, 2012

Relevant unsteady phenomena for surging wind turbines



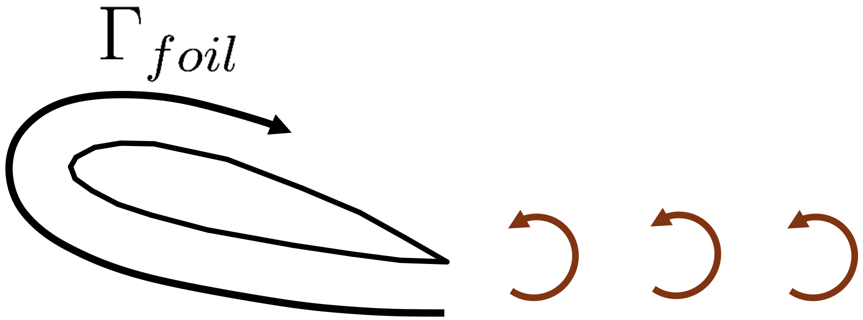


Figure: Burton et al., 2011

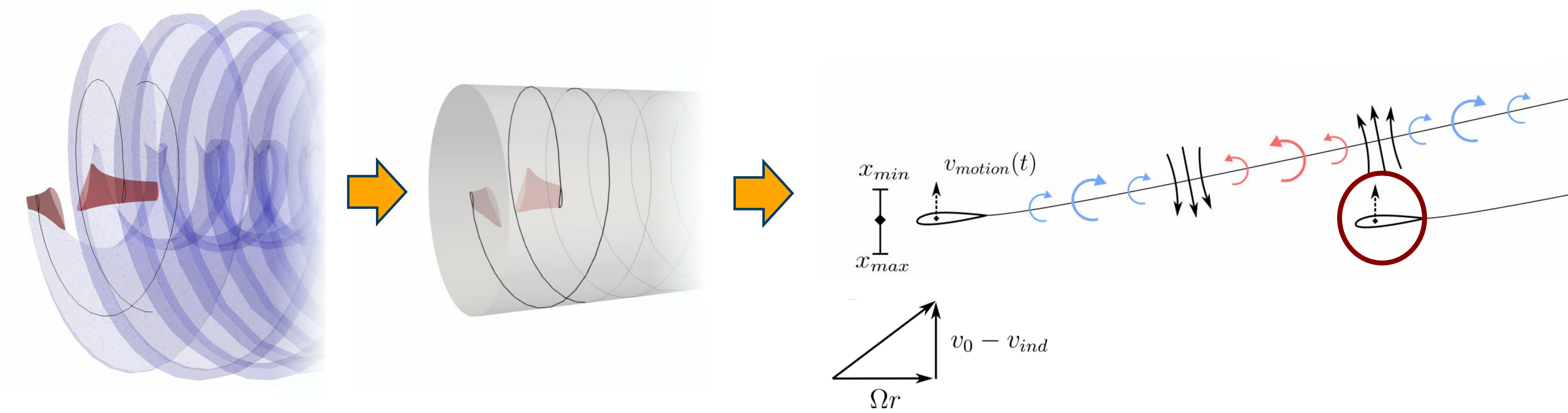
Unsteady airfoil effect (Theodorsen)

- **Attached flow**
  - **2D** thin airfoil theory
  - **Circulatory** / vortex shedding
  - Leads to **delayed response of lift** force (exponential)
- Characterised by **airfoil reduced frequency**

$$f_a = \frac{\pi f c(r)}{\sqrt{v_0^2 + (r\Omega)^2}}$$

- Dynamic stall: Minor relevance in this case

Relevant unsteady phenomena for surging wind turbines: Returning wake effect



- Known from **helicopter aerodynamics**
- **Maximum** influence on loads when surge frequency equals **3P frequency**

- Characterised by

$$q_b = \frac{2\pi f}{n_b \Omega}$$

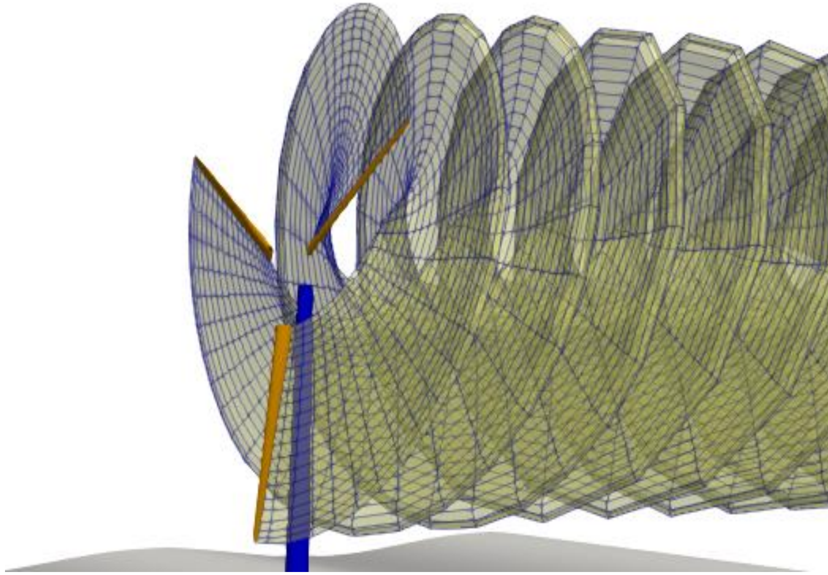
Relevance of the returning wake effect for large-scale FOWT

1 Unsteady phenomena
- Unsteady airfoil and dynamic inflow effect
- Returning wake effect

2 **Simulation methods**

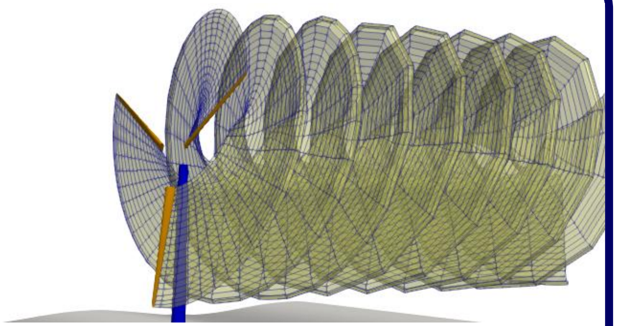
3 Results: IEA 15MW in surge motion
- Thrust force amplitude
- Analysis of three unsteady regions
- Appearance at wave frequency

4 Conclusion



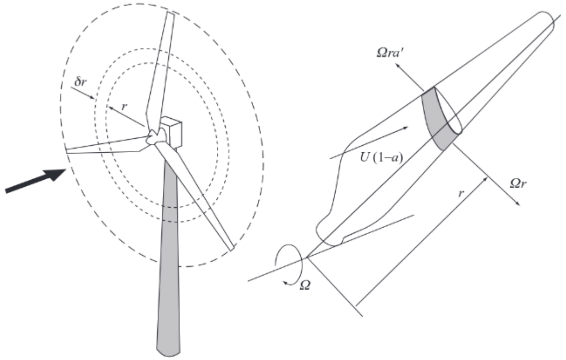
Simulation methods

panMARE



- Blade replaced by **vortex line**
- **3D, unsteady wake** representation
- Lift and drag forces from empirical coefficients
- **Unsteady effects** modelled:
  - Circulatory UA effect, dynamic inflow effect, **returning wake effect**

AeroDyn
OpenFAST



- **B**lade **E**lement **M**omentum Theory (**BEM**)
- Unsteady corrections
  - ***Dynamic inflow***
  - ***Unsteady airfoil*** correction (Leishman-Beddoes model)
  - Dynamic stall
- **No correction for returning wake effect**

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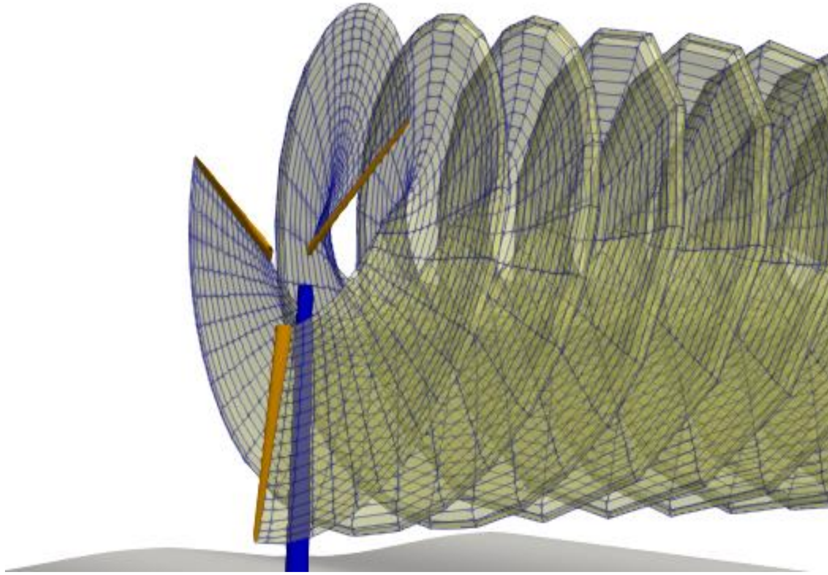
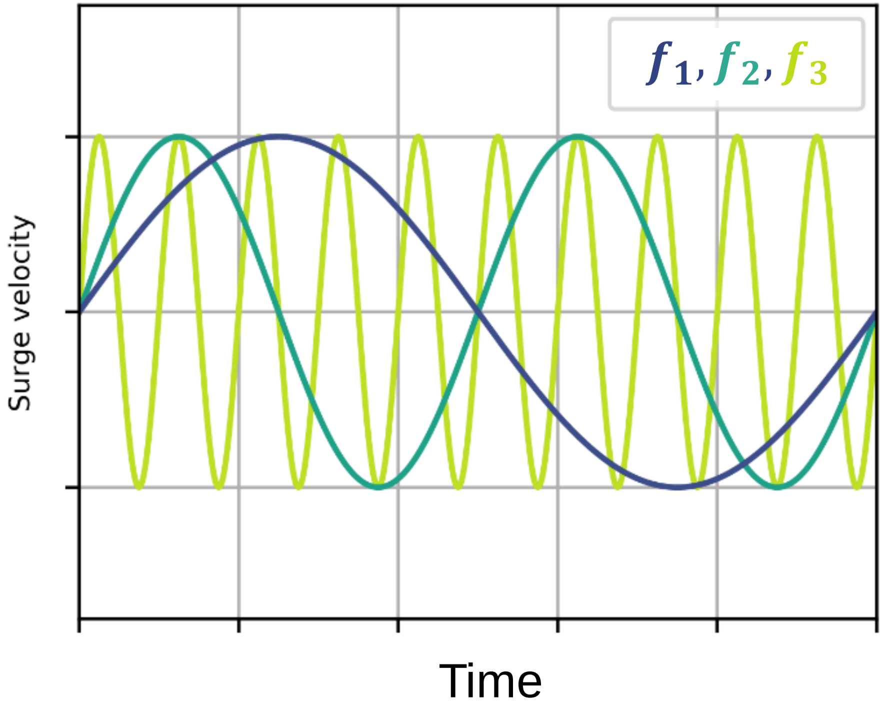


Simulation scenarios for the identification of unsteadiness during surge motion

Definition of scenarios

- Basic idea:
  - Load case set from **very low to very high** motion **periods**
  - **Same variation of TSR** for all cases
  - ➡ **Same result for all load cases** in case of **no unsteady contribution**
- Surge motion:
  - **Constant surge velocity amplitude**
  - Constant rotational speed and wind speed



Surge motion velocity
Periods: approx. 3 up to 300 s

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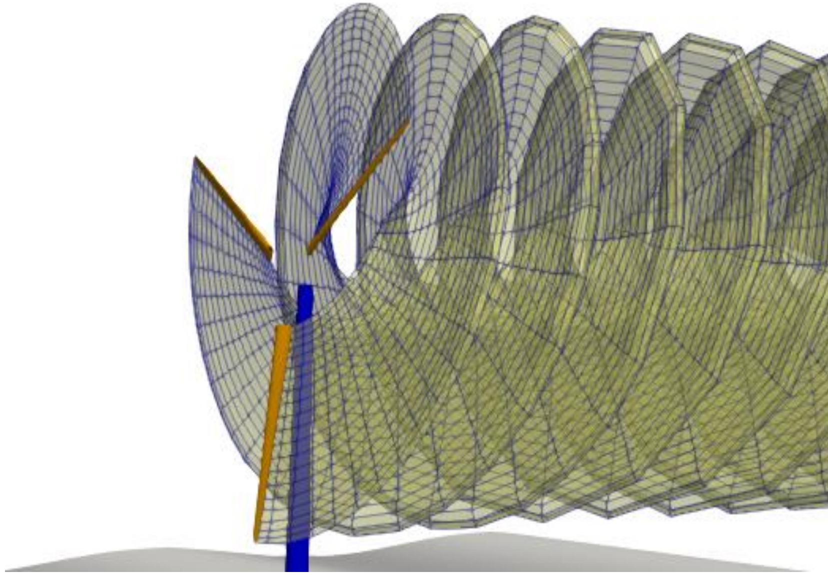
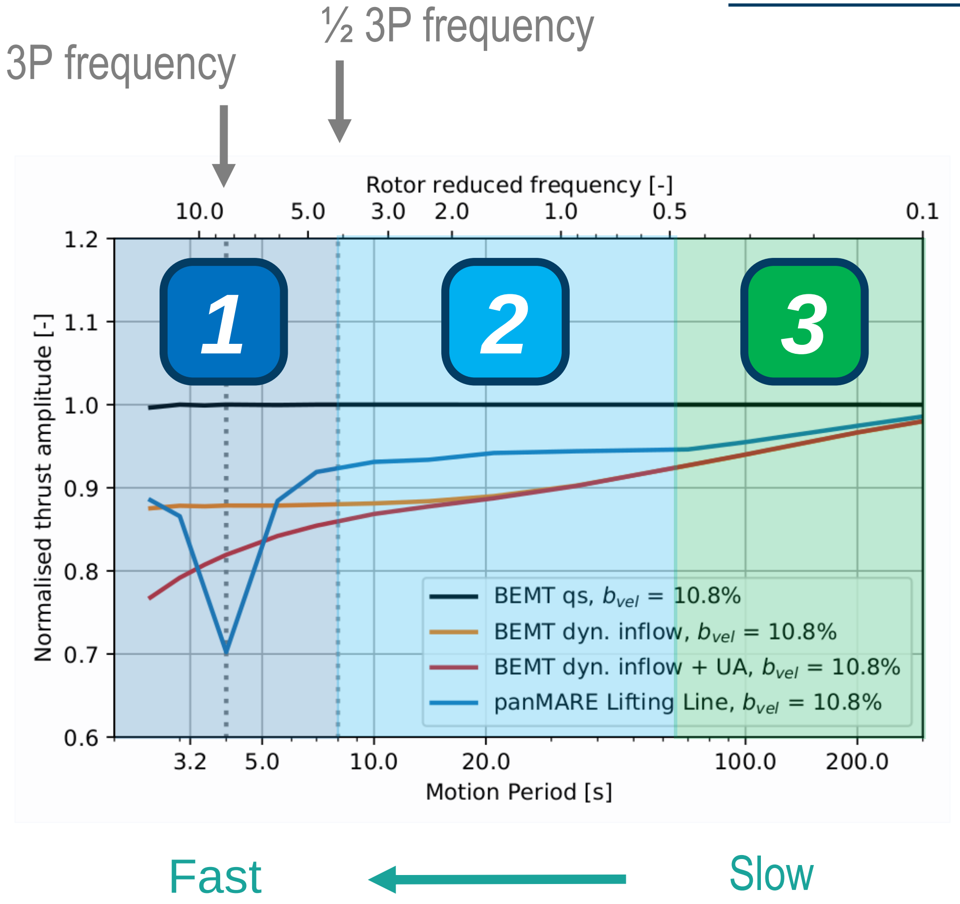


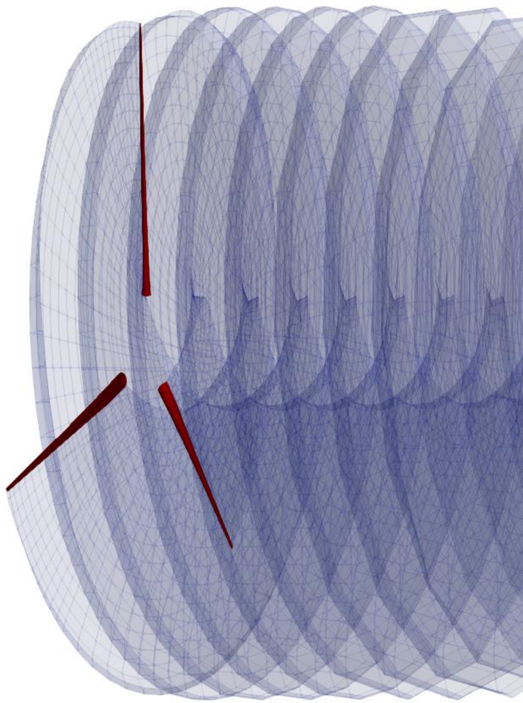
IEA 15MW in surge motion: Rotor thrust amplitude



Rotor thrust amplitude

(@ 7 m/s uniform wind)

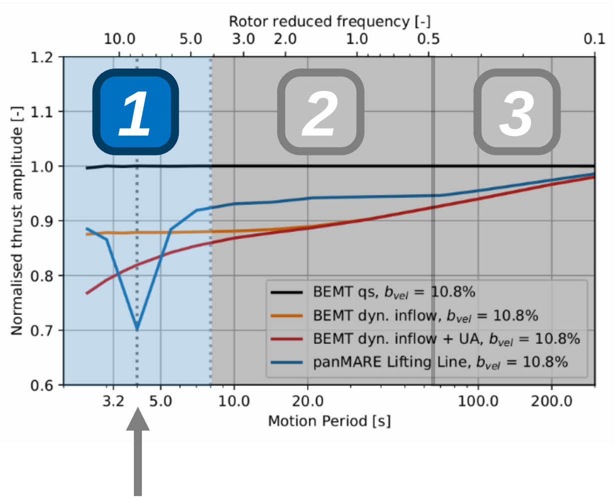
- **Thrust normalised** to case with **highest period**
- Plotted over **motion period** (log scale)
- **OpenFAST** BEMT simulations
  - **Quasi-steady**
  - **Dynamic inflow** correction
  - **Dynamic inflow + unsteady airfoil** corrections
- **Quasi-steady model acts quasi-steady**
- Significant **unsteady contributions**
- Analysis of unsteady regions



Simulation setup:

LL elements:	*24*
Wake panels:	*14,400*
Min. blade radius:	*r/R = 0.04*
Wake length:	*4 D*

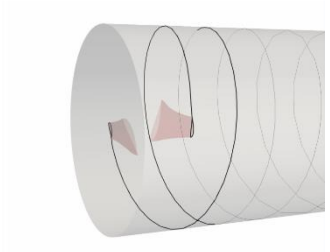
IEA 15MW in surge motion: Unsteady region 1

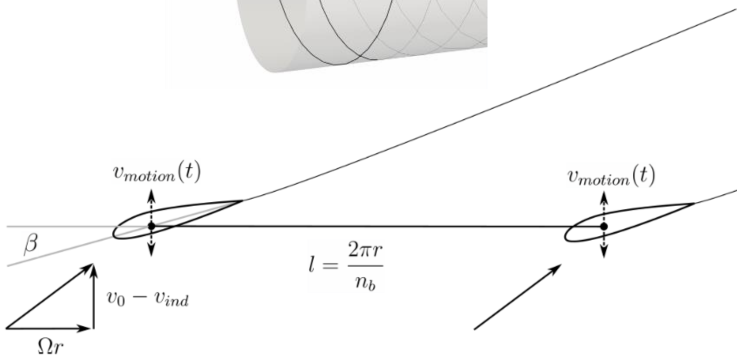


3P frequency

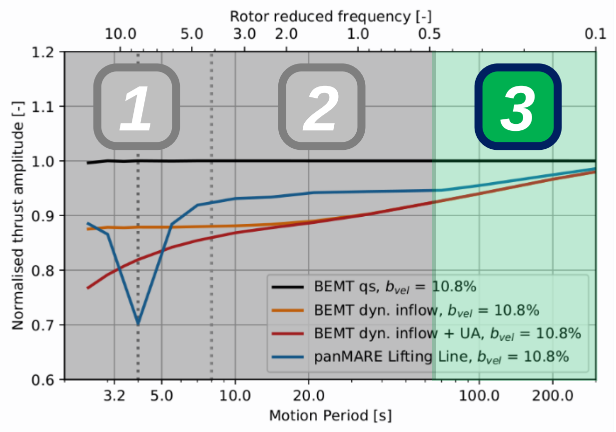
Unsteady effects in region 1 (up to 8s)

- Minimum @ motion frequency = 3P
  - **Returning wake effect**
  - **Not modelled in BEMT**
- Findings from 2D simulations at r/R = 0.64
  - Unsteady airfoil effect is prerequisite
    $$f_a > 0.02$$
  - Strong influence of returning wake effect when
    $$q_b = \frac{2\pi f}{n_b \Omega} \qquad q_b > 0.25 \dots 0.5$$
  - Contribution of returning wake effect at **periods lower than 20s**

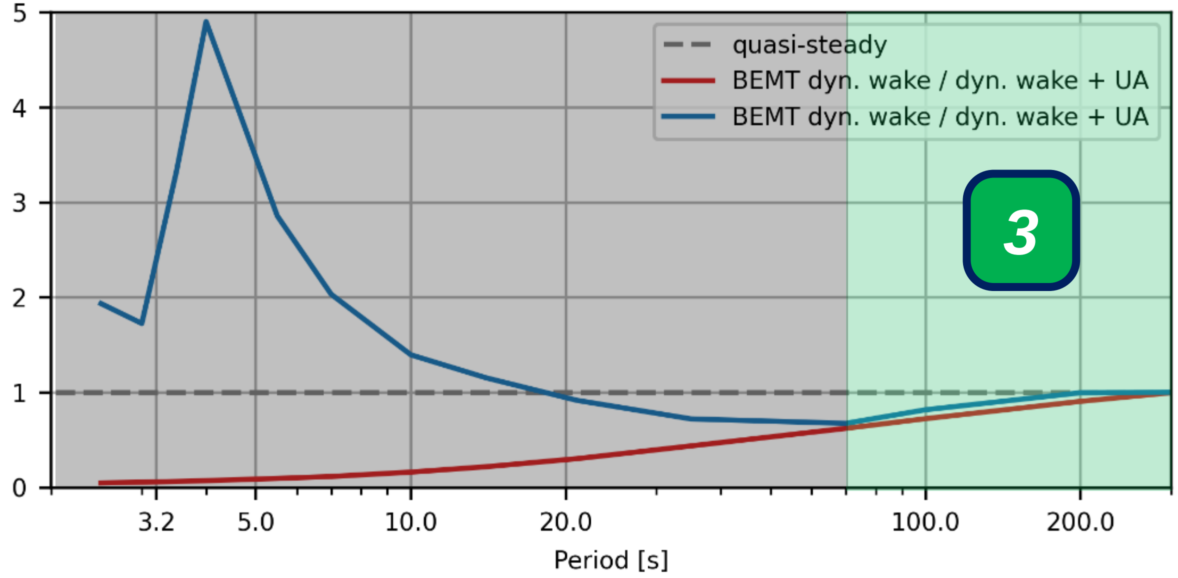




IEA 15MW in surge motion: Unsteady region 3



Amplitude of rotor averaged axial induction



Unsteady effects in region 3 (70 to 300s)

- Both methods: **gradual decrease** of thrust amplitude
- Amplitude of axial induction
  - Normalised to quasi-steady case
  - Regions 1 and 2 **not comparable between LL and BEMT**
  - **Low pass filter** effect in both methods
  - Dominated by **dynamic wake effect**

$f_r > 0.1$ ... ?

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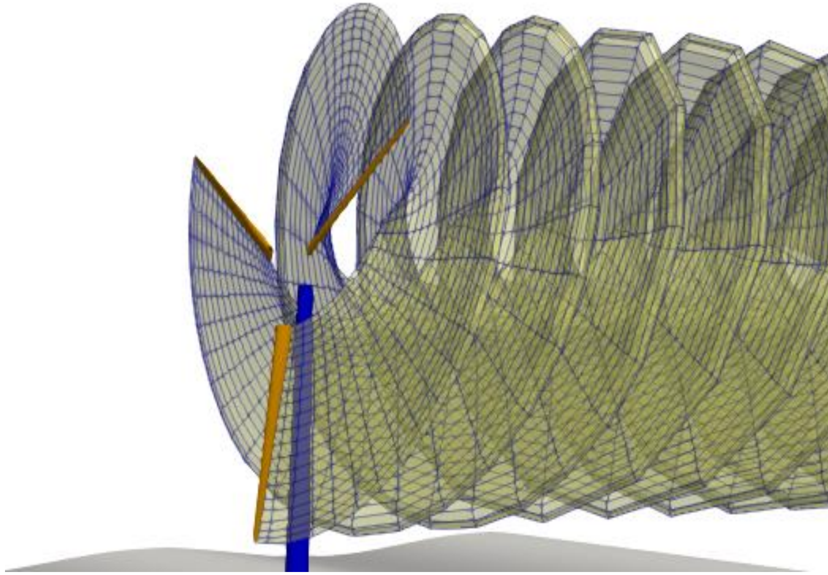


Realistic wave periods

Gulf of Maine

Significant Wave Height [m]	Tp (s)								
	1<Tp<2	2<Tp<3	3<Tp<4	4<Tp<5	5<Tp<6	6<Tp<7	7<Tp<9	9<Tp<11	Tp>11
<1	0,03%	4,69%	7,29%	7,02%	3,91%	5,91%	13,49%	6,27%	0,08%
1< Hs <2		0,00%	0,92%	6,64%	6,85%	7,32%	7,90%	8,36%	0,16%
2< Hs <3			0,00%	0,09%	0,55%	2,71%	2,91%	3,31%	0,15%
3< Hs <4				0,00%	0,01%	0,12%	1,11%	1,04%	0,08%
4< Hs <5						0,00%	0,19%	0,47%	0,04%
5< Hs <6							0,02%	0,21%	0,01%
6< Hs <7								0,08%	0,01%
7< Hs <8								0,02%	0,01%
Hs >8								0,00%	0,00%

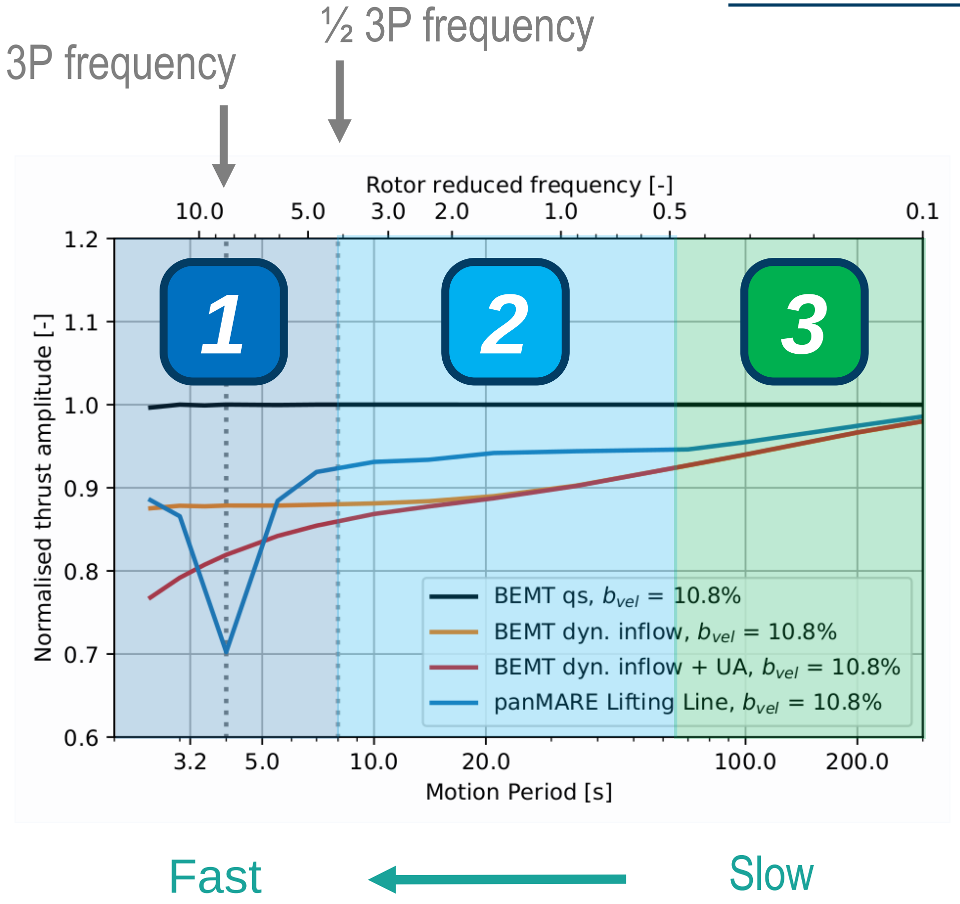
1*

Table 26: GoM significant wave height-peak period distribution

* for 7 m/s wind speed

Source: Lifes50+ Report, Deliverable 1.1 Oceanographic and meteorological conditions for the design

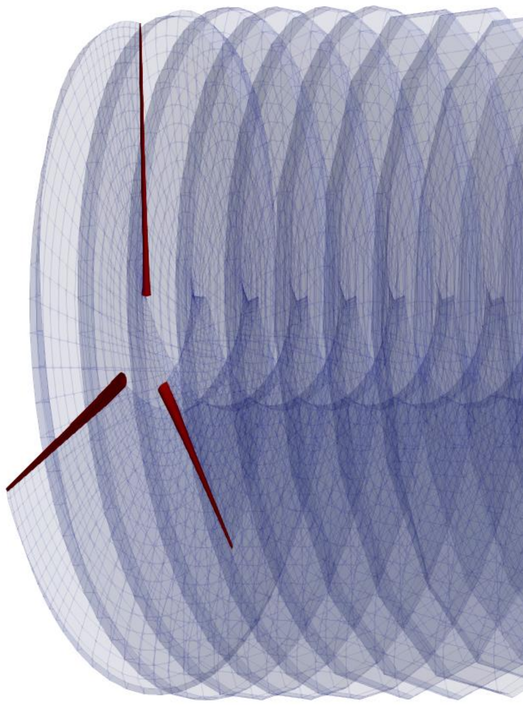
IEA 15MW in surge motion: Rotor thrust amplitude



Rotor thrust amplitude

(@ 7 m/s uniform wind)

- **Returning wake effect** is present **at realistic wave periods!**
  - Especially at low wind speeds
  - Reduction of thrust amplitude of up to **25%**



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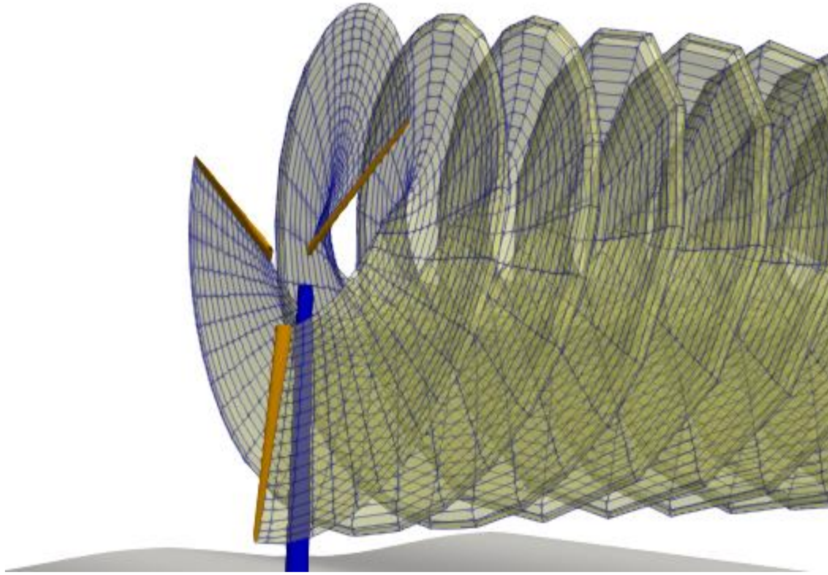
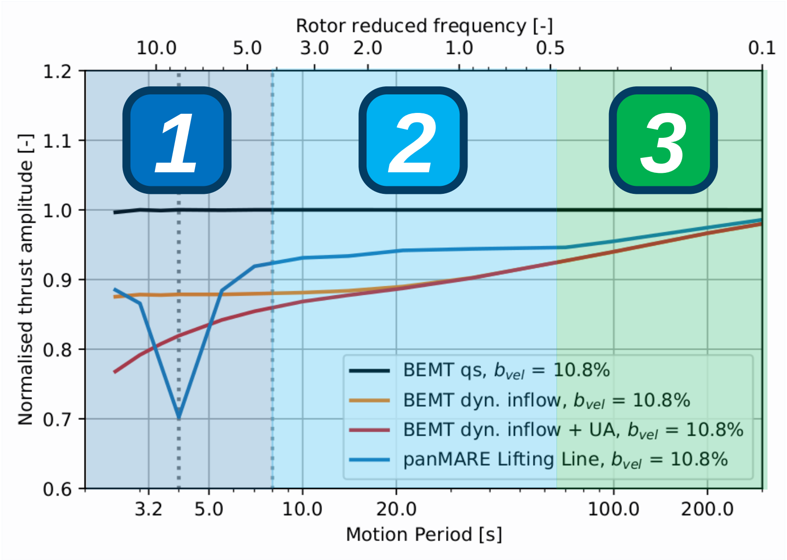


Conclusions

- Unsteady contributions to rotor loads of the IEA 15 MW from
  - **Dynamic wake** effect
  - **Unsteady airfoil** effect
  - **Returning wake** effect
- Unsteady phenomena can be identified by interplay of
  - **Rotor reduced frequency**
  - **Airfoil reduced frequency**
  - **Ratio of motion and 3P frequency**
- Returning wake effect **occurs at realistic wave frequencies**
- **Simulation inaccuracies must be expected when using classical BEMT methods**



Related publications

Two related publications and can be found at

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New publication follows in first half of 2024

Acknowledgements

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