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Technical modeling challenges for large idling wind turbines

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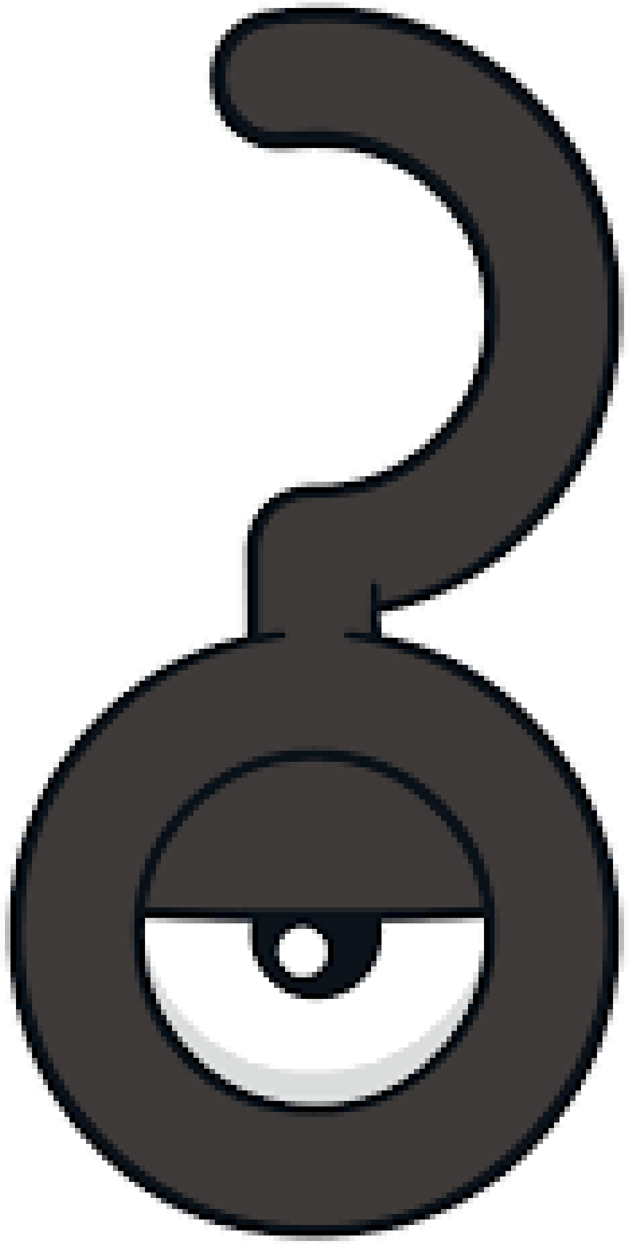
Introductions

Introduction

Let’s start by asking ourselves

- What do we understand about the aerodynamics under idling cases
- Do we really need to model dynamic stall?
- How sensitive is dynamic stall calculations using engineering model in idling conditions?
- How the aerodynamic damping influences the loads?



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Introduction

The danger of deep stall…..

Aerodynamics of Deep Stall

- Massively separated flow which includes all complex characteristics
- Vortical structures interact and change the instationary loads

Bangga et al, 2017

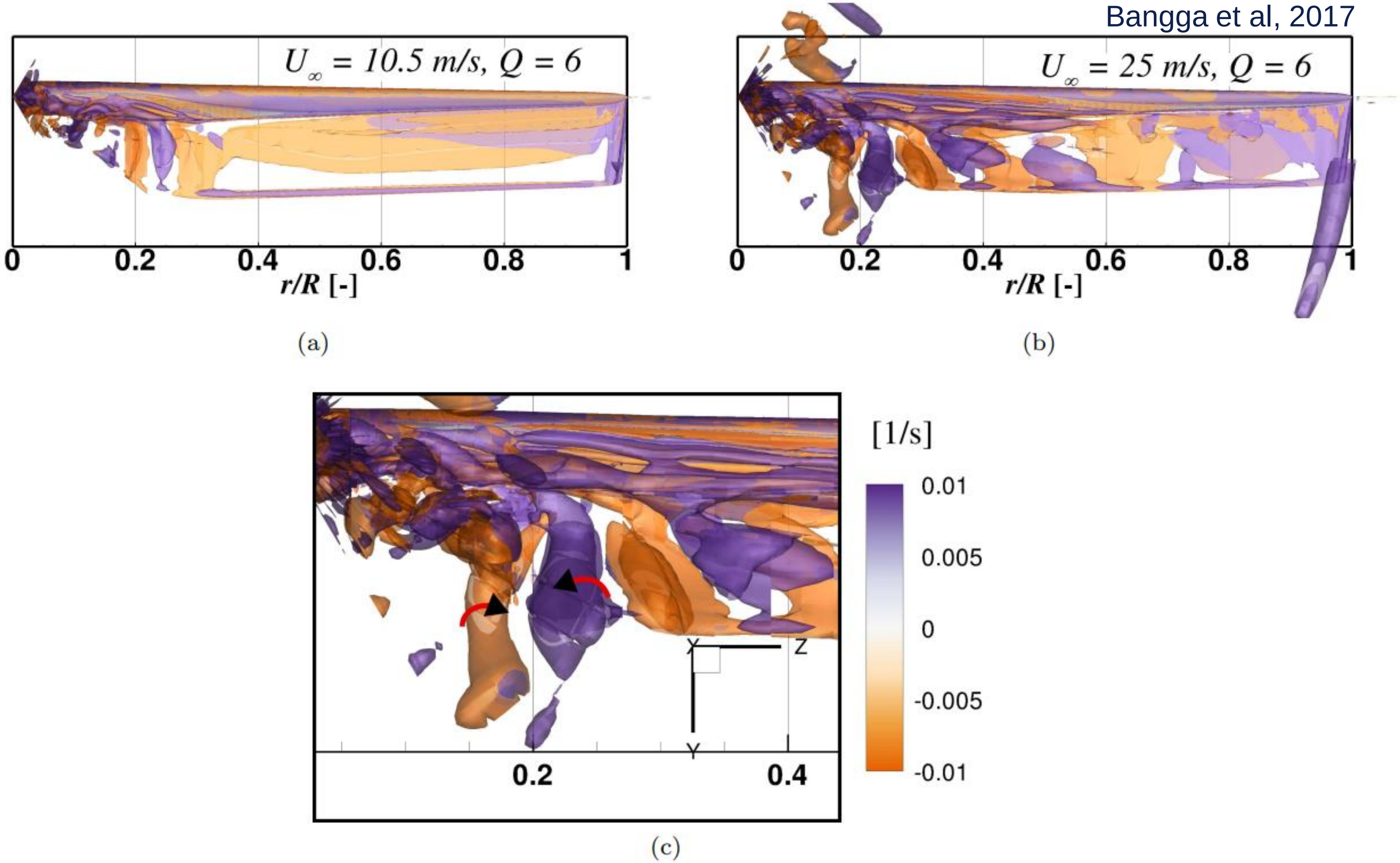
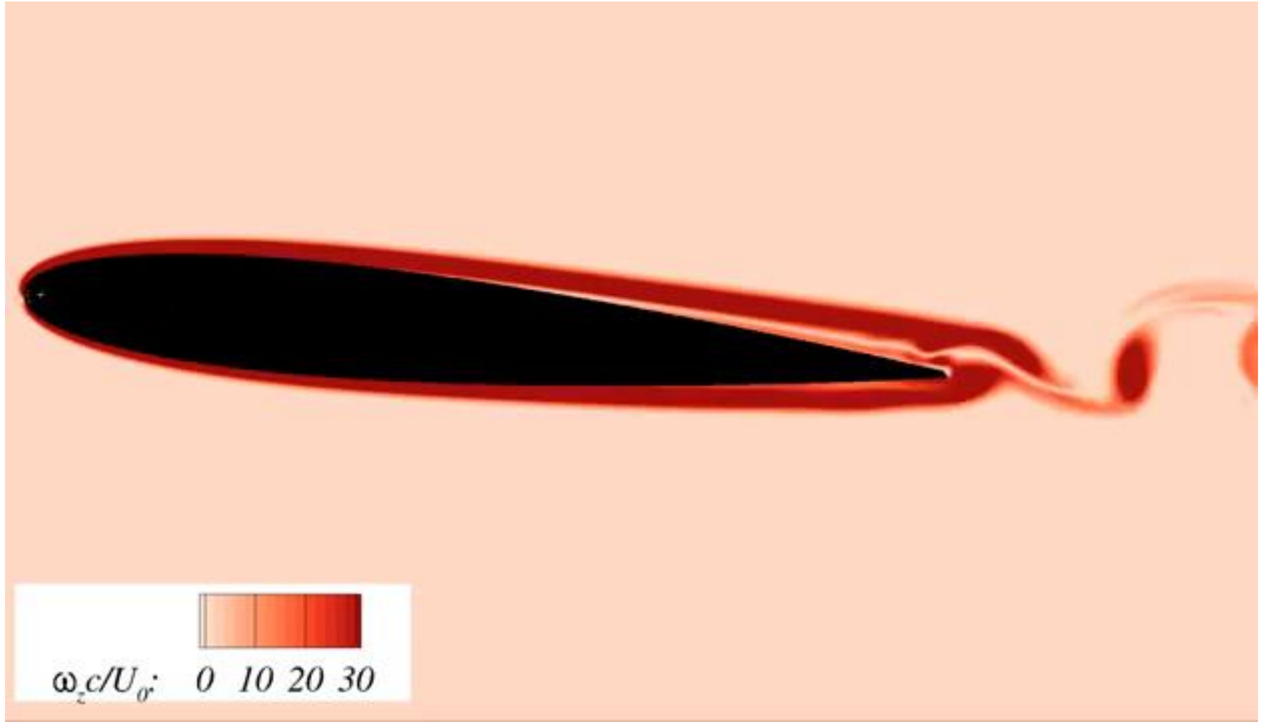


Figure 11: Trailing vortices in the inboard region of the blade illustrated by Q-Criterion colored by Y-vorticity [1/s]. The inboard vortex system becomes stronger with increasing wind speed, showing distinct counter-rotating trailing vortices which induces downwash.

Aerodynamics of Deep Stall

- Massively separated flow which includes all complex characteristics
- Vortical structures interact and change the instationary loads
- Unsteady excitation from angle of attack variation leads to a phenomenon called dynamic stall
- There are strong vortex interactions on the airfoil (blade) surface. Two main vortices are the leading edge vortex (LEV) and trailing edge vortex (TEV)

Ouro et al, 2018



Some facts and issues

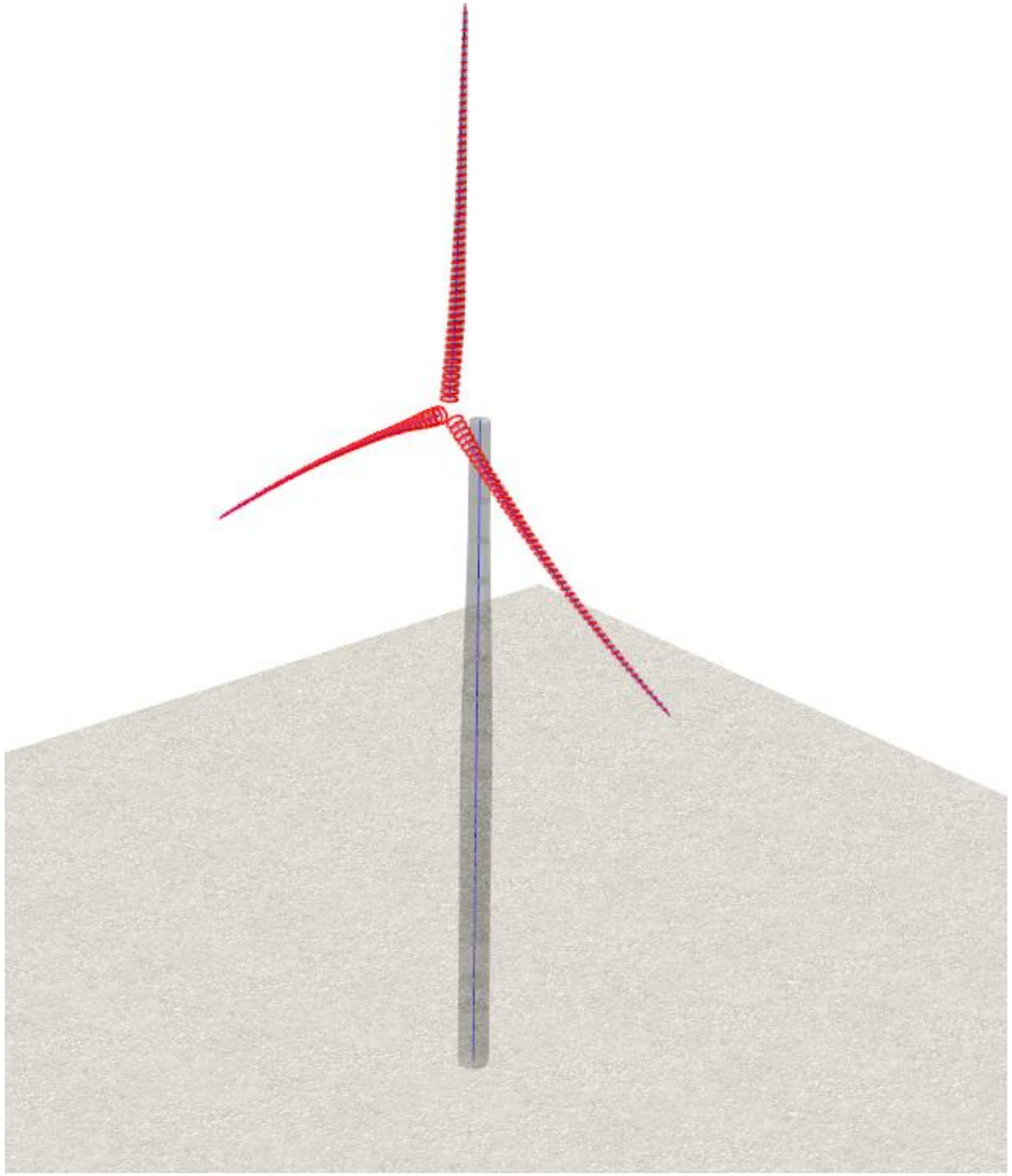
- The accuracy of wind turbine load predictions is influenced by correct modeling/capturing of 3D and unsteady effects.
- Dynamic stall (DS) remains one of the most difficult cases for wind turbine aerodynamics.
- The flow field during DS is complex and its mechanisms are insufficiently understood.
- Existing dynamic stall models hardly provide reliable predictions concerning the higher harmonic effects
- Many dynamic stall models are developed only for lift coefficient, only limited number of them consider drag and pitching moment
- In idling conditions, engineering models often underestimate the true aerodynamic damping → causing stronger instabilities than the real situations

Research Methodology

Simulation Strategy

Turbine and test cases

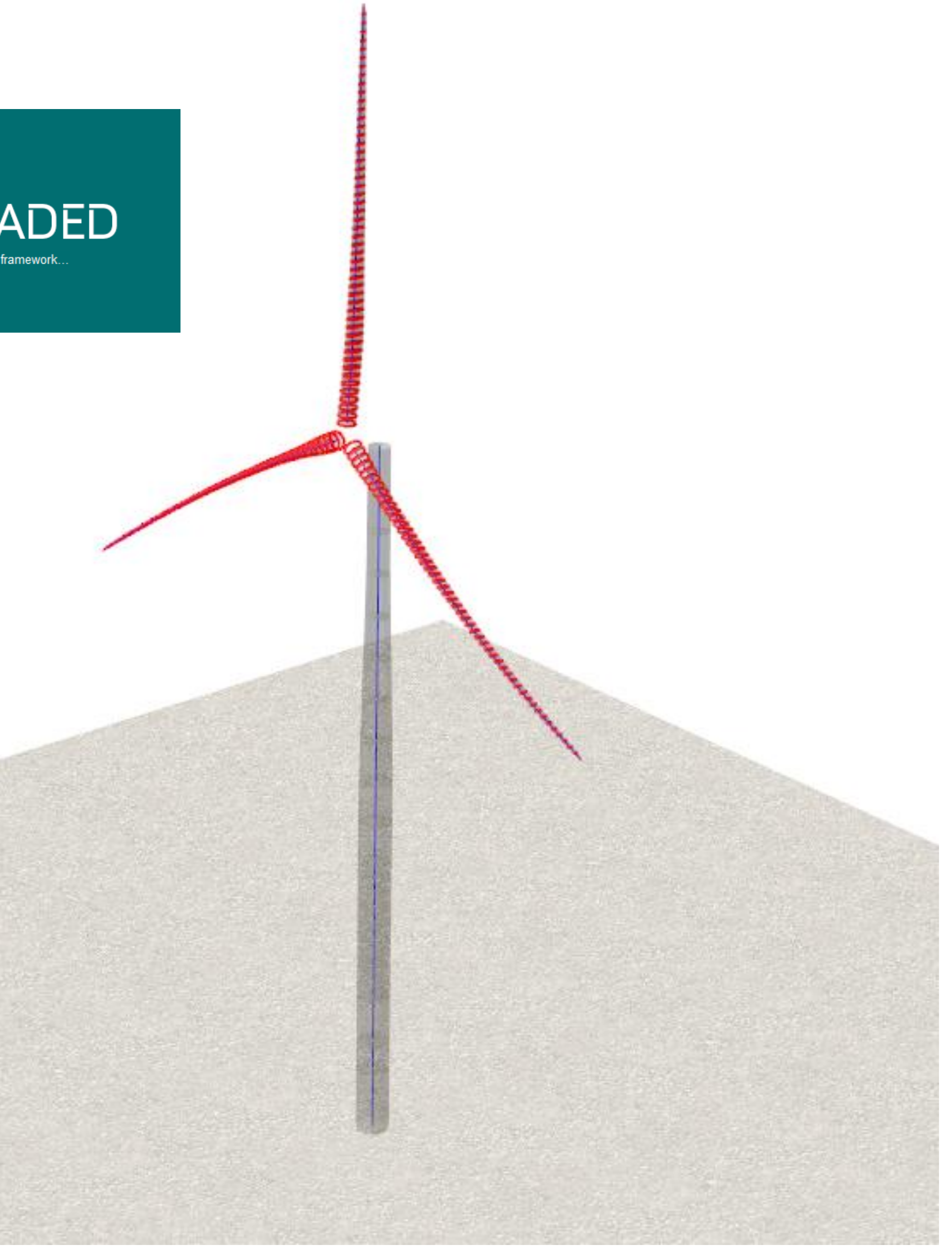
- IEA 15 MW turbine
- Rotor diameter = 242 m
- Idling DLC 6.3 case
  - $\bar{U} = 40$ m/s
  - $\psi = [-20°, 0°, +20°]$
  - $TI_X = 11\%$, $TI_Y = 8.8\%$, $TI_Z = 5.5\%$



Simulation Strategy

Turbine and test cases

- Simulated using a development version of Bladed
- A new dynamic stall model “IAG Model”[1] has been recently implemented in Bladed
- Studies were performed by changing the dynamic stall modeling
- Simulations were carried out by adopting Bladed BEM and Bladed Vortexline (free wake + lifting line) modules



[1] Bangga, G., Lutz, T. and Arnold, M., 2020. An improved second-order dynamic stall model for wind turbine airfoils. *Wind Energy Science*, *5*(3), pp.1037-1058.

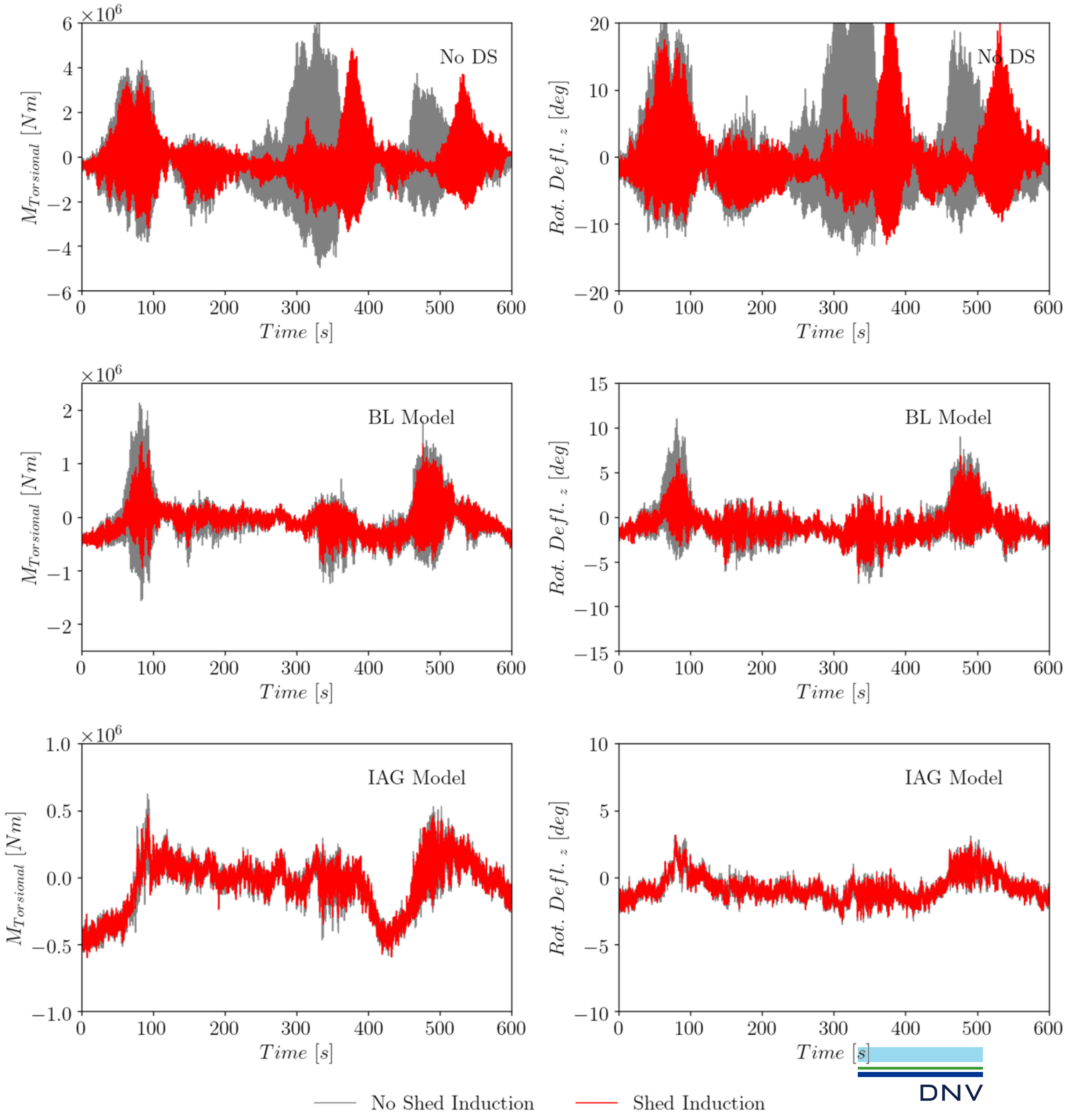
Results and Discussion

Effects of shed vortex inductions

- Computed wind turbine loads and blade tip torsion rotational deflection using Vortexline are affected by unsteady models

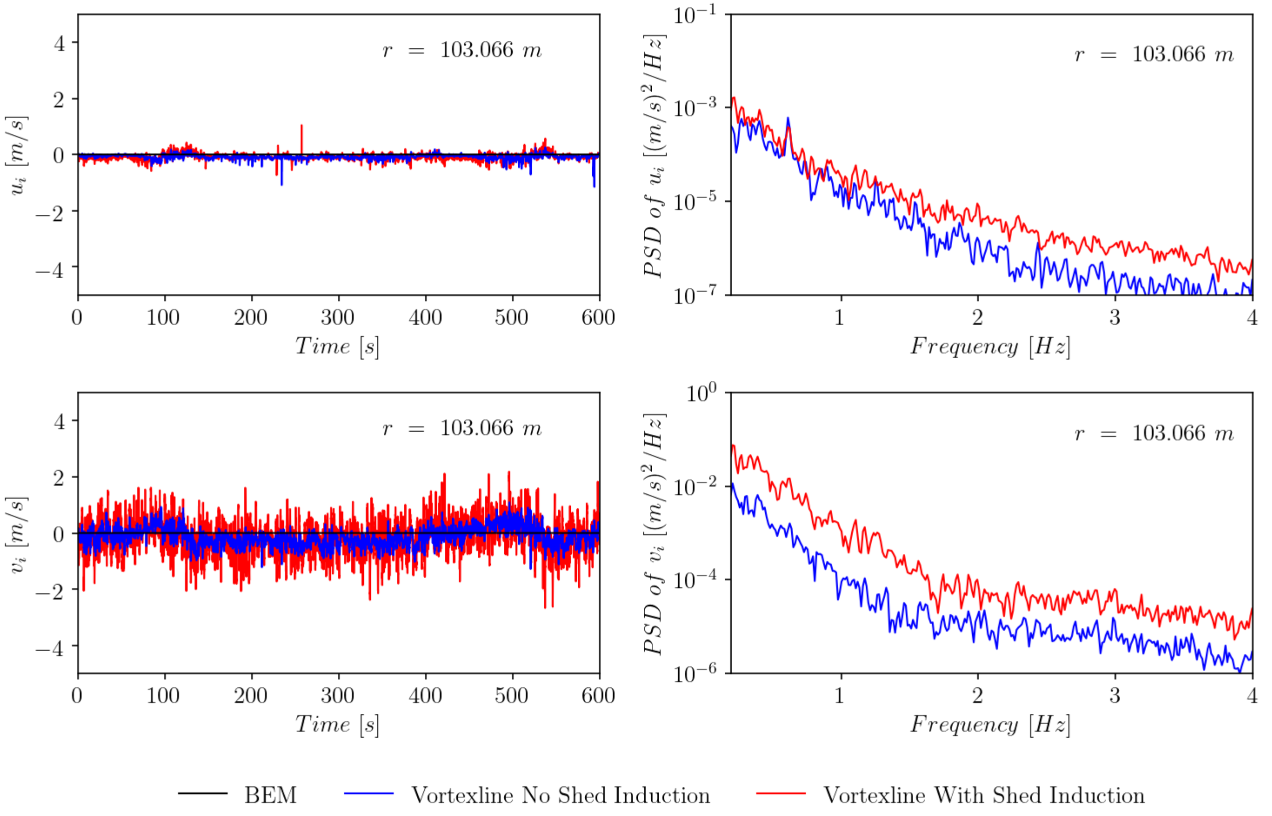
- The shed vortex effect introduces aerodynamic damping which helps stabilizing the results

- Shed vortex effects are pronounced when no dynamic stall model is adopted

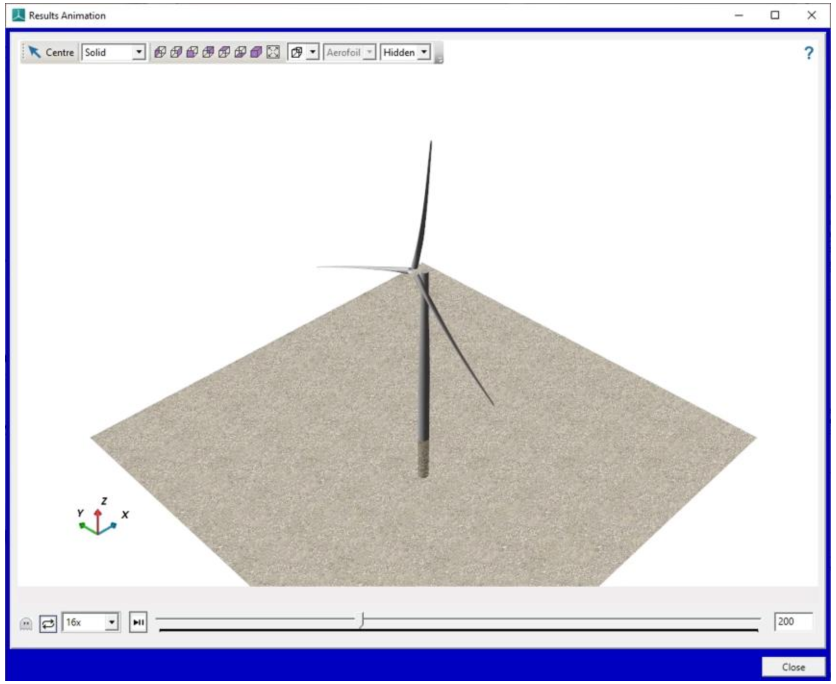


Effects of shed vortex inductions

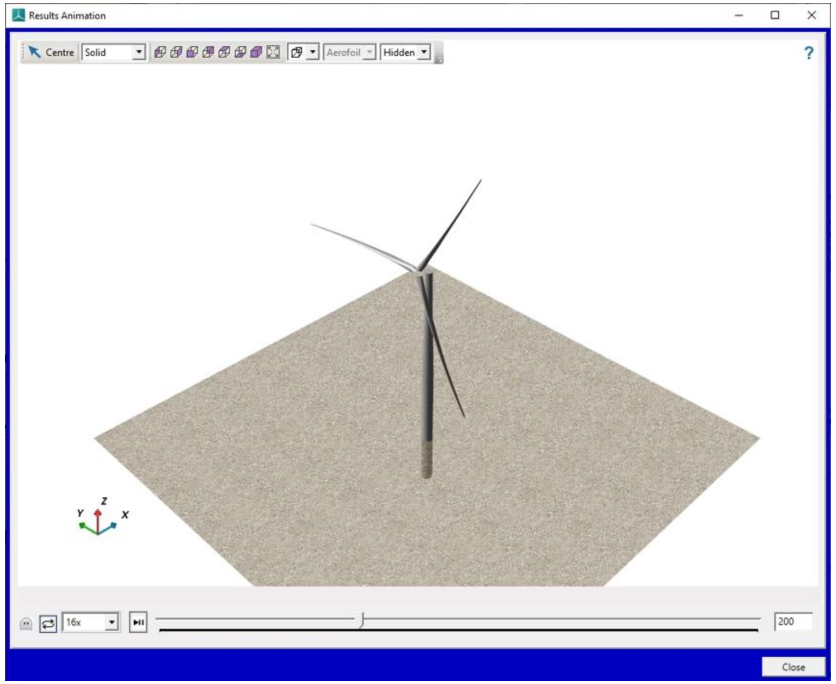
- Computed wind turbine loads and blade tip torsion rotational deflection using Vortexline are affected by unsteady models
- The shed vortex effect introduces aerodynamic damping which helps stabilizing the results
- Shed vortex effects are pronounced when no dynamic stall model is adopted
- This causes variations of the induced velocities seen by the blade sections, even under idling conditions



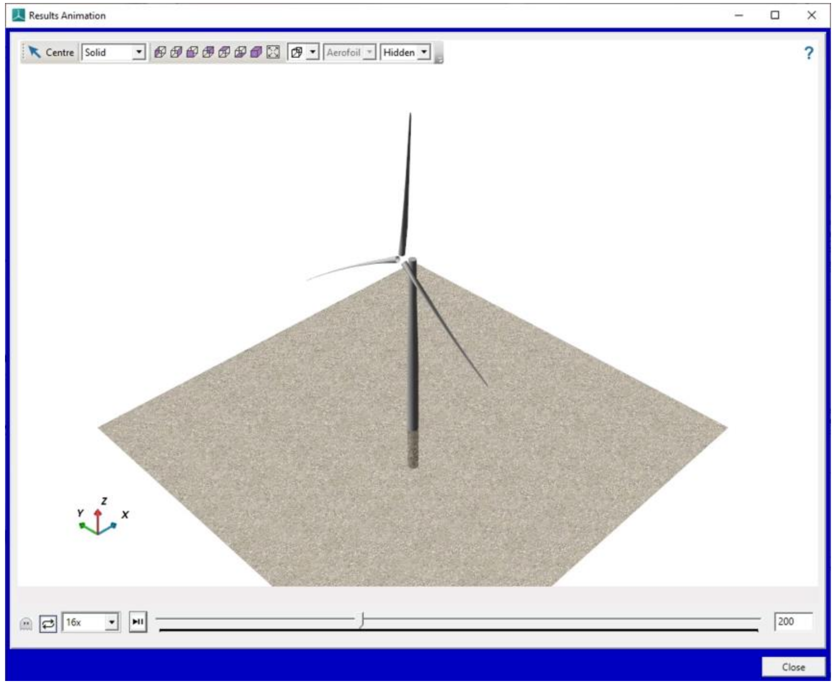
Dynamic stall modeling influence



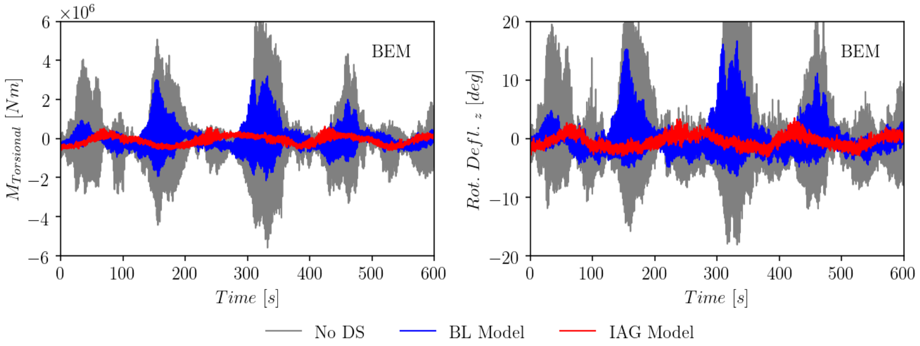
BEM + No DS

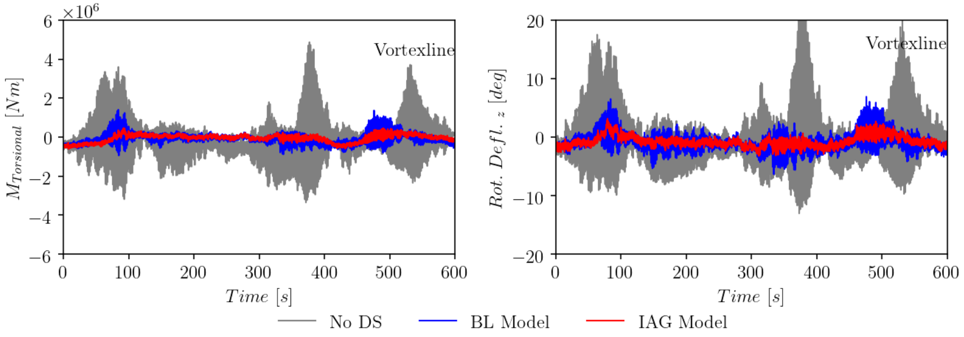


BEM + BL Model



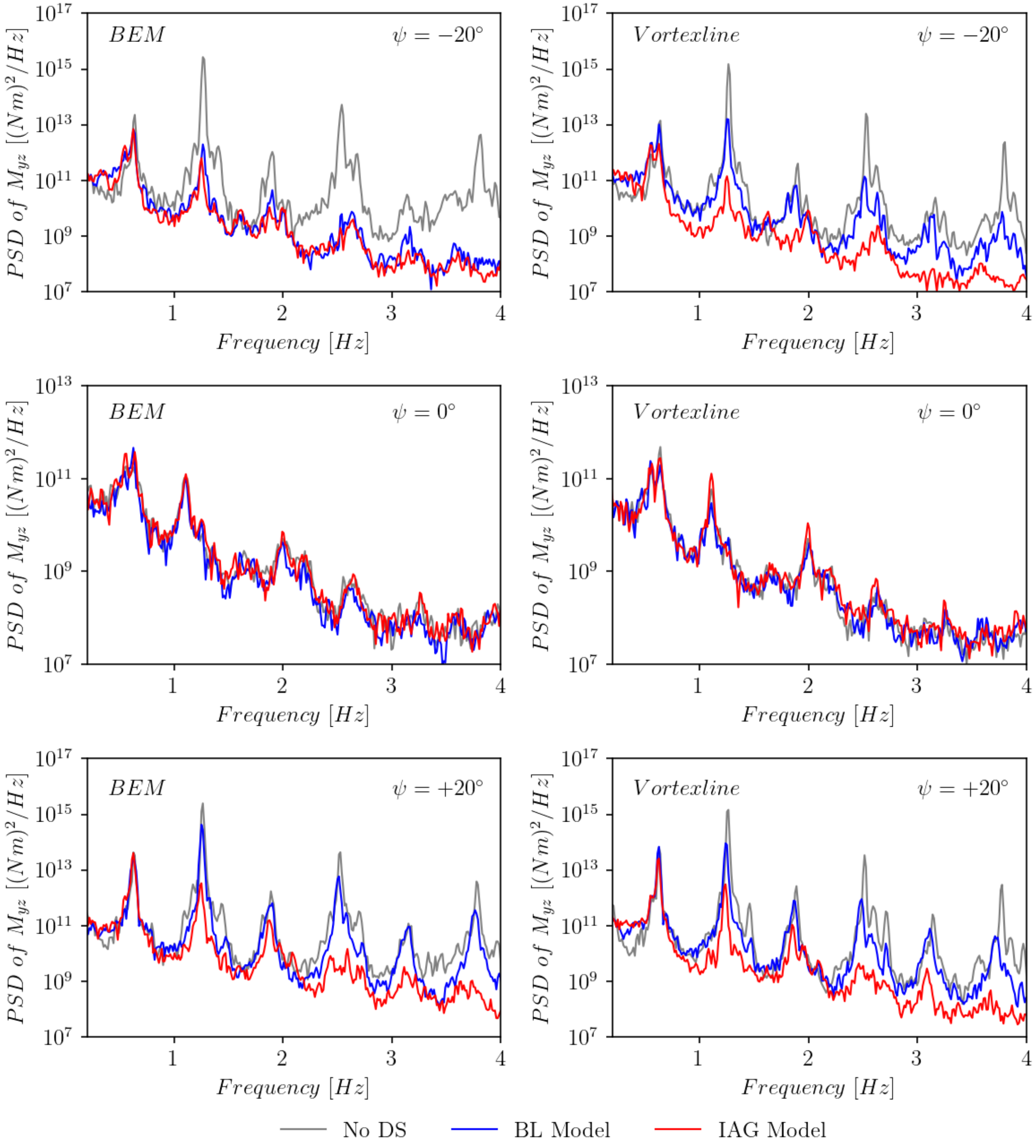
BEM + IAG Model





Yaw angle influence

- Increasing/decreasing yaw angle highlights the importance of dynamic stall modeling
- Without modeling the dynamic stall effects, hub resultant moment amplitudes become unreasonably large → due to missing aerodynamic damping
- IAG model predicts the smallest amplitudes, highlighting the characteristics of the higher aerodynamic damping for the studied test cases



Conclusions and Remarks

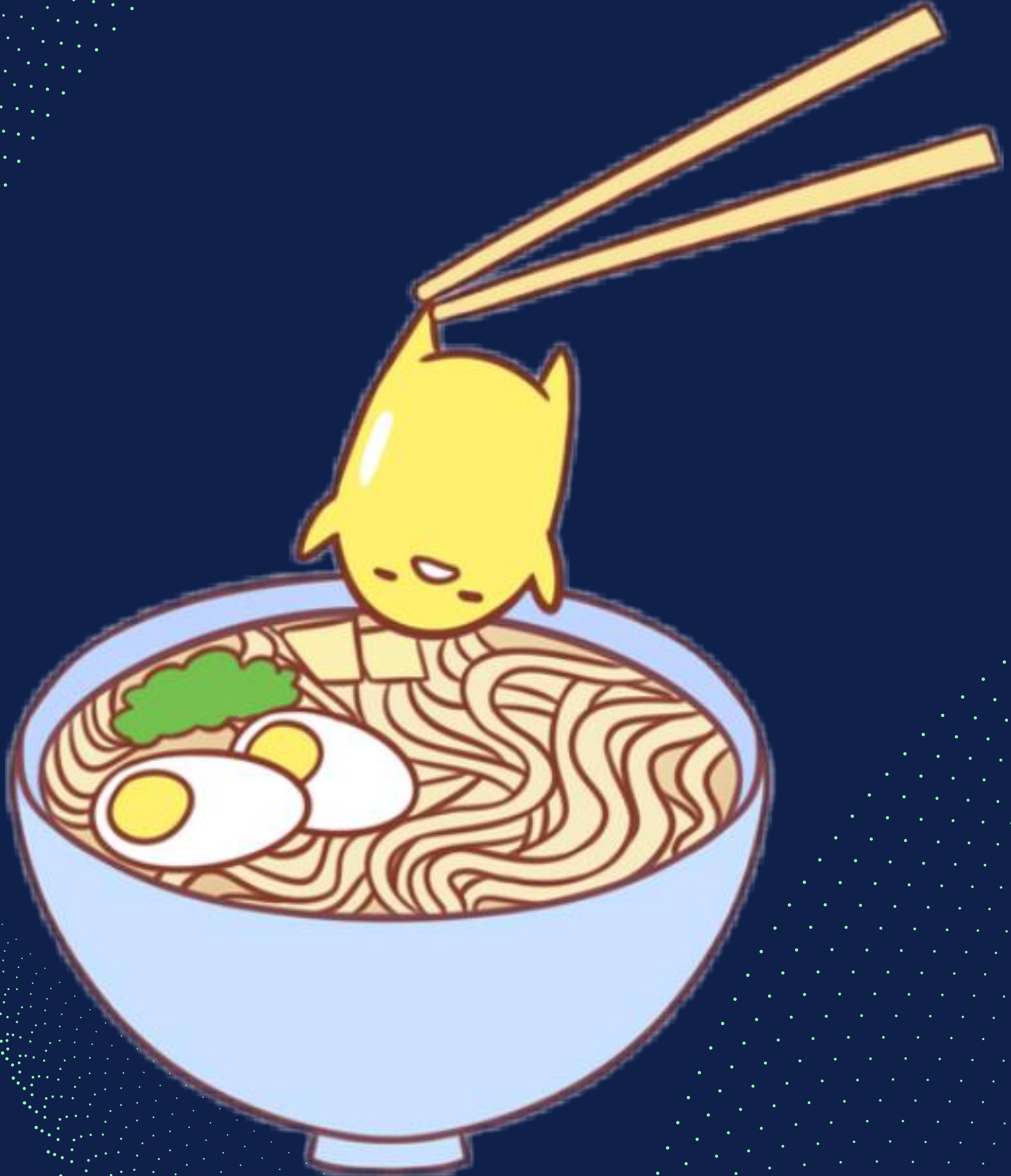
Conclusions and Remarks

- Idling instability predictions depend on the unsteady aerodynamic modeling especially the inclusion of the dynamic stall model.
- Calculations without dynamic stall model yield massive instabilities which are unlikely to be physically correct.
- The IAG dynamic stall model predicts more reasonable instability level which can be helpful for the loads analysis.
- Vortexline calculations incorporate induction dynamics even for idling conditions which allows the induced velocity especially in tangential direction to vary.
- The dynamics of the induced velocities partially extracts the energy of the flow and increases the aerodynamic damping. This effect is more pronounced when the shed vortex effect is included.

More details are given in the paper when it is published!

Thank you!

*now time for ~~snacks~~ questions



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