Aerodynamics & blade technology II

Vortex-Induced Vibrations

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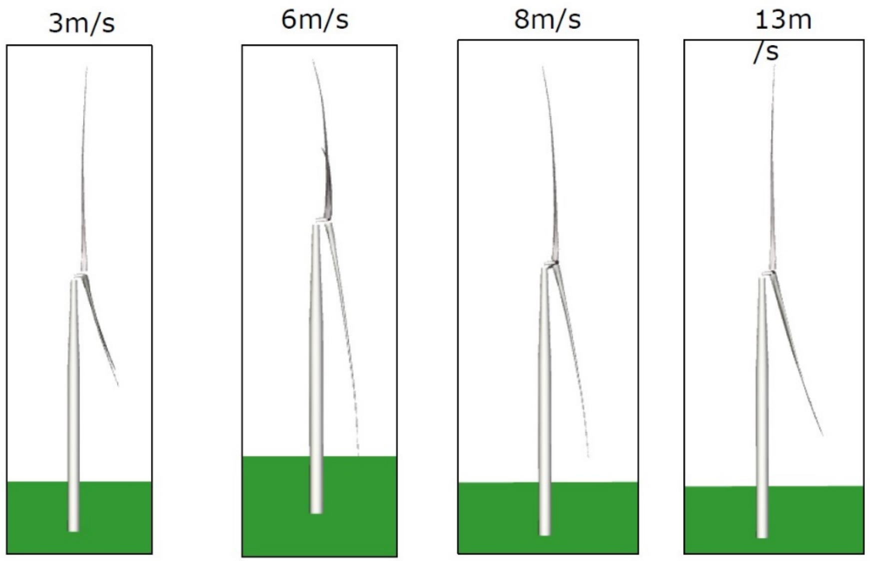
General context

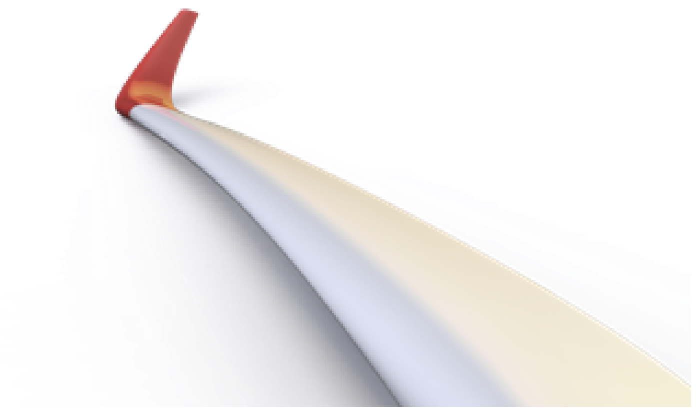
- Cross-sectional activities within **Wind Turbine Design** division of **DTU**
- **Aeroelasticity** modelling for **rotor design**
- Involving several **researchers** and **disciplines**.
  - N. N. Sørensen, F. Zahle, C. Grinderslev (**Computational Fluid Dynamics** and **Fluid Structure Interaction**)
  - T. Barlas (**multi-body analysis** and **experiments**)
  - A. Li, G. Pirrung (**engineering aerodynamic** models)
  - N. Ramos-Garcia (**vortex methods**)
  - …
- Two-folded mission:
  - Progress in the **understanding** of **particular** aeroelastic **phenomena**
  - **Improve** current **tools** (high fidelity -> engineering models)

Drivers

- The **times** we live in
  - **Current** and **next** generation of wind turbines
  - **Rotor-upscaling**: as a shifter of the role played by aeroelasticity
- The pursuit of **innovative** designs and concepts, examples:
  - **Low wind** project
  - **Smart Tip** project
- Working **together** with **industry**, to answer some questions around **numerical methods**:
  - What could we do **better**?
  - What could we do **faster**?
  - What are we **missing**?

https://windenergy.dtu.dk/english/research/research-projects/lowwind





https://windenergy.dtu.dk/english/research/research-projects/completed-projects/smart-tip

DTU coupling: the Trojan Horse

- Combines different **solvers** of the the **department**
- **Unified aeroelasticity framework**

DTU coupling

Aerodynamic models

Engineering models (HAWC2 built-in): ranging from BEM to Near Wake

Vortex solver (MIRAS): ranging from lifting line to viscous/inviscid panel method.

Computational Fluid Dynamics (EllipSys3D): including actuator-line and rotor-resolved.

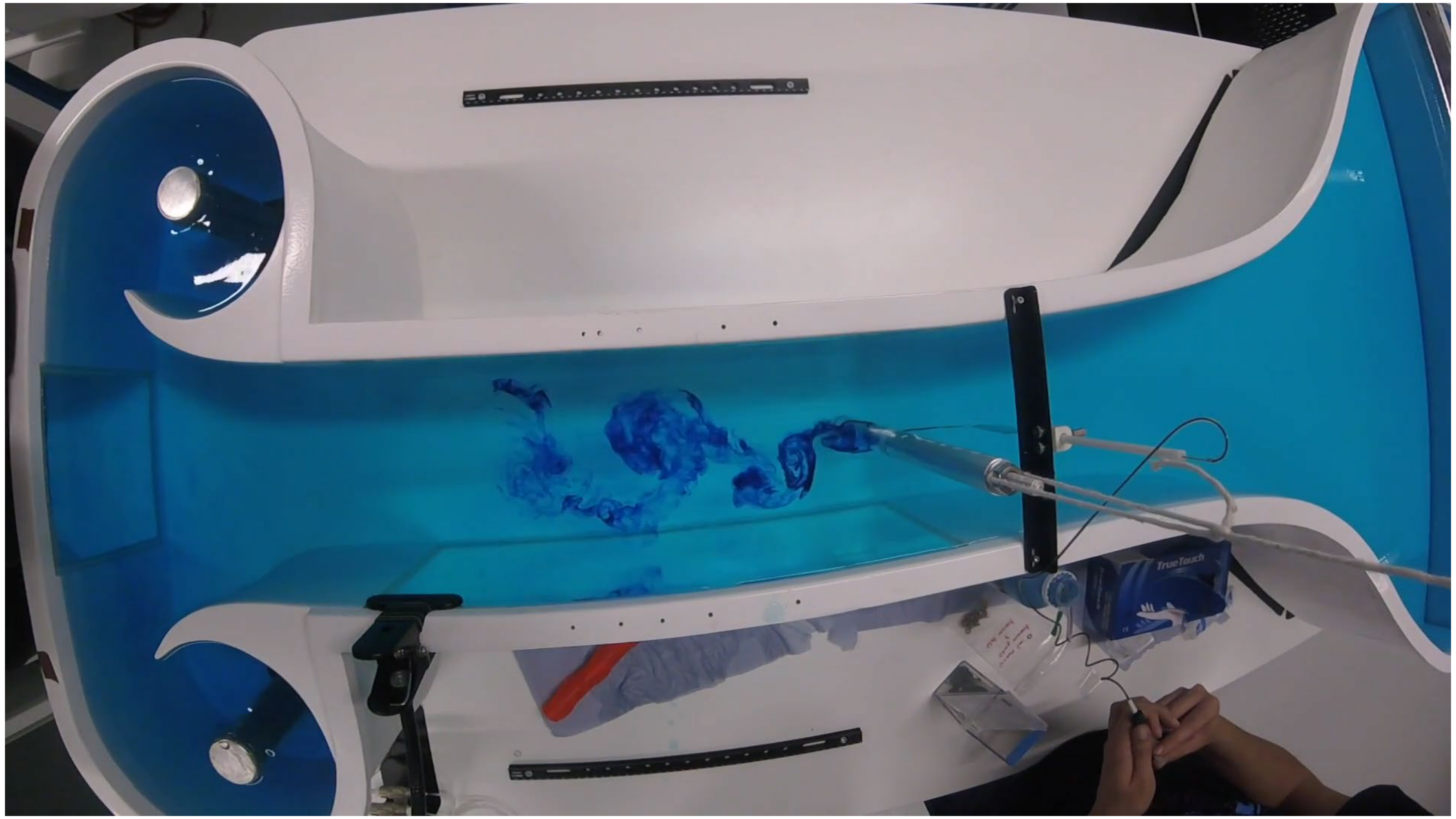
Structural model

Aeroelastic solver of HAWC2:

- Beam elements and multi-body formulation
- Solution through Newmark algorithm, with predictor/corrector

Focus of this presentation

- A **phenomenon** we are probably **missing**
  - **Vortex Induced Vibrations** (VIV)
- Occurring at:
  - **Blades** (standstill)
  - **Towers**
- Could **limit design** and impose **operational constraints**



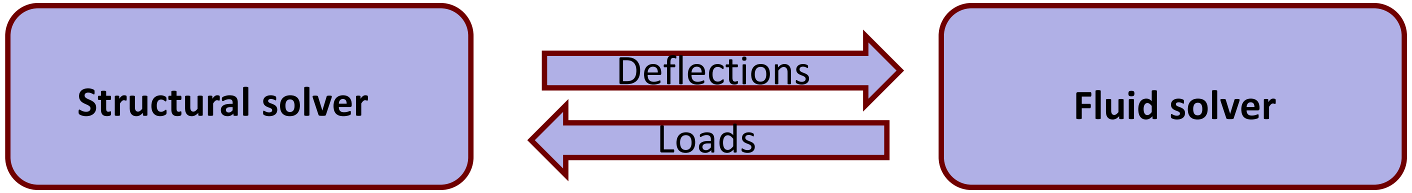
Experiment at University of Southampton [https://www.youtube.com/watch?v=UHFJPmtKqGo]

Vortex-Induced Vibrations

- Introduction
- **Methods**
- Applications
- Conclusions

About the numerical methods

- **Vortex shedding** is **hard to model** with engineering models
  - Usually requires of the so-called **Computational Fluid Dynamics** (CFD) tools
- **VIV** are hard to model in a decoupled way:
  - Usually requires to pass to a **Fluid Structure Interaction** (**FSI**) approach
  - Involving not only a CFD solver, but **also a structural model**
- For the DTU case, we follow a staggered approach:
  - Existing CFD solver (**EllipSys3D**), in-house commercial software
  - Existing FEM-multibody solver (**HAWC2)**, in-house commercial software



Example of numerical model

- Model of the **IEA 10MW blade** [Horcas et al. (2020)]
  - Body-fitted structured mesh of 12.6 millions of cells
  - Hybrid Reynolds-averaged Navier Stokes (**RANS**) and large eddy simulation (**LES**)

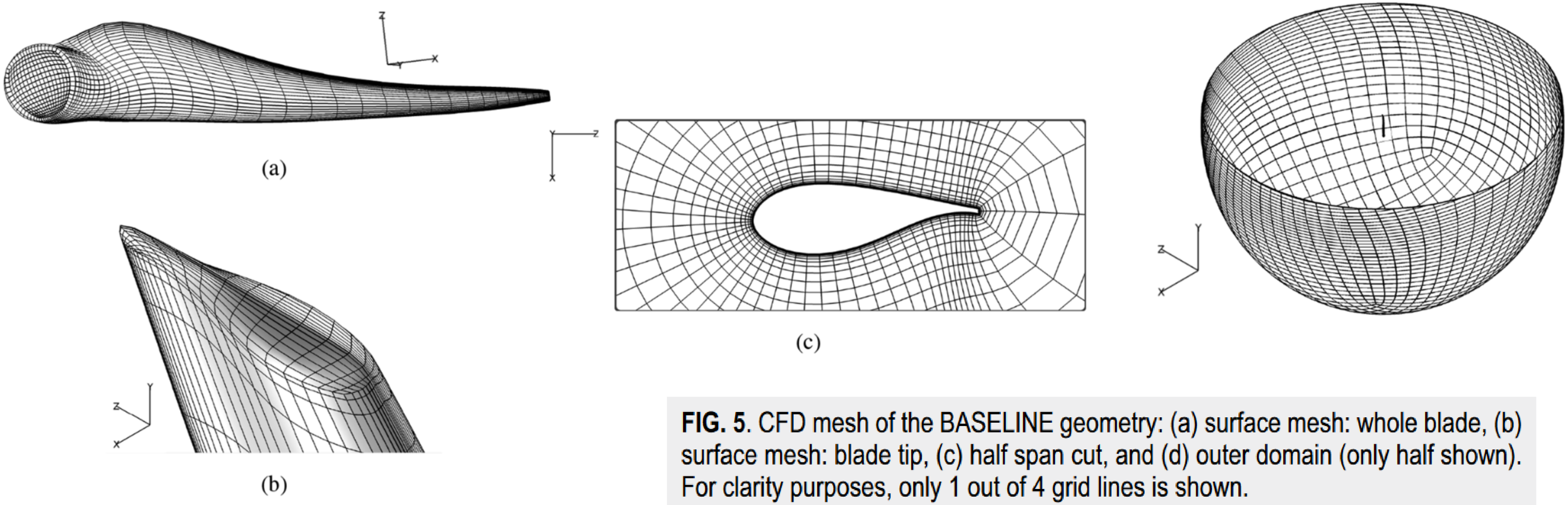


FIG. 5. CFD mesh of the BASELINE geometry: (a) surface mesh: whole blade, (b) surface mesh: blade tip, (c) half span cut, and (d) outer domain (only half shown). For clarity purposes, only 1 out of 4 grid lines is shown.

- Typical CPU cost per simulation, modern cluster: **12-24 hours** when using **300 processors**

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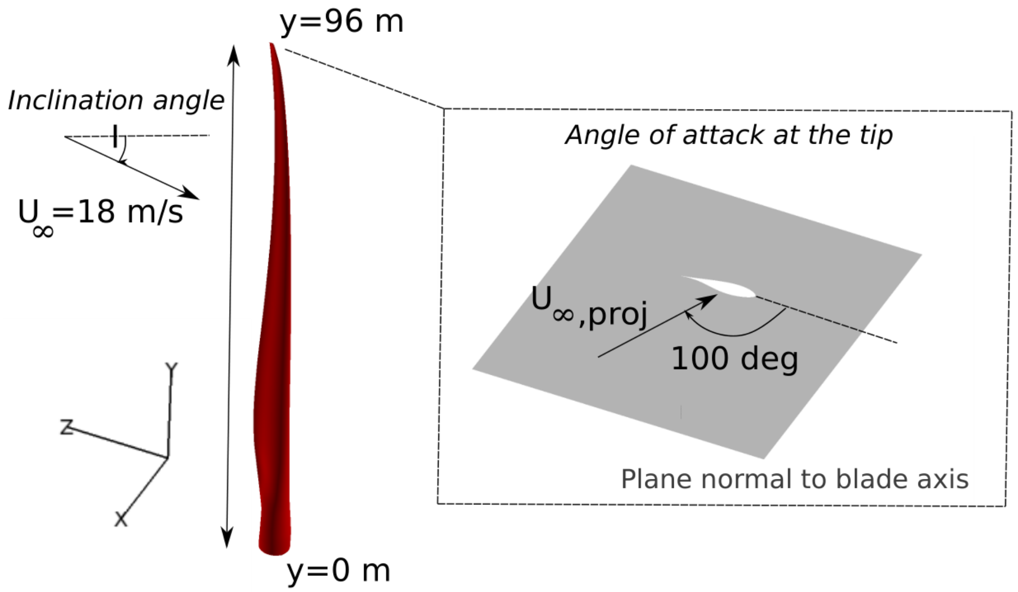
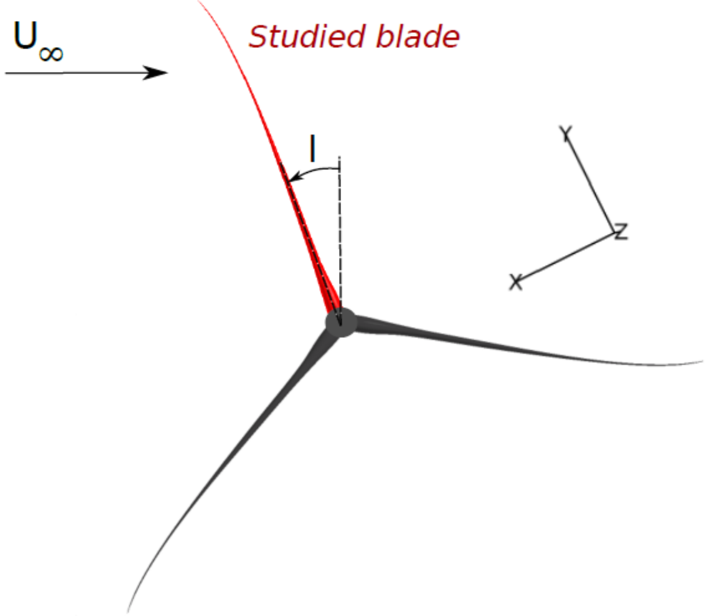
WT edgewise vibration in Standstill

- Can occur at **low-to-moderate** wind **speeds** [10-20] m/s, exciting **first edgewise**
- The phenomenon seems to appear when:
  - **Incoming flow** ≈ **normal** to **blade**
    - AOA of sections around ±90 deg
  - **High inclination angles *I*** (> 20 deg)
    - Velocity component from tip to root.
- In operation, it means:
  - **Installation/Yaw failure**
  - Blade **braked** at a certain angle.



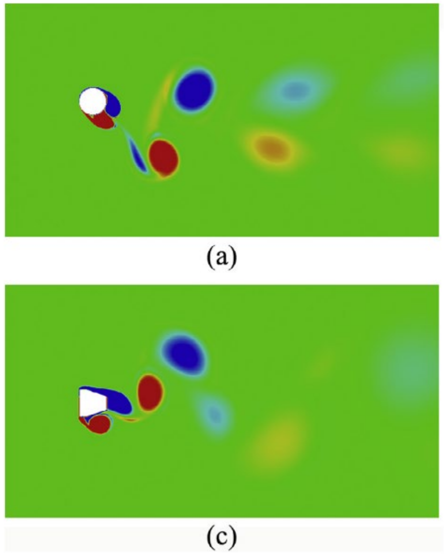


Horcas et. al (2020)

Main challenges for blades VIV

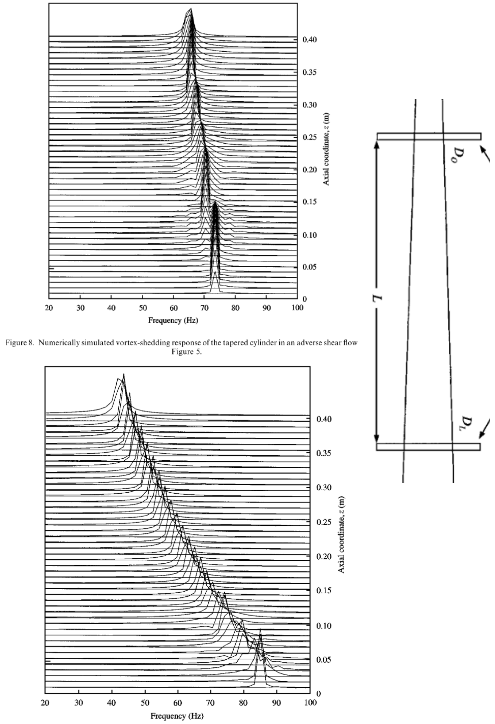
- **Complexity of the flow**: requiring high fidelity (CPU cost)
- Variability of **inflow conditions** (and interference with other wakes).
- Dependence on **blade geometry** and **structural properties**.
- **Hard to relate to traditional** [circular cylinder] VIV **research**. But we anticipate:

Cross-section + Re for VIV



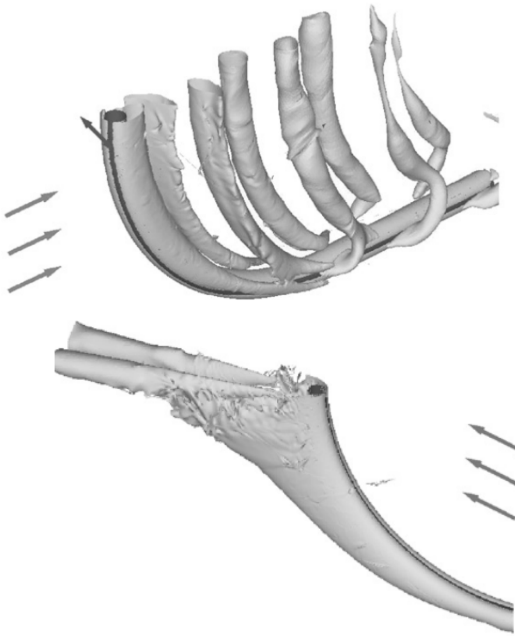
Ding et al. (2015)

Shear + tapering



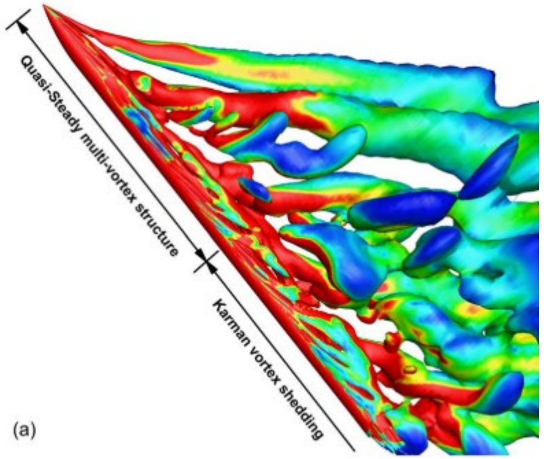
Balasubramanian *et. al (1998)*

Curvature



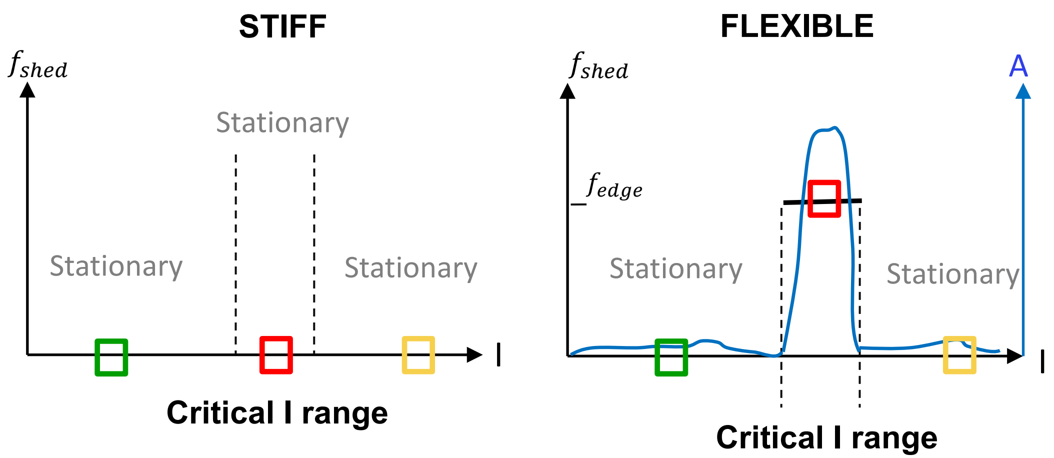
Miliou *et. al (2007)*

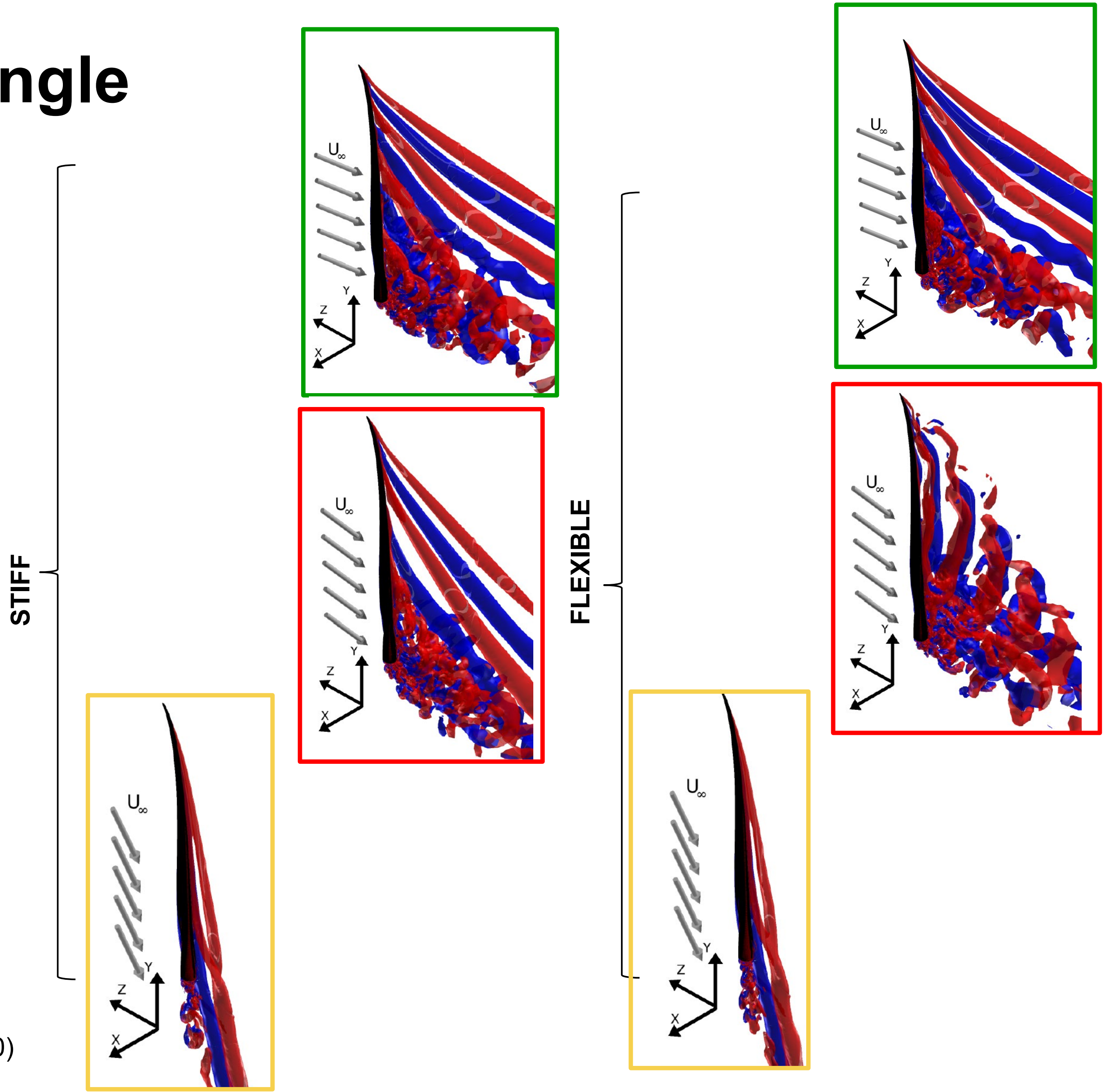
Inclination and tip effects



Ma et. al (2014)

Effect of inclination angle



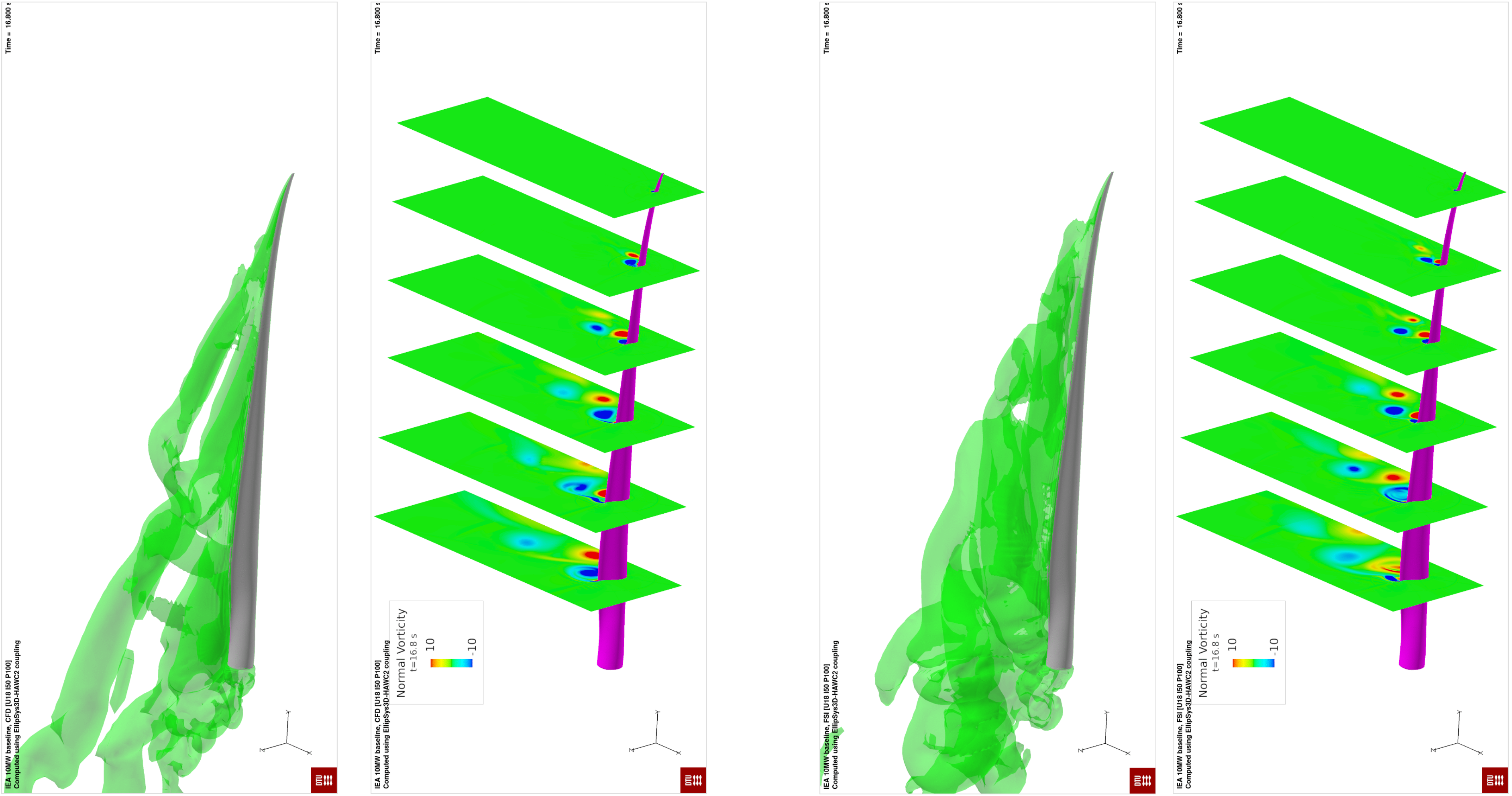


Q-criterion iso-surfaces, colored by sign of vertical vorticity. Horcas et. al (2020)

Example of VIV animation

STIFF

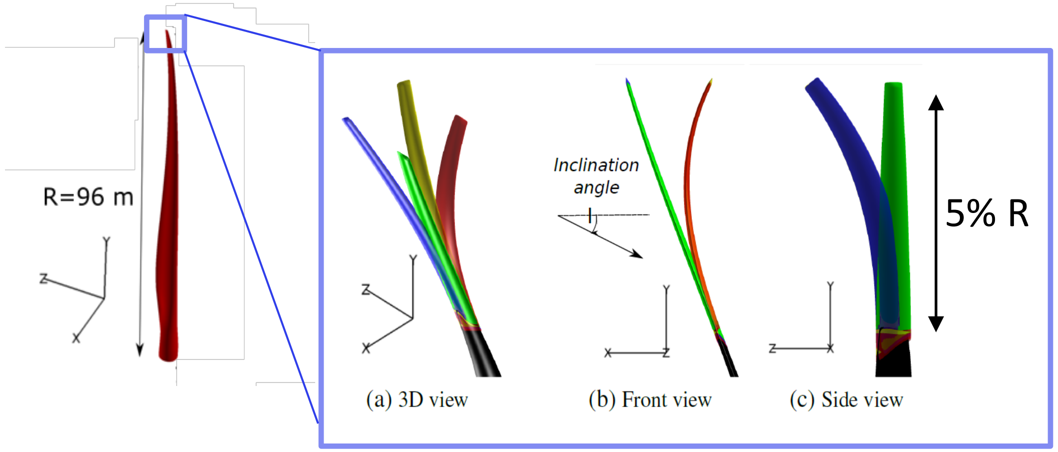
FLEXIBLE

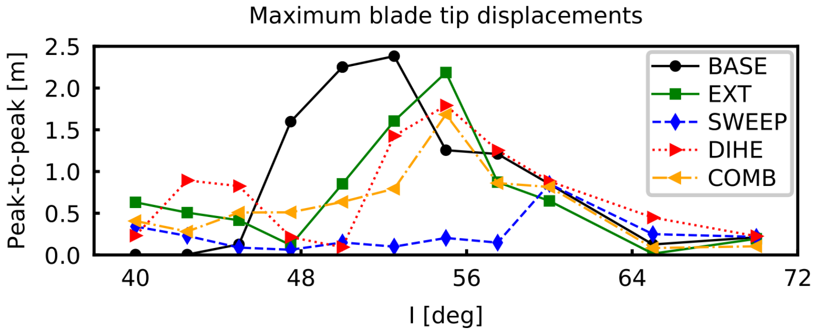


Horcas et. al (2020)

Sensitivities of WT blade VIV

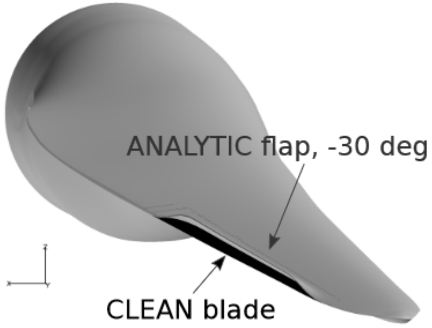
- The region of VIV is very sensitive to the local blade geometry at the tip.





Source: Horcas et. al (2020)

- Installation of trailing edge flaps/spoilers may also help to prevent the phenomenon.



Source: Horcas et. al (2019)

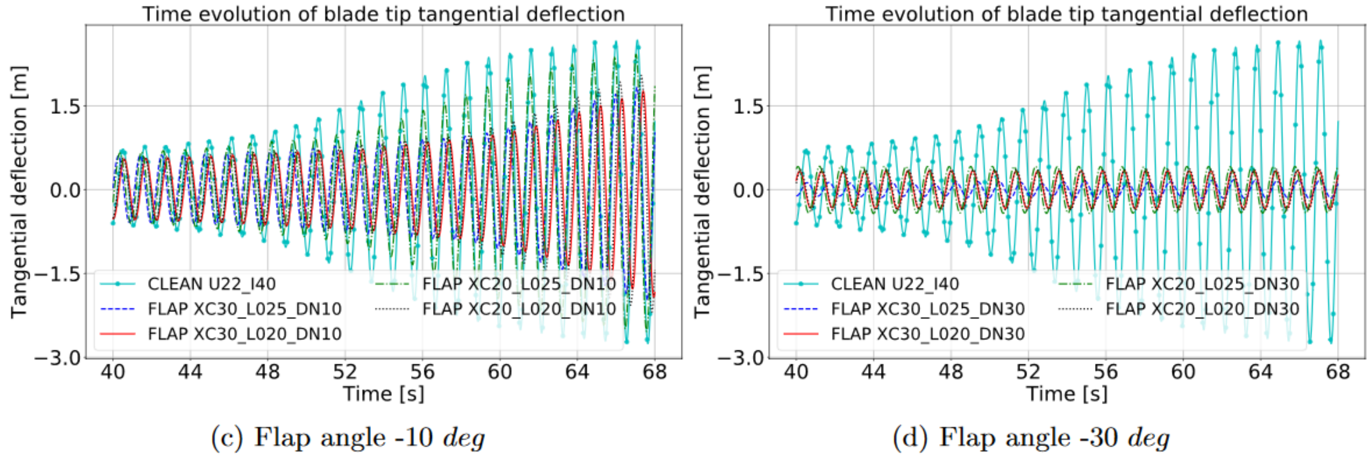


Figure 7: Blade tip tangential deflection transient for different analytic flap configurations and operating angles.

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Tower vibrations

- Some aspects regarding **tower VIV** may **simplify** the problem:
  - **Less complex** geometry (closer to literature)
  - More **normal flow**
  - Experience on **similar structures** (e.g. chimneys)

https://www.youtube.com/watch?v=rlpUhgfEZPU

- However:
  - **High Reynolds** literature is still very scarce
  - Particularities of **geometry** and **structure**
  - WT **assembly topology** and **transportation**

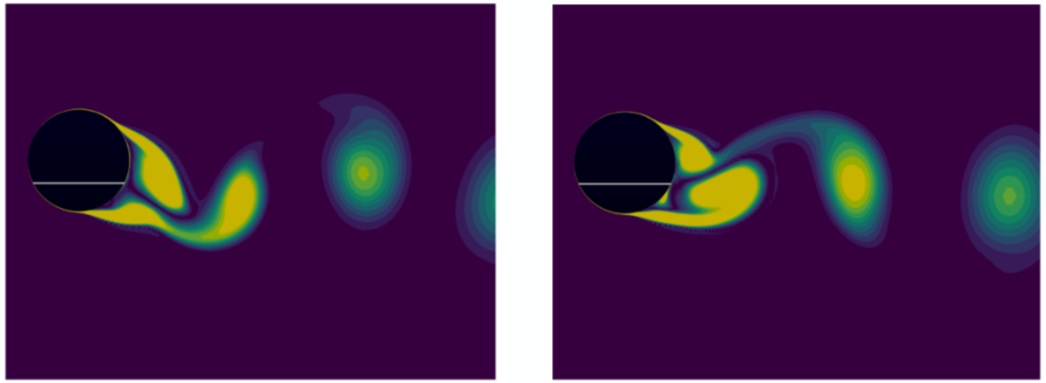

Figure 14. Instantaneous non-dimensional vorticity magnitude for $U^* = 3.1$ at the maximum positive displacement: $t/T_s = 143.5$ (left) and $t/T_s = 146.5$ (right). The vorticity is filtered to the range $0 \leq \xi D/U_\infty \leq 5$. Figures taken from Derksen (2019).

Vire et. al (2020)

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Conclusions

- Current and future WT designs could be subjected to:
  - **Blade VIV** in standstill
  - **Tower VIV**
- High fidelity models are needed
  - Requiring of high **CPU time**
  - Requiring of a **muti-displicinary team** to be successfully run
- So far, **numerical simulations have predicted** the phenomena
  - **Validation efforts** are needed
- **Industry and academia** should **work together** to solve such a **complex** problem
  - Through **commercial agreements**
  - **Research**-oriented projects

End of presentation

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