SIMULATIONS AÉRO-ÉLASTIQUES D’UNE VAWT DE 600KW (NENUPHAR 1HS) – INFLOW EU PROJECT

GDR EMR: SIMULATION ET OPTIMISATION POUR LES ENERGIES MARINES RENOUVELABLES

F. BLONDEL, IFPEN, 10/01/2018

CONTEXT

- EU INFLOW project (https://www.inflow-fp7.eu/)
  - Industrialization Setup of a FOWT*
  - Commercial-sized floating deepwater VAWT*

- What we need: validated fully-coupled analysis
  - Aerodynamics, Hydrodynamics
  - Structural elasticity
  - Mooring lines, anchors, control…

- Why we need it
  - Concept evaluation
  - Thousands of DLCs*
  - Certification

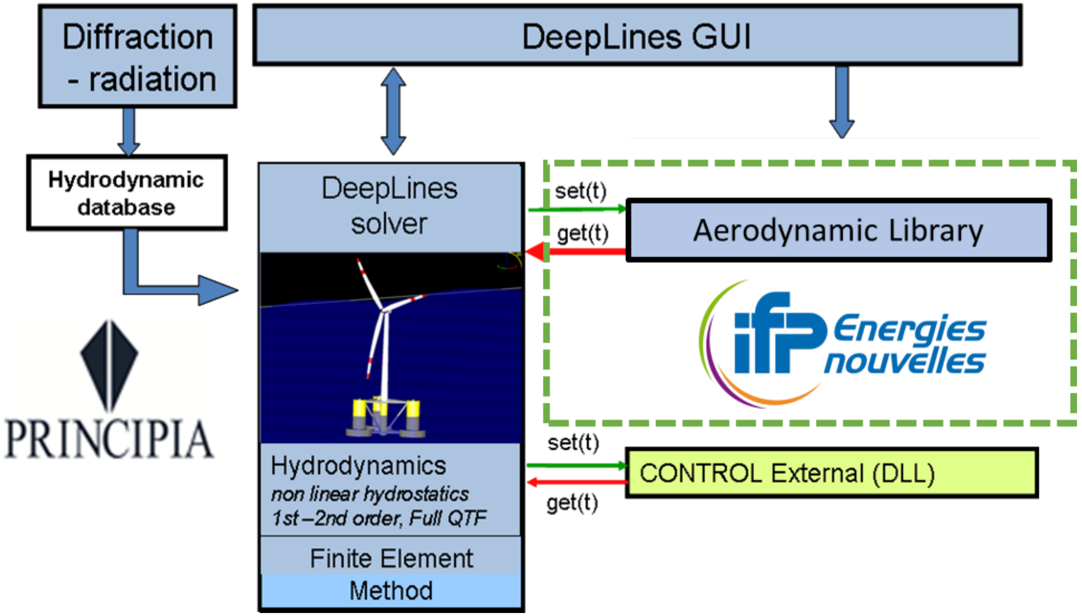
NENUPHAR
OFFSHORE WIND TURBINES

DTU Technical University of Denmark

Nenuphar floating VAWT concepts
(https://www.inflow-fp7.eu/photos/,)

***FOWT: Floating Offshore Wind Turbine**
***VAWT: Vertical Axis Wind Turbine**
***DLCs: Design Load Cases**

- DeepLines Wind^{TM} (Principia, LeCunff et al.)
  - Finite-elements, aerodynamics, hydrodynamics, control, mooring, control
  - Turbulent winds, waves, etc.



- VAWT aerodynamics

Le Cunff et al., FULLY COUPLED FLOATING WIND TURBINE SIMULATOR BASED ON NONLINEAR FINITE ELEMENT METHOD, OMAE 2013.

AERODYNAMIC MODELS FOR VAWTS

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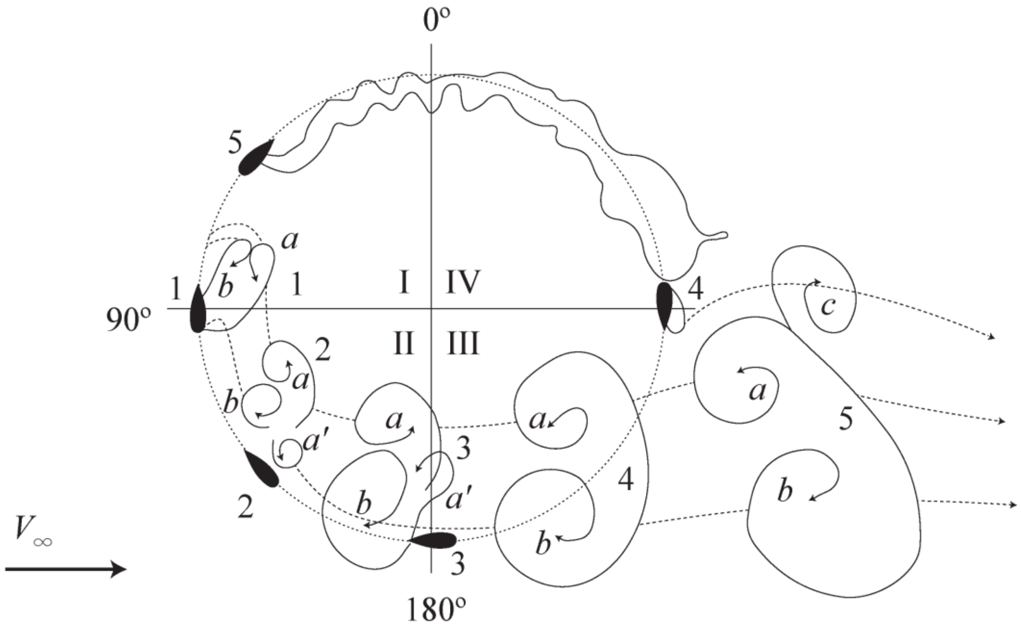
- BEM models are not adapted (Ferreira et al.)
    - Unsteady/complex wake
    - Strong blade/wake interactions

- Alternatives

	AC*	Vortex 2D	Vortex 3D	CFD-AL*	CFD
Accuracy	+	+	++	++	+++
CPU time	+++	++	+	-	--
Aeroelastic	++	++	+	-	-



Wake dynamics of a VAWT (Brochier et al.)

C.S. Ferreira et al., COMPARISON OF AERODYNAMIC MODELS FOR VERTICAL AXIS WIND TURBINES, TORQUE 2016.
Brochier et al., WATER CHANNEL EXPERIMENTS OF DYNAMIC STALL ON DARRIEUS WIND TURBINE BLADES. AIAA J. PROPUL. POWER 1986, 2, 445–449.
H.H. Madsen, THE ACTUATOR CYLINDER, A FLOW MODEL FOR VERTICAL AXIS WIND TURBINES, 1982.

***AC: Actuator Cylinder**
***CFD-AL: Computational Fluid Dynamics with Actuator Line representation of the blades**

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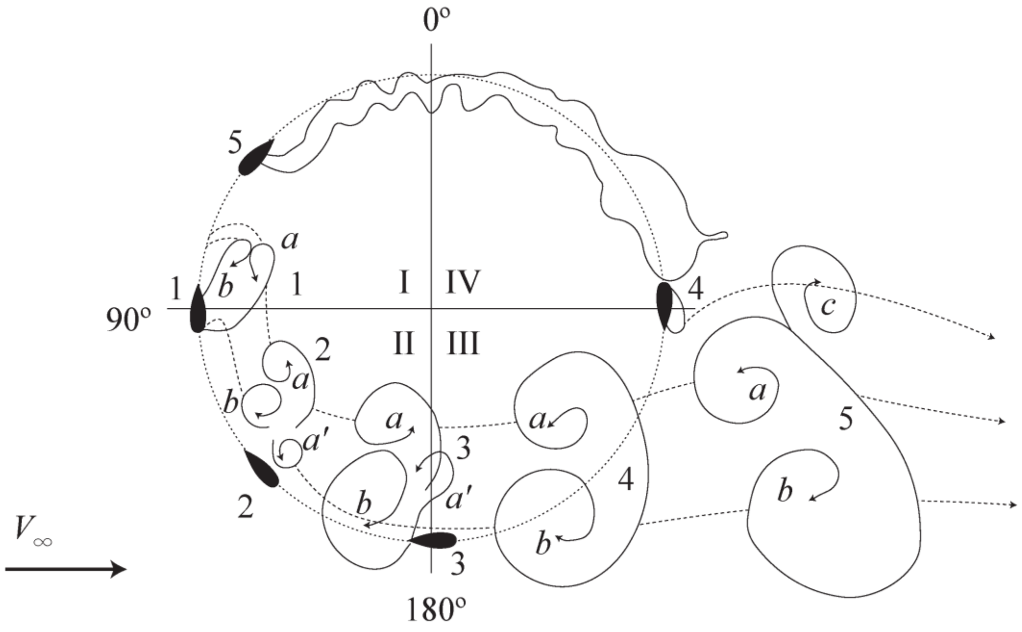

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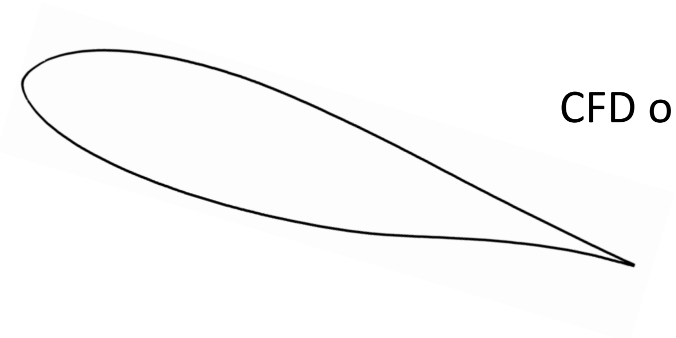
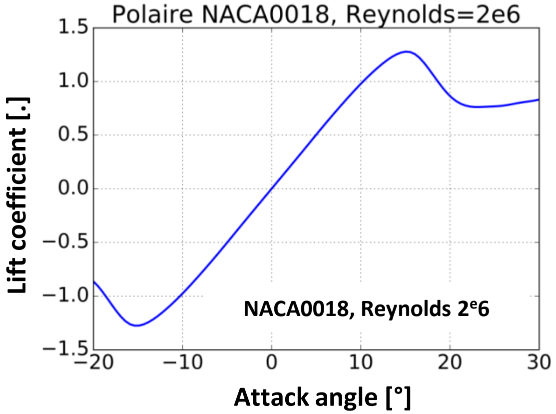
VORTEX METHODS FOR VAWTS

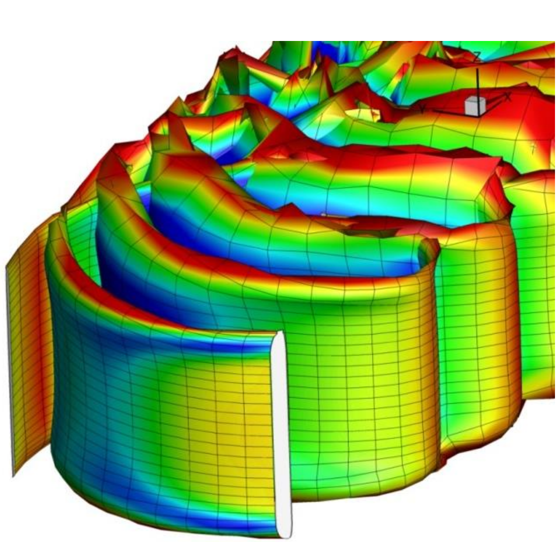
- Lifting-line
  - Blades → airfoil polars
- Inviscid wake
  - Vortex particles (2D)
  - Vortex filaments (3D)
  - Free deformation
- Dynamic stall
  - **Beddoes-Leishman**
  - Snel
  - Others…
- CPU programming (2D)
- GPU programming (3D)
- Load assessment:
  - **2D model recommended**

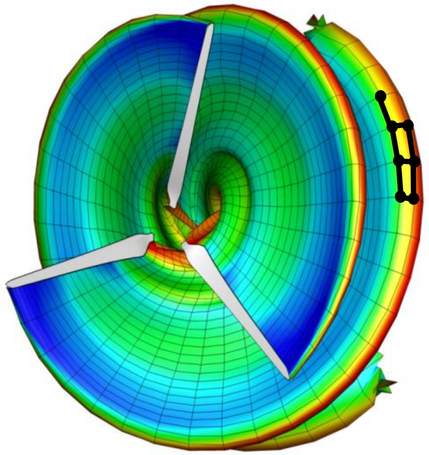


CFD or Measurements ⟷



Lifting-line theory: airfoil polars are considered





Sample VAWT (left) and HAWT (right) vortex simulations

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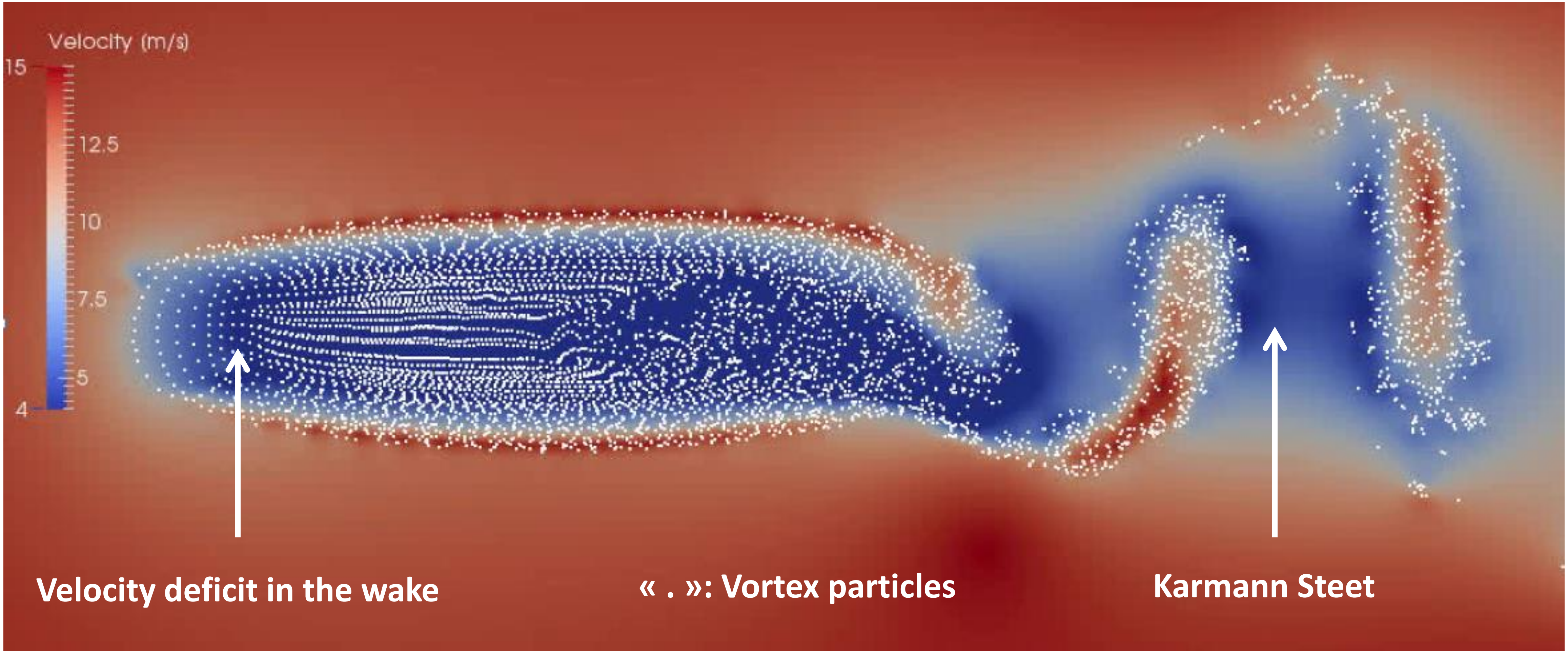
Velocity field reconstruction based on a 2D vortex simulation

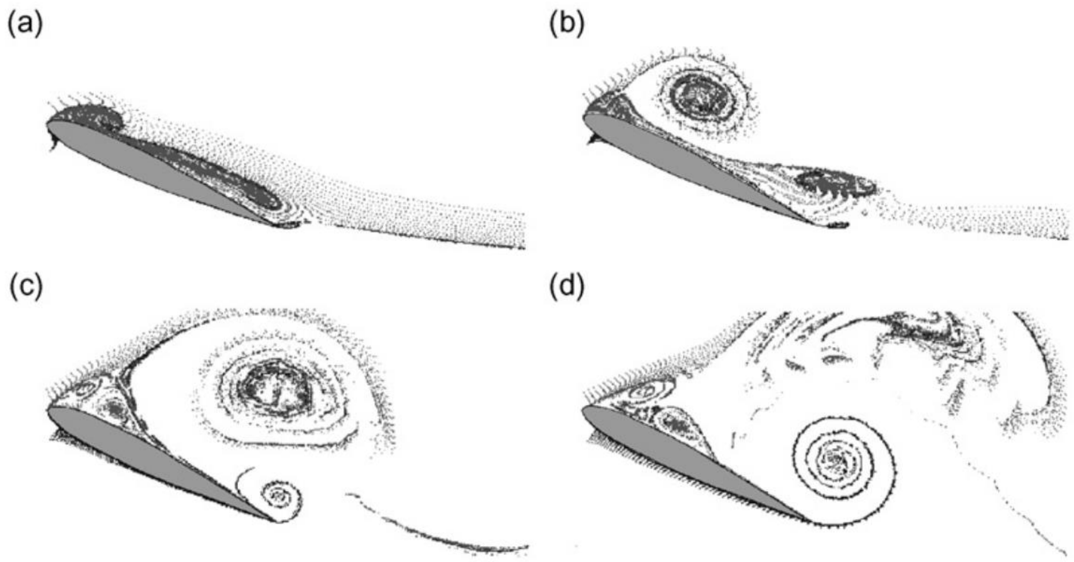


Sample VAWT simulation using the 2D vortex model

DYNAMIC STALL MODELLING

DYNAMIC STALL MODELLING

- VAWTs are prone to **dynamic stall**
  - Many empirical models
  - Models coupling, attached flow
- Lifting-line → dynamic stall model required
- Beddoes-Leishmann model (Hansen et al.)
- Comparison between
  - Geometric AoA + attached flow module (*MSM)
  - **Efficient AoA + attached flow module (*V2D)**
- **Ohio State University** dataset



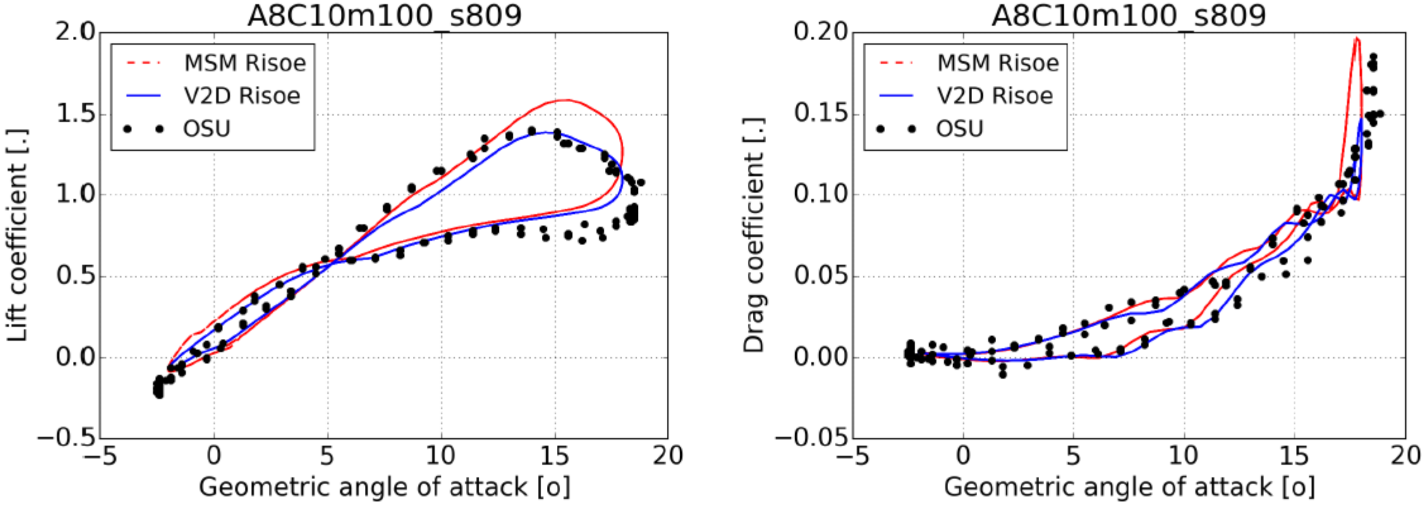
Dynamic stall phenomena on a blade (Larsen et al.)

Hansen et al., A BEDDOES-LEISHMAN TYPE DYNAMIC STALL MODEL IN STATE-SPACE AND INDICIAL FORMULATIONS, RISOE-R-1354(EN), 20014.
Larsen et al., DYNAMIC STALL MODEL FOR WIND TURBINE AIRFOILS, J. OF FLUIDS AND STRUCTURES, 2007.

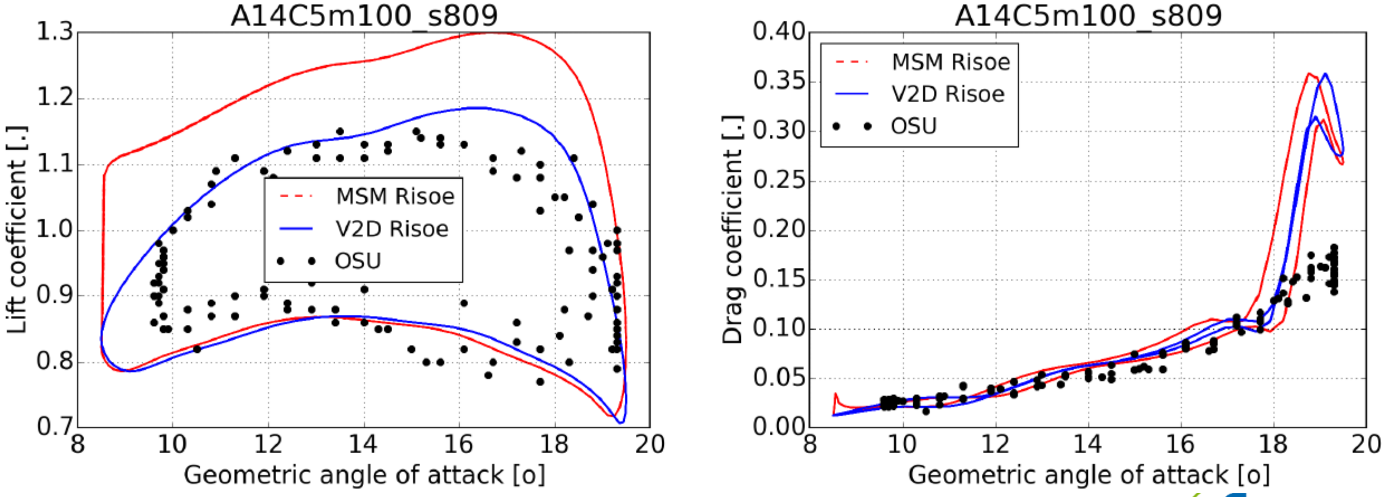
***MSM: Multiple Streamtube Model (BEM-type model for VAWTs)**
***V2D: Vortex 2D model**

DYNAMIC STALL MODELLING

- OSU database
  - S809 airfoil
  - 3 mean AoA (8, 14, 20°)
  - 2 dAoA (5, 10°)
  - 3 frequencies (0.6, 1.22, 1.66Hz)
- Partially representative of VAWTs
- Much better agreement with
  - **Vortex 2D (V2D) + Efficient AoA**
  - Vortex solver handles attached flow part
- Further results in Blondel et al.



AoA=8°, dAoA=10°, f = 1,22Hz, lift (left) and drag (right)



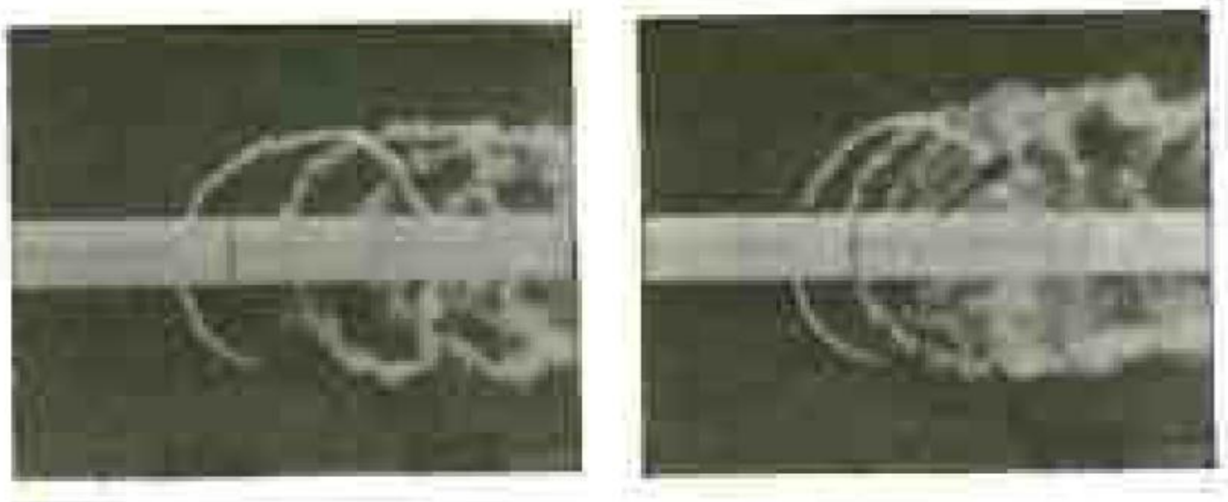
AoA=14°, dAoA=5°, f = 1,22Hz, lift (left) and drag (right)

Blondel et al., BENCHMARKING ACTIVITIES (CODE TO CODE COMPARISON) ON THE RIGID 1HS 3-BLADED VAWT, INFLOW EU PROJECT, IFPEN REPORT, 2017.

VALIDATION ELEMENTS

STRICKLAND VAWT

- **VAWT** tested in a **towing tank**
  - 1, 2 or 3 blades
  - 3 towing velocities
- Small VAWT
  - Radius = 0.6100m
  - Chord = 0.0914m
- NACA 0012 profiles
- Low Reynolds number: **Re=40000**
- **Normal** and tangential **force measurements**

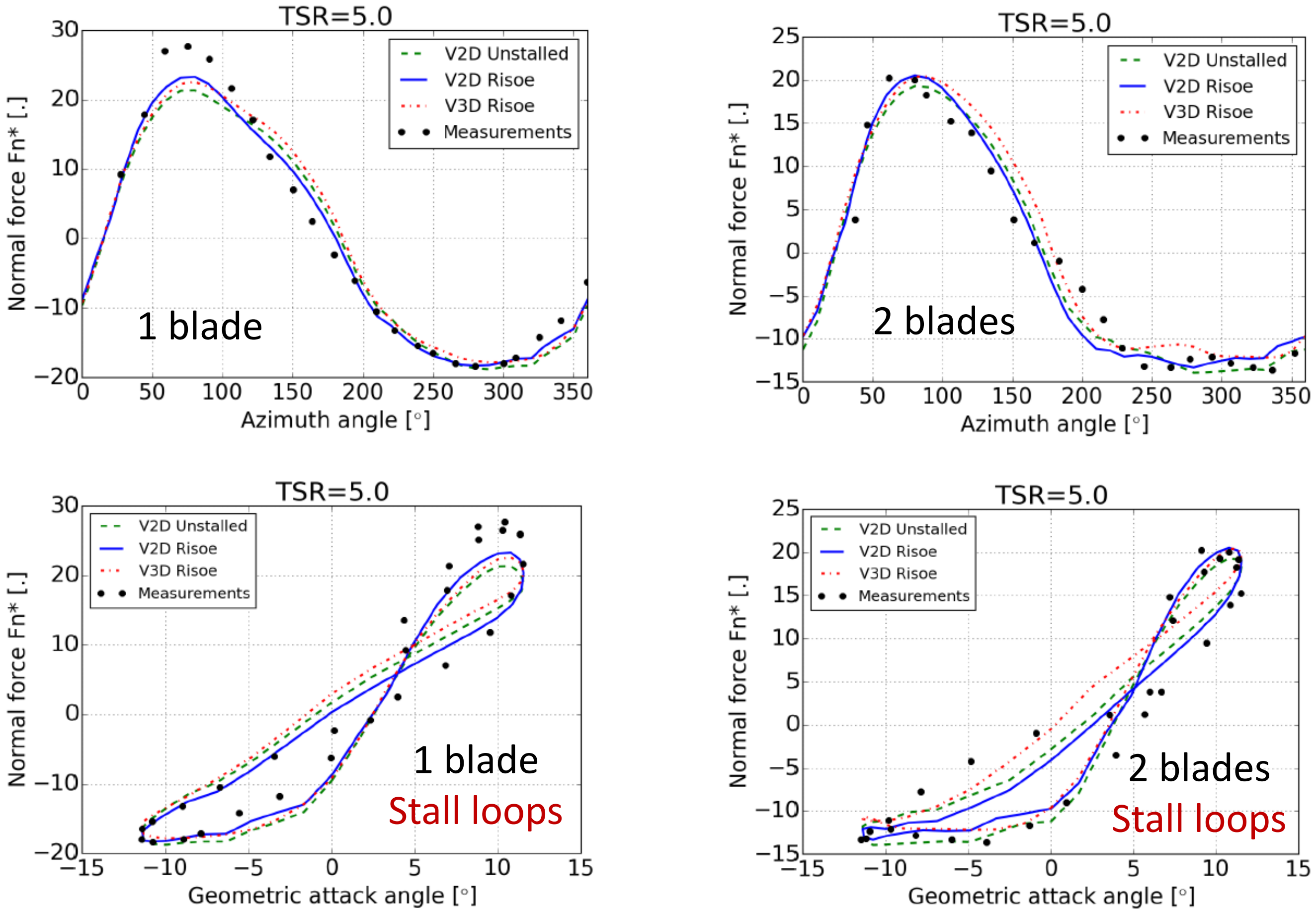


Visualization of VAWT wake in a tow tank (Nguyen)

T.V. Nguyen, A VORTEX MODEL OF THE DARRIEUS TURBINE, PHD THESIS, TEXAS TECH UNIVERSITY, 1987.

STRICKLAND VAWT

- Sample results from Blondel et al., 1 blade (left) and 2 blades (right)



1 blade (left) and 2 blades (right), Normal forces vs. azimuth (top) and geometric AoA (bottom)

- Normal forces comparisons
  - Very good agreement (2D/3D)
  - Stall loops well predicted
- Upwind / Downwind effects
  - Well predicted
    - → abs(Fn*) lower downwind

(More results in Blondel et al.)

Blondel et al., BENCHMARKING ACTIVITIES (CODE TO CODE COMPARISON) ON THE RIGID 1HS 3-BLADED VAWT, INFLOW EU PROJECT, IFPEN REPORT, 2017.

CODE 2 CODE COMPARISONS

Step 1: comparison of aerodynamic methods, rigid turbine

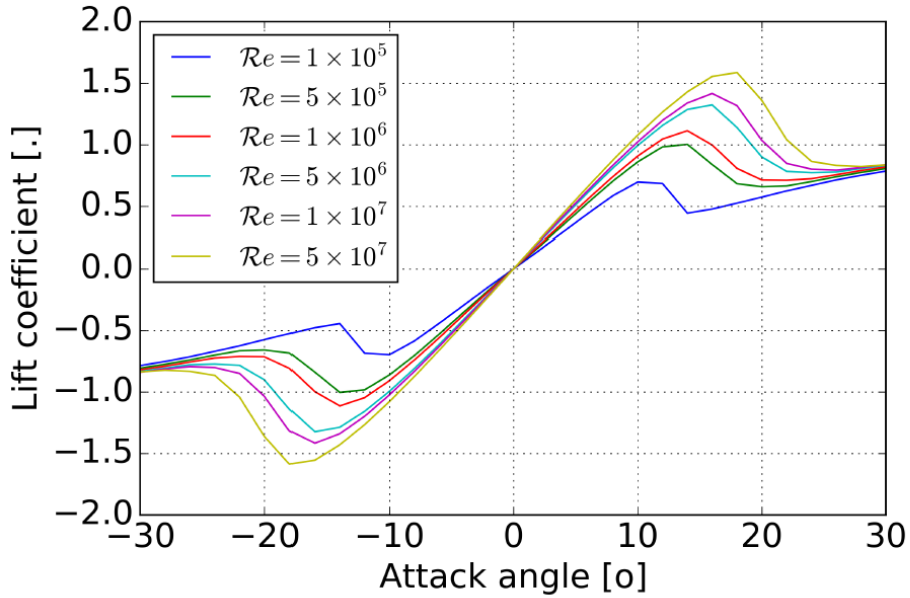
Step 2: comparison of aero-elastic simulations with measurements

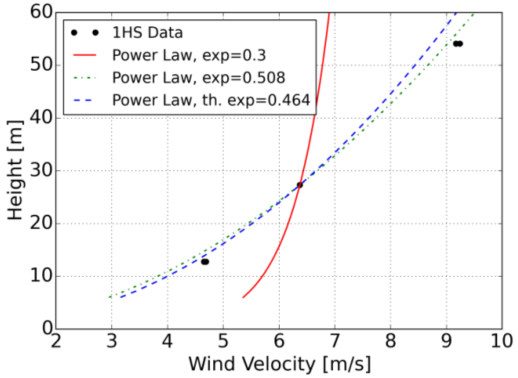
CODE TO CODE AND MEASUREMENTS COMPARISONS

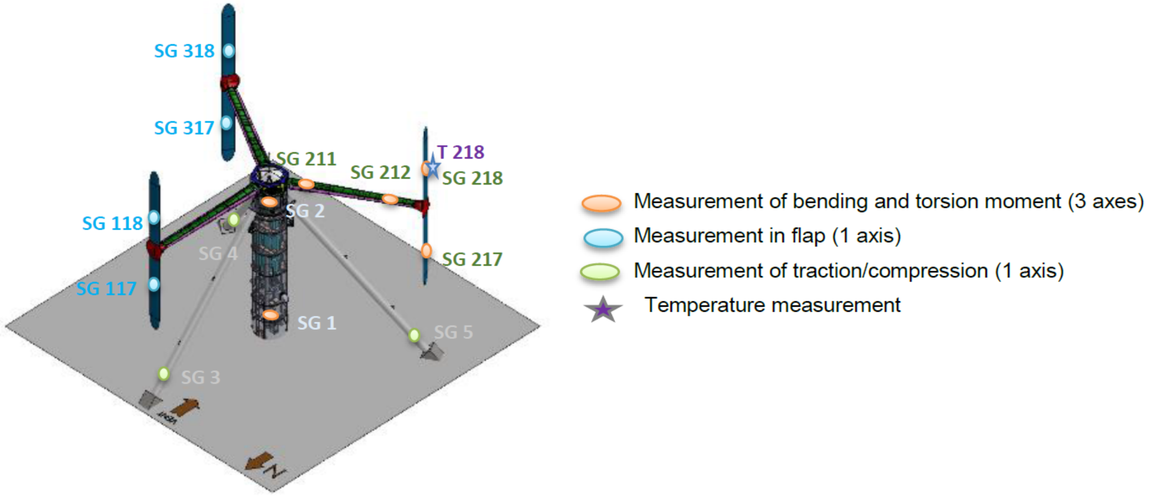
- Collaborative work
  - **DTU** performed simulations
  - **HAWC2** – Actuator Cylinder aerodynamic model

  - **IFPEN** performed simulations
  - **DeepLines Wind™** – MSM/ Vortex 2D and 3D aerodynamic models
  - **SU2** CFD simulations for airfoil polars

  - **NENUPHAR** provided a large database of measurement data
  - **Loads** on blade / struts as well as relevent **operational data** provided
    - Bending moments are used here
    - Comparisons with strut loads will be performed soon



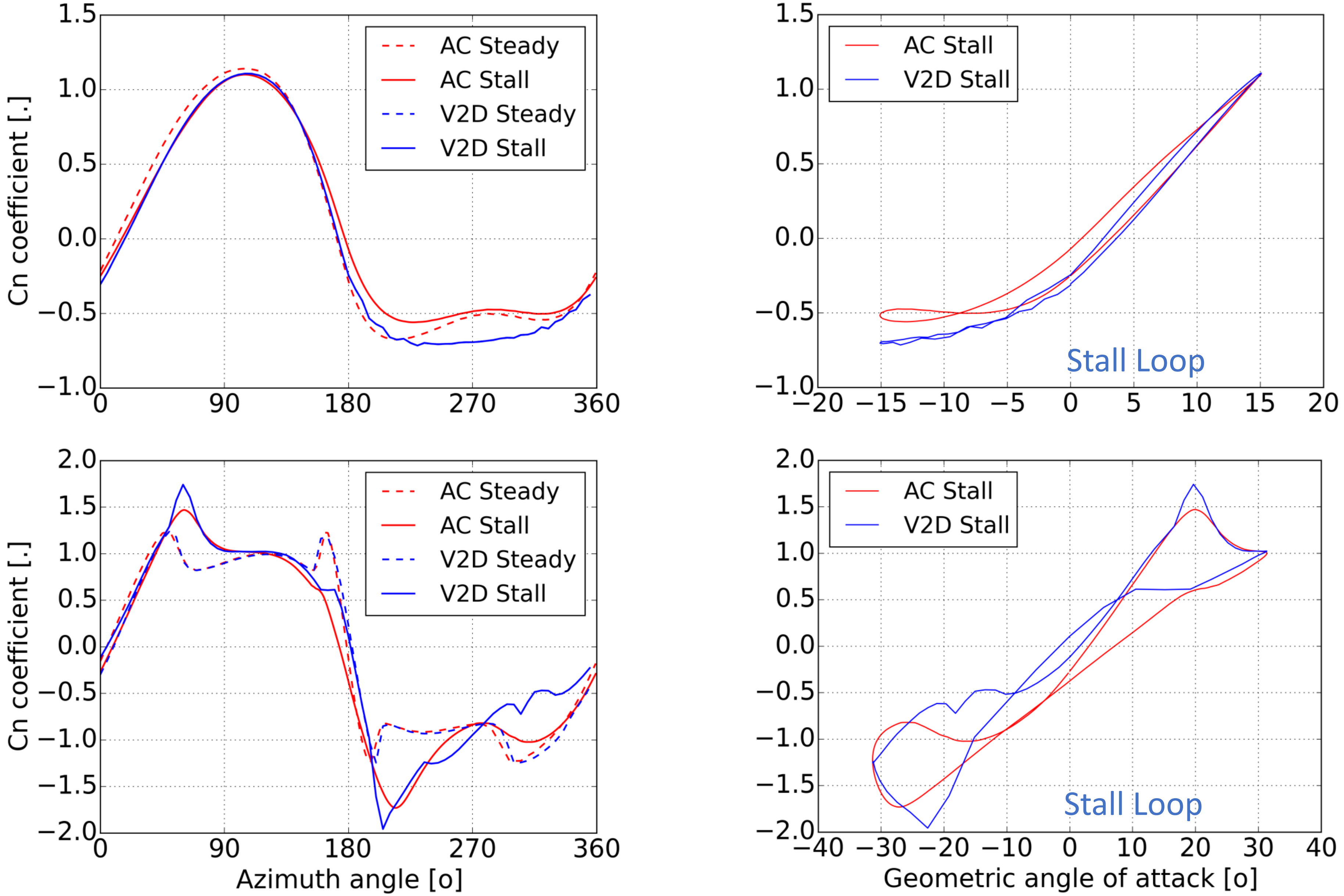




CODE 2 CODE COMPARISONS, RIGID TURBINE

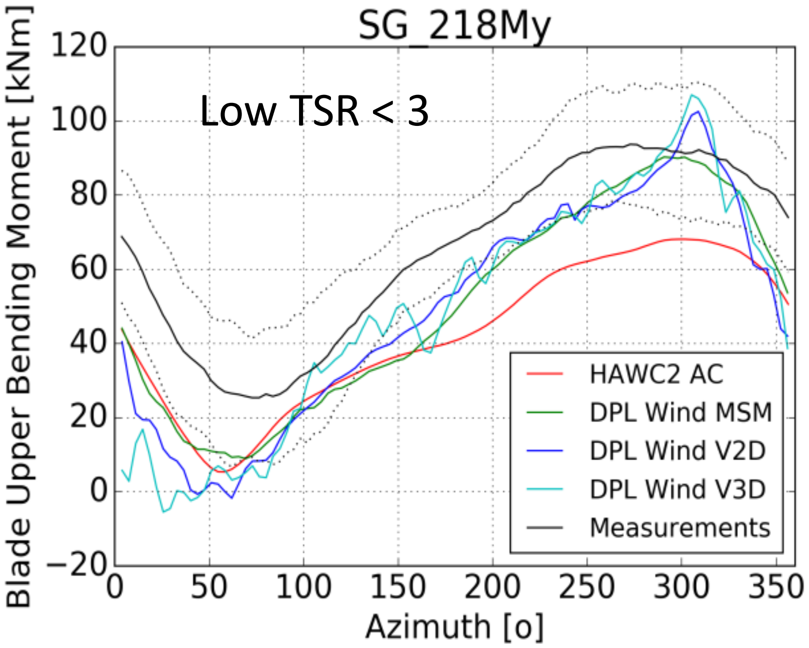
Wind = 8m/s

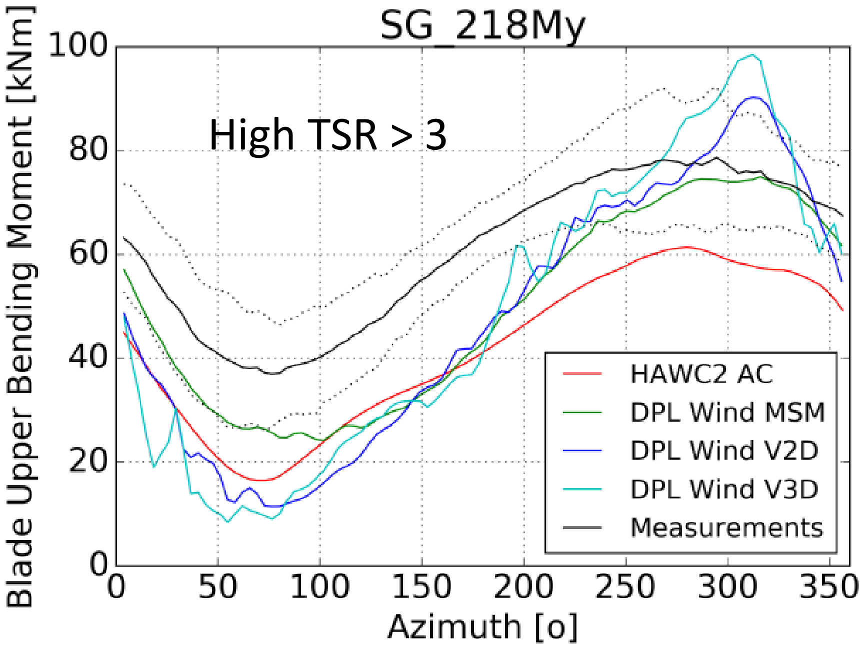
Wind = 16m/s



CODE 2 CODE COMPARISONS, FLEXIBLE BLADES

- Comparison between:
  - **HAWC2** – Actuator Cylinder (AC)
  - **DeepLines Wind™** - (DPL Wind)
  - Measurements
- Exp. data +/- 2stdev





CONCLUSIONS

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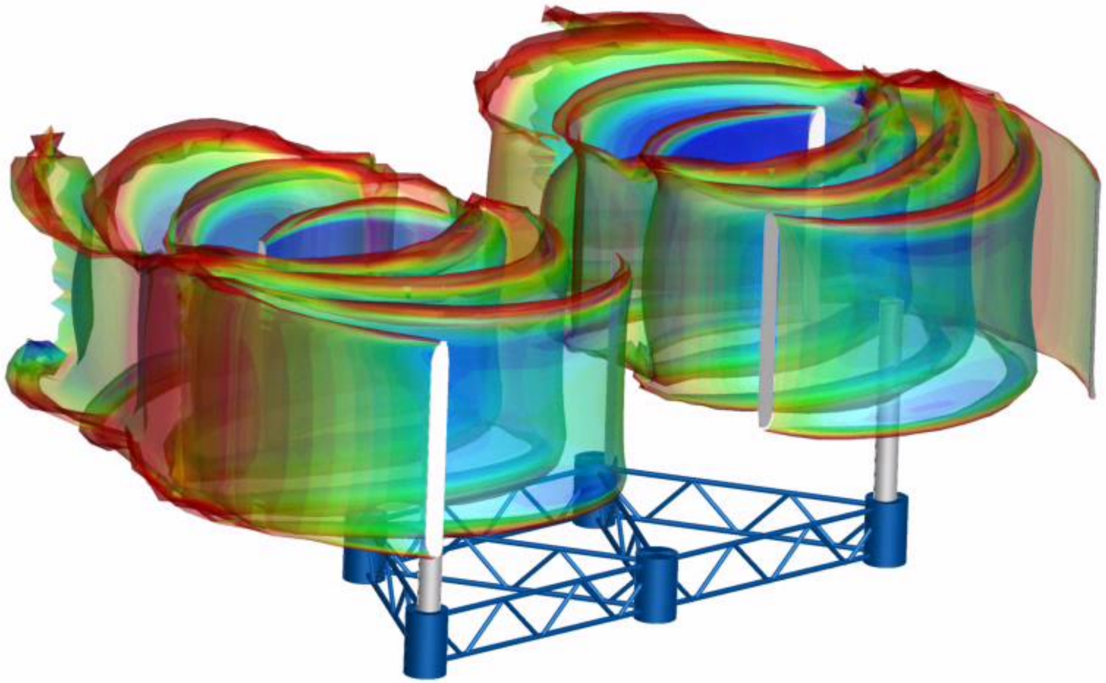
- In the framework of the **INFLOW** EU project:
  - **Vortex models** have been developed and validated on **VAWTs**
  - **Dynamic stall** models have been coupled
  - Comparison have been made with Normal/Tangential forces (public experimental data)
  - Vortex methods
    - **Full modelling** of the wake
    - Accurately reproduce **wake/wake and blade/wake interactions**
  - **Dynamic stall**
    - Attached flow module should be deactivated in BL-type models when **coupled with vortex solvers**

CONCLUSIONS

- Vortex model have been coupled with **DeepLines Wind™**
- Cross comparisons have been performed with **DTU** on a rigid blade turbine
- **Aero-elastic** simulations validated against NENUPHAR's flexible-blade prototype
  - Comparison with the **DTU HAWC2** solver have also been performed
- *Results (rigid and elastic) will be published at the **TORQUE 2018** conference (http://www.torque2018.org)*
- *Promising coupling of the AC flow model with a Beddoes near wake model (AC3D) will be published at the **TORQUE 2018** conference (http://www.torque2018.org)*

LATEST RESULTS: COUNTER-ROTATING SETUP



SEVENTH FRAMEWORK PROGRAMME

InFLOW

<u>Special thanks to the team…</u>

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M. Cathelain, G. Ferrer	(IFPEN)

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