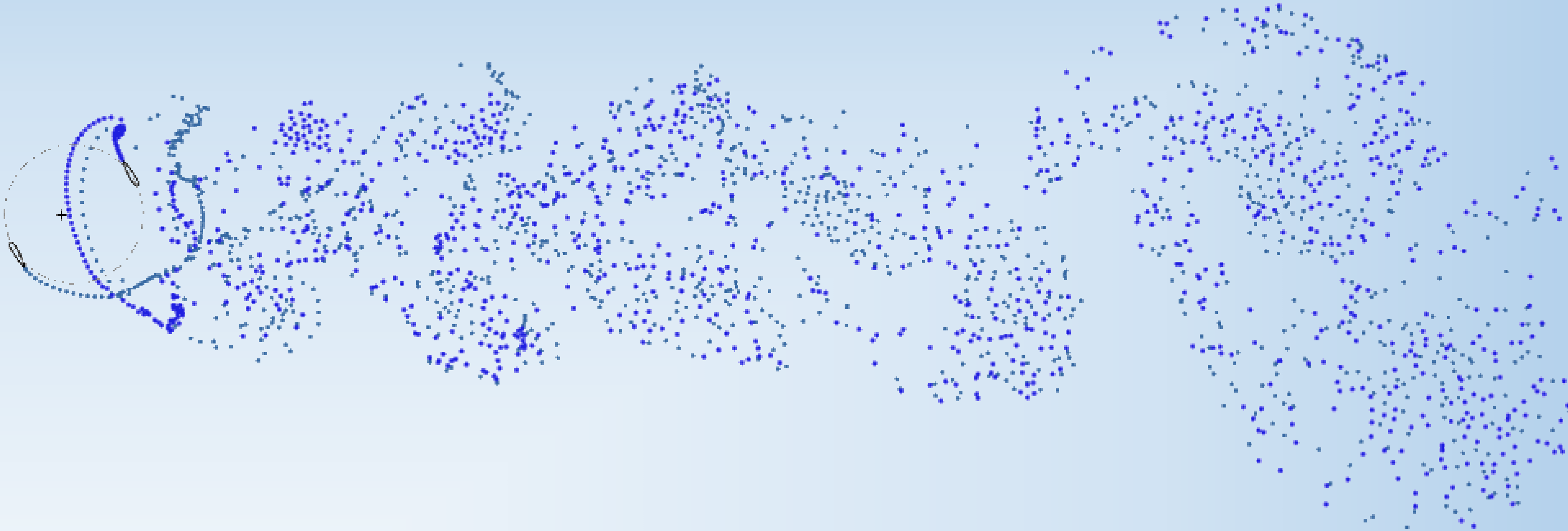

Presenter: Federica Perassi
(MSc SET – TU Delft)

"Fluid-structure interaction between vertical-axis tidal turbine and floating structure"

Outline

- Tidal energy & the floating vertical-axis turbine concept
- Problem statement
- Methodology
- Case study: intense surging motion on the Haineng 1 VATT
- Conclusions

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Tidal energy

&

the floating vertical-axis turbine concept

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Harvesting tidal current energy

Ocean energy is a large untapped resource and its capacity is expected to grow over the next decades (European commission, 2020).

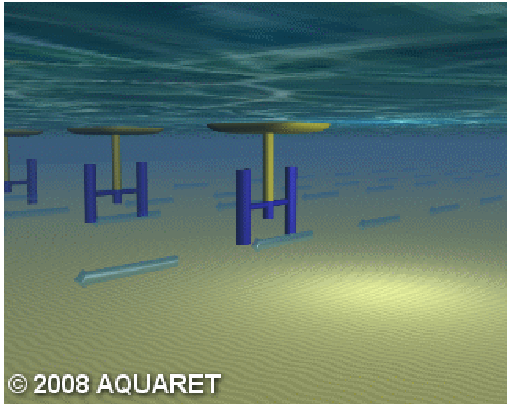
Current status (2020)	→	**EU objectives**
34MW installed ocean energy capacity globally		1GW by 2030 40GW by 2050

Tidal stream/current energy is a promising ocean energy technology due to its:

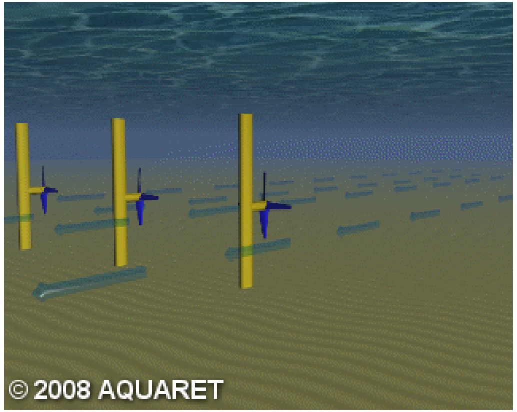
- Predictability and dependability → grid stability
- Large energy density
- Potential of decarbonizing coastal nations

The floating vertical-axis concept

Vertical-Axis Turbines (VATTs)



Horizontal-Axis Turbines (HATTs)



- Omni-directional (no yaw control)
- Reduced installation and O&M costs (electrical components above sea surface)
- Advantageous for less energetic sites (higher torque at lower current speed)

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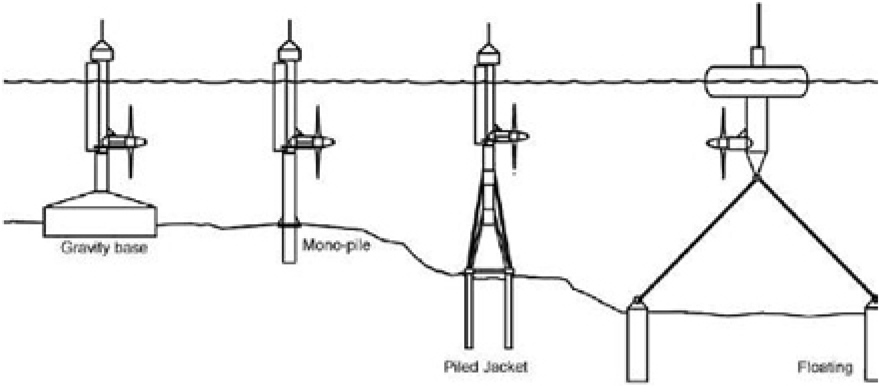
Harvesting tidal current energy

Floating concepts are gaining interest in the offshore energy industry:

- Exploitation of resources in deeper water
- Minimization of visual impact
- Reduction of costs compared to subsea concepts (installation and O&M)



Support structure concepts

Source: http://www.aquaret.com/index4961.html?option=com_content&view=article&id=119&Itemid=262&lang=en

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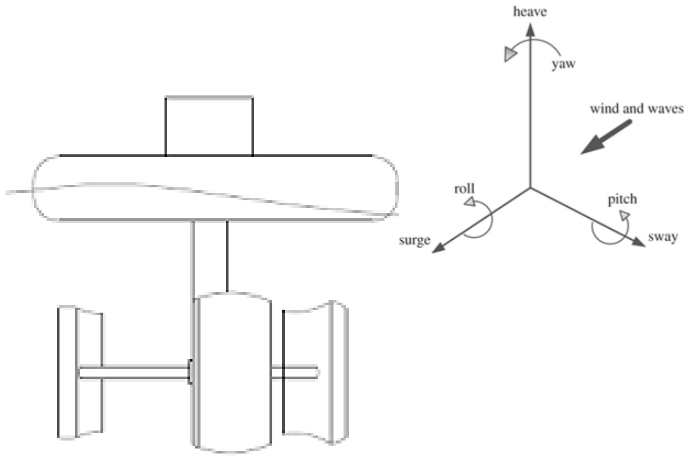
Problem statement

Problem statement

Floating platforms under real sea conditions introduce motions in 6DOF which affect the hydrodynamic performance of VATTs, by changing the relative inflow conditions perceived at the turbine blades.



Floating vertical-axis tidal turbine and degrees of freedom (source: www.esru.strath.ac.uk)

Problem statement

The floater's motions and VATT rotation are strongly coupled:

Floating platform wave response motion

COUPLING ⟷

∝ environmental and operational conditions

VATT forces due to relative current speed

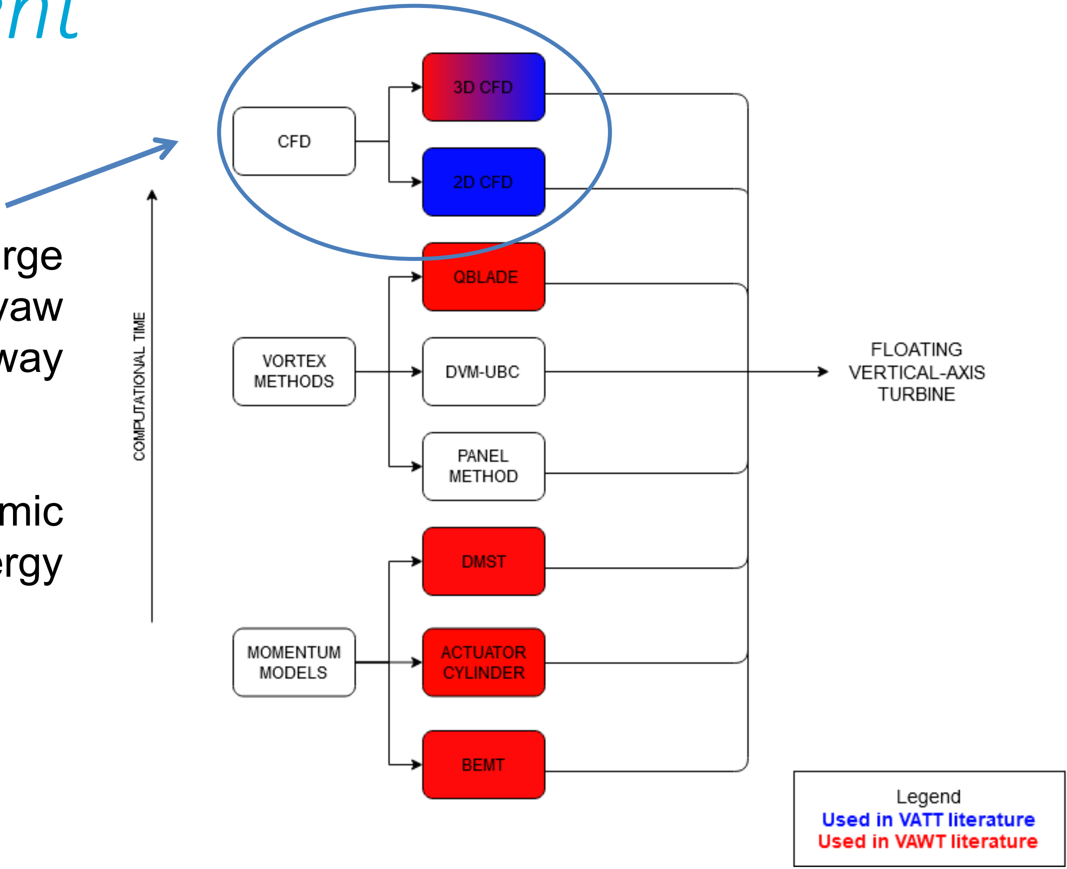
Relevant for:

- Performance (power output) variation in time
- Hydrodynamic loads from rotor to floating platform

Problem statement

Limited scientific literature:

- Yaw (Wang et al., 2016), surge (Sheng et al., 2016), surge & yaw (Wang et al., 2018), surge & sway (Xu et al.,2019)
- General reviews of the dynamic behaviour of floating marine energy devices (Weller et al., 2013)
- Assessing the uncoupled system



Overview of the methods used in the literature of floating vertical-axis turbines.

Approach

1. Definition and validation of an alternative approach to CFD simulations: 2D vortex panel method.

2. Study of the hydrodynamic response of commercial VATT under surge motion, investigating the details of the flow at the blades.

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Methodology

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2D Panel code

2D vortex panel code by C.J. Simão Ferreira:

- Unsteady method
- Simple integration of platform's motions in the code (MATLAB)
- Trade-off between accuracy and computational cost
- Follows the formulation described by Katz and Plotkin (2001)
- Free wake model (computational time of few hours)

Verified with the work of Xu et al. (2019) and Wang et al. (2018).

Verification of 2D panel code

- The 2D vortex panel method provides results of accuracy similar to 2D CFD simulation results, at a reduced computational cost.

- The 2D panel code predicts slightly larger loads due to the assumption of inviscid flow.
  - Possible corrections to account for viscous effects
  - Fast & conservative design tool

- The physic description of vortex panel methods is easier to understand and interpret compared to CFD (reduced complexity). Meaningful aspects of the flow phenomena can be understood by knowing the process the solution is computed with.

Case study: intense surging motion on the Haineng 1 VATT

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Haineng 1 under intense surge

Geometry

diameter [m]	Aspect ratio	Solidity σ	# blades	chord [m]	airfoil	fixed blade position [m]	design power [kW]
4	1.4	0.45	2	0.9	NACA0018	0.25c	150

Simulation inputs and set-up

190 panels, closed TE

3° displacement per time step for 80 rotations

Uniform current velocity $U_{current} = 2m/s$

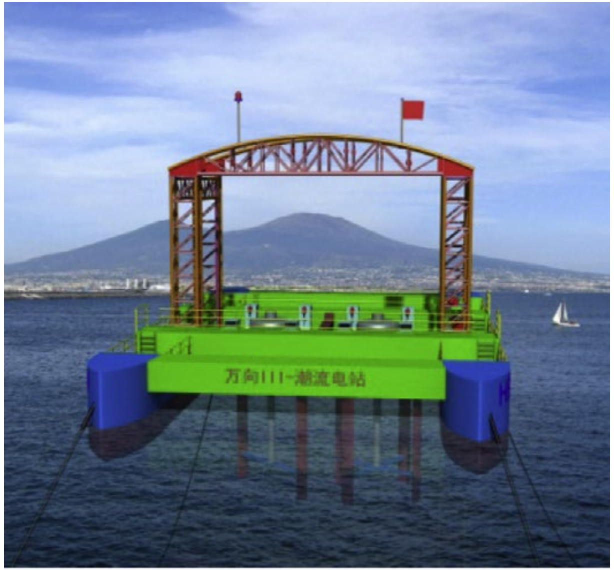
Constant turbine rotational speed $\lambda = 1.5$

Intense surge motion

$A_{SURGE} = 1m/s$

$T_{SURGE} = 5s$

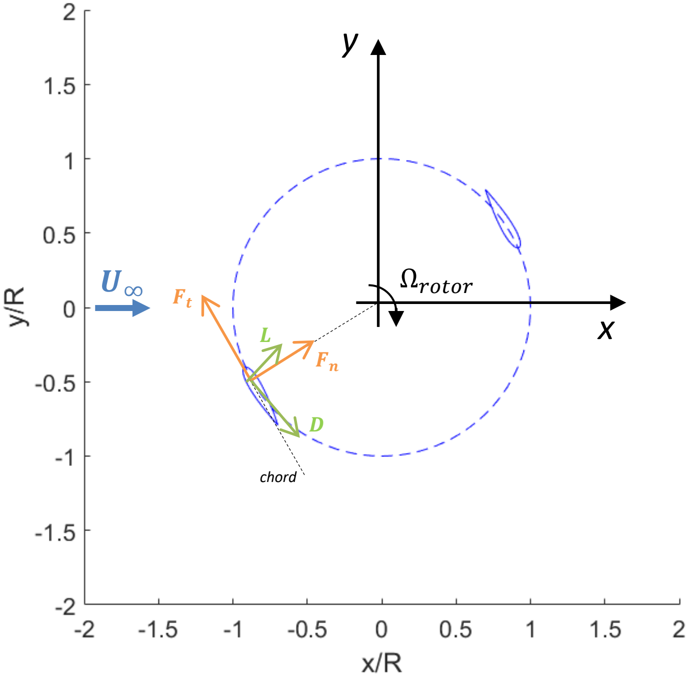
$$X_{SURGE} = Re\left(i\,\frac{A_{SURGE}}{\omega_{SURGE}}\,e^{-i(\omega_{SURGE}\,t\,-\phi_{SURGE})}\right)$$



Source: Sheng et al., 2016

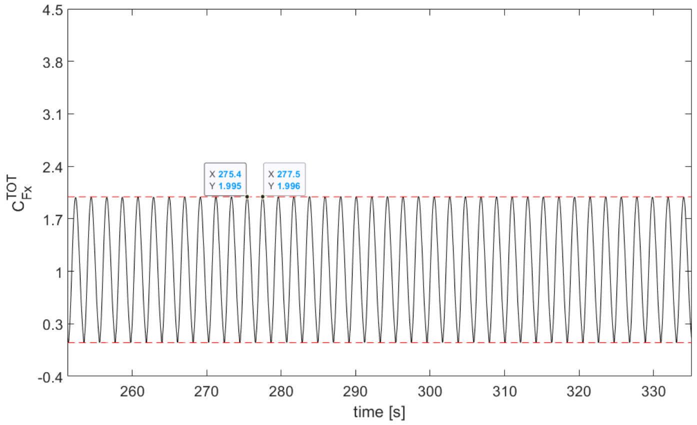
Haineng 1 under intense surge

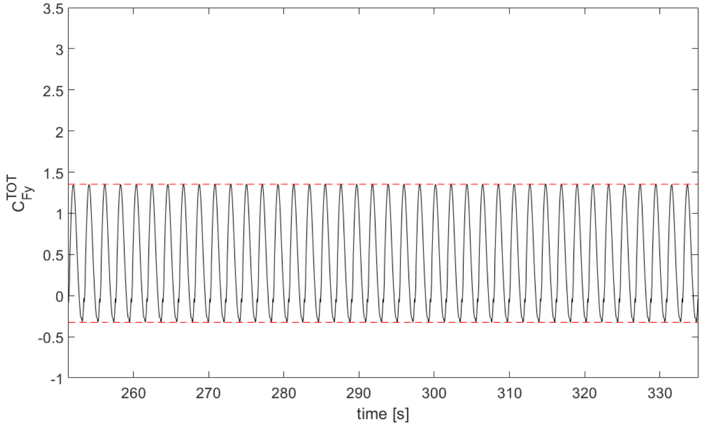
Convention followed by the code



Force coefficients

Only rotation motion: the total force coefficients oscillate periodically with frequency $B \cdot \Omega$ (here T/2=2.1s) between two straight envelopes, due to the steady inflow conditions and constant operational parameters.

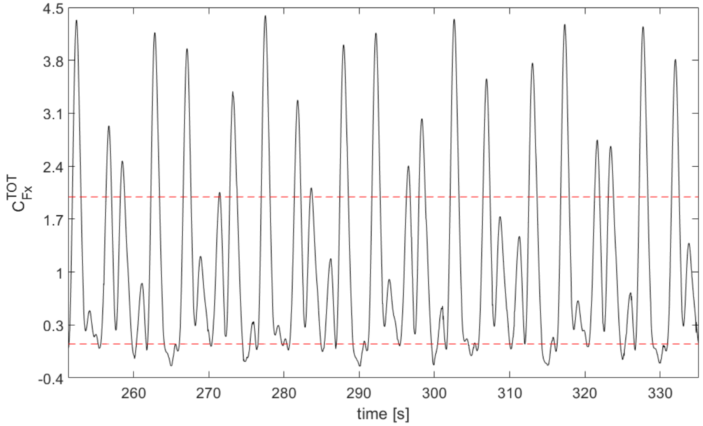


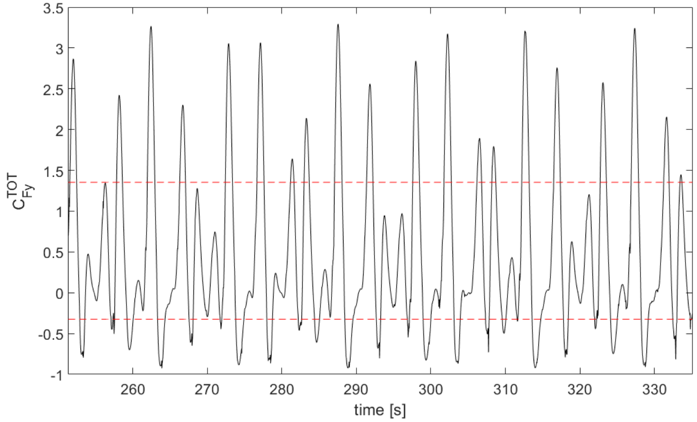


Force coefficients

Under platform's surge motion:

- unsteady behaviour of the loads, with frequency of load oscillation related simultaneously to $B \cdot \Omega$ and ω_{surge}
- for $U_{surge} > 0$ increase of both C_{Fx} and C_{Fy}
  for $U_{surge} < 0$ decrease of load (towards 0)





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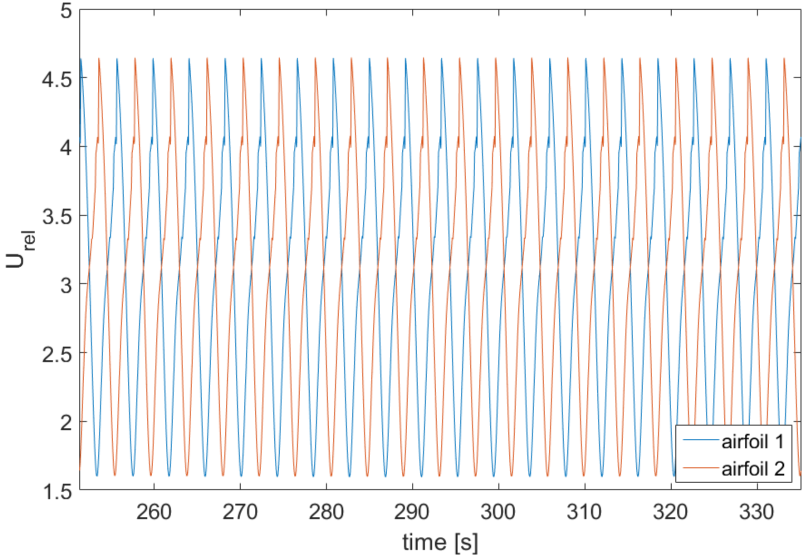
Velocity triangles

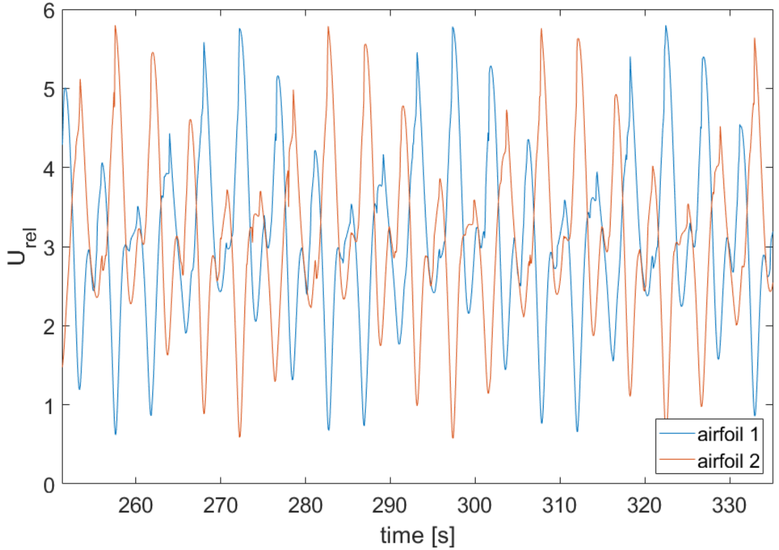
velocity → $C_{pressure}$ → C_{force}

Only rotation case



- Repeats at airfoil 2 after half rotation
- Repeats at the same airfoil after 1 full rotation

Surging motion case



- Repeats at airfoil 2 after 15.5 rotations and 13 surge cycles
- Repeats at the same airfoil after 6 full rotations and 5 surge cycles

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Velocity triangles

$\propto \Omega$, U_{surge}

$$\boldsymbol{U_{relative}} = \boldsymbol{U_{current}} + \boldsymbol{U_{displacement}} + \boldsymbol{U_{induced}}$$

constant (assumption)

$\propto X_{surge}$

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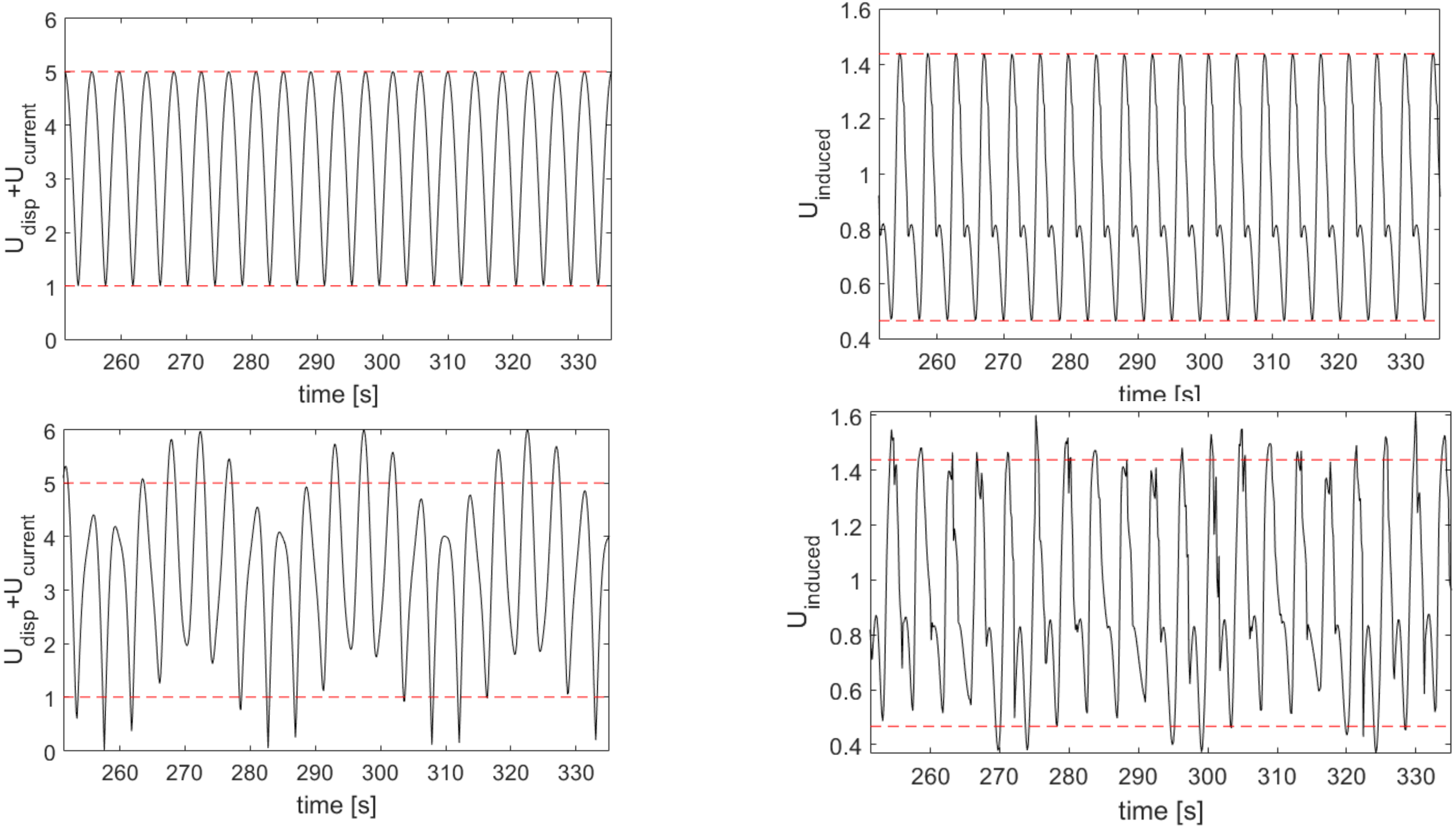
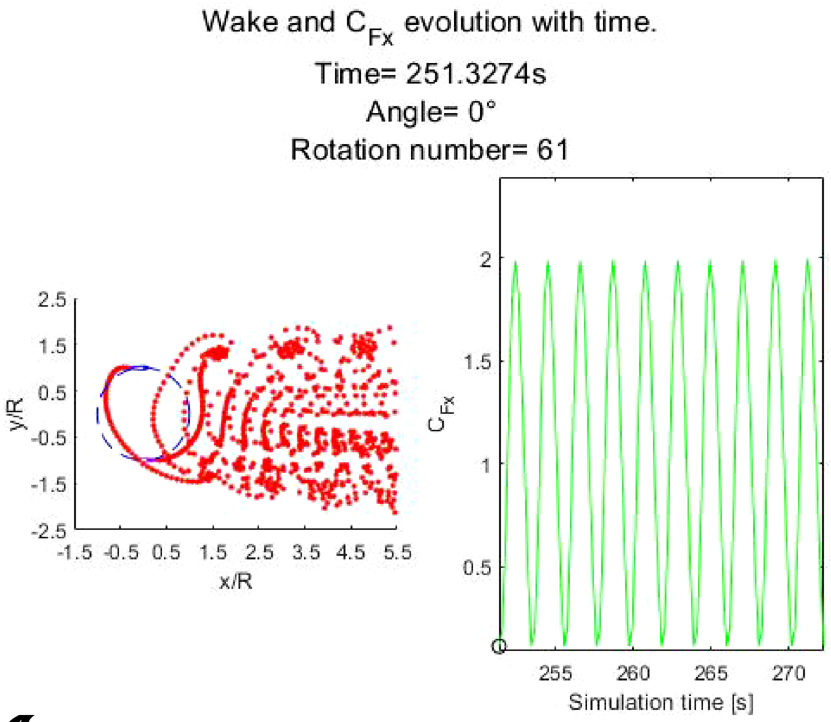
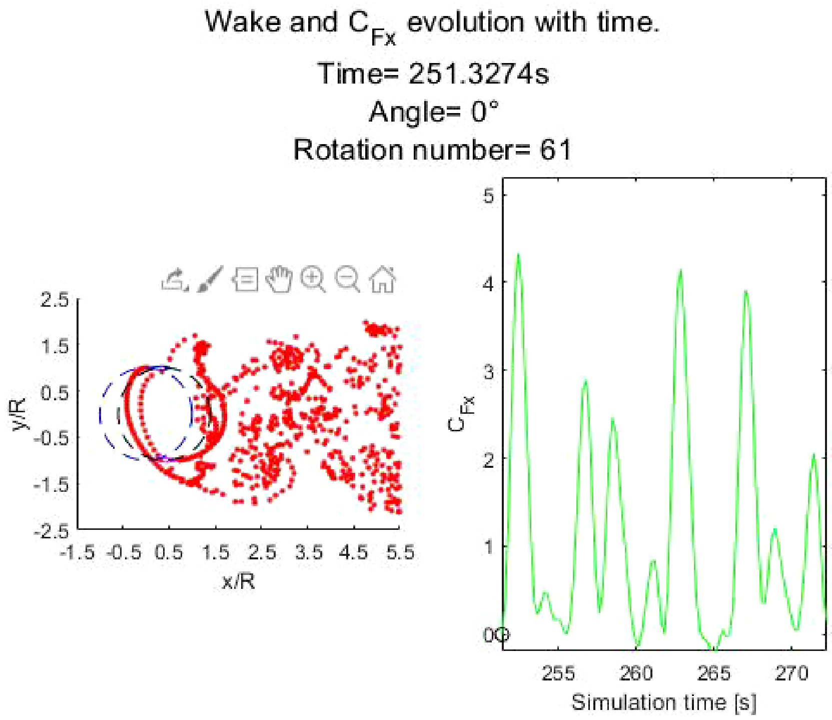
Velocity triangles

Velocity triangles for airfoil 1 (starting phase 0°) over rotations 60 to 80



Velocity and wake evolution





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Conclusions

Conclusions

- The 2D vortex panel method is a conservative and fast tool to assess the hydrodynamic response of vertical-axis tidal turbines under floating platform's motions.

- Surge affects the hydrodynamic load response mainly due to two effects:
  - *Surge velocity* directly affecting the displacement velocity and so inducing relative velocity amplitude variations depending on the surge direction
  - *Surge displacement* affecting the induced velocity by modifying the interactions of wake vortices and airfoils

- Further analysis is being conducted to study:
  - Frequency analysis, effect on the power coefficient, possible cavitation, relevance of viscous effects, etc. on Haineng 1
  - Kobold turbine under intense surge (3-bladed, smaller solidity)

References

References

EC/European Commission. (2020). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. *An EU Strategy to harness the potential of offshore renewable energy for a climate neutral future*.

EC/European Commission. (2020). Report from the Commission to the European Parliament and the Council. *On progress of clean energy competitiveness*.

EC/European Commission (2017), *Study on Lessons for Ocean Energy Development.*

Weller, S., Johanning, L., & Davies, P. (2013). Best practice report–mooring of floating marine renewable energy devices.

Sheng, Q., Jing, F., Zhang, L., Zhou, N., Wang, S., & Zhang, Z. (2016). Study of the hydrodynamic derivatives of vertical-axis tidal current turbines in surge motion. *Renewable energy*, *96*, 366-376.

Wang, K., Sun, K., Sheng, Q. H., Zhang, L., & Wang, S. Q. (2016). The effects of yawing motion with different frequencies on the hydrodynamic performance of floating vertical-axis tidal current turbines. *Applied ocean research*, *59*, 224-235.

Wang, S. Q., Xu, G., Zhu, R. Q., & Wang, K. (2018). Hydrodynamic analysis of vertical-axis tidal current turbine with surging and yawing coupled motions. *Ocean Engineering*, *155*, 42-54

References

Xu, G., Li, H., & Wang, S. (2019). Numerical Study on the Vertical-Axis Tidal Current Turbine with Coupled Motions (Part I). Journal of Coastal Research, 97(SI), 273-288.

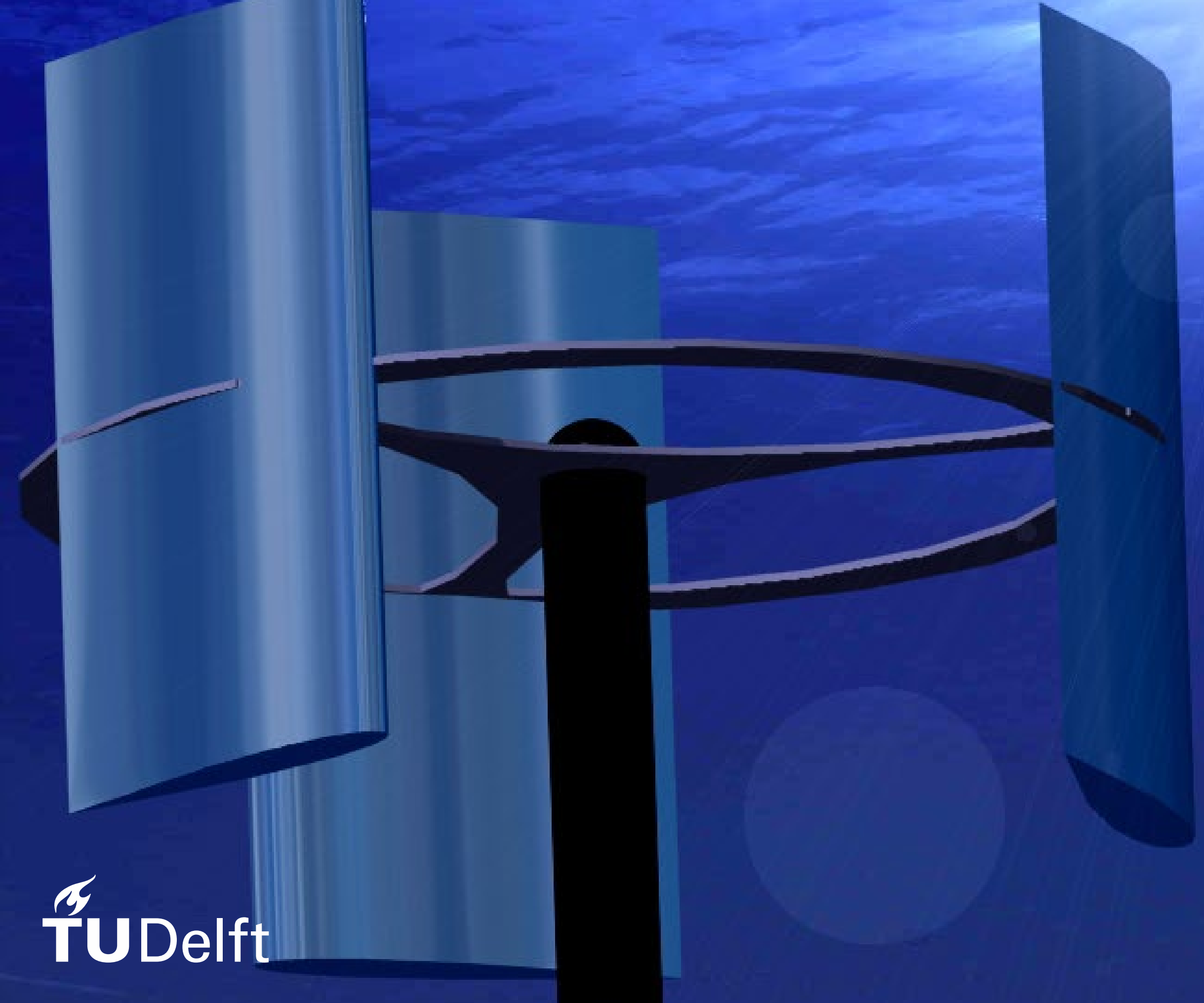
Katz, J., & Plotkin, A. (2001). *Low-speed aerodynamics* (Vol. 13). Cambridge university press.

Chowdhury, M. S., Rahman, K. S., Selvanathan, V., Nuthammachot, N., Suklueng, M., Mostafaeipour, A., ... & Techato, K. (2020). Current trends and prospects of tidal energy technology. *Environment, Development and Sustainability*, 1-16.

Khalid, S. S., Liang, Z., & Shah, N. (2012). Harnessing tidal energy using vertical axis tidal turbine. *Research Journal of Applied Sciences, Engineering and Technology*, *5*(1), 239-252.

D. De Tavernier, 2020. *VAWT aerodynamics* [PowerPoint slides]. Delft University of Technology.

Thank you!



Source:http://www.esru.strath.ac.uk/EandE/Web_sites/05-06/marine_renewables/technology/vertaxis.htm

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Questions?

Additional slides

Verification

The output of the 2D panel code is verified against the 2D CFD simulations presented in the scientific literature, for:

- Surge
- Sway
- Yaw
- Surge & sway coupled motions
- Surge & yaw coupled motions

Assumptions:

- The platform wave response is a stable simple harmonic motion
- $U_{current} = constant$
- $\Omega_{rotor} = constant$
- $C_F = \frac{F}{\frac{1}{2}\rho U_\infty^2 D}$

Verification – set-up

Rotor geometry – HEU turbine

Radius [m]	Chord [m]	Number of blades B	Airfoil	Fixed blade position l_0	Set-up angle [°]
0.4	0.12	2	NACA0018	0.3c	0

Inflow conditions

$U_{current} = 1\ m/s \quad \lambda = 2.5$

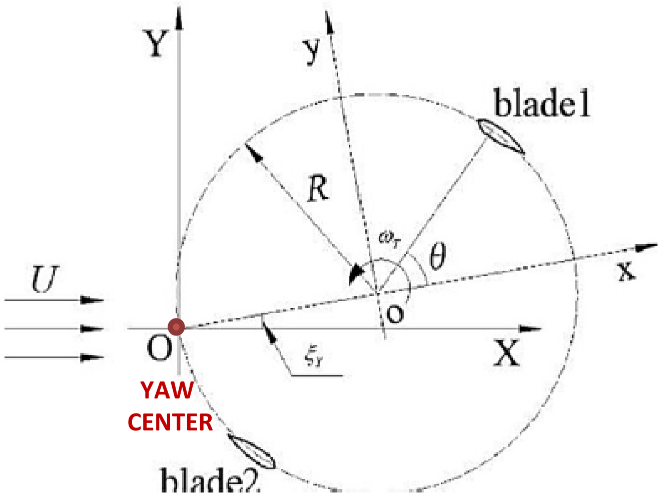
$X_{surge} = A_{surge}\sin(\omega_{surge}t) = 0.2\ [m]\sin\left(1\left[\frac{rad}{s}\right]\cdot t\right)$

$Y_{sway} = A_{sway}\sin(\omega_{sway}t) = 0.2\ [m]\sin\left(1\left[\frac{rad}{s}\right]\cdot t\right)$

$\theta_{yaw} = A_{yaw}\sin(\omega_{yaw}t) = \frac{\pi}{18}\sin\left(1\left[\frac{rad}{s}\right]\cdot t\right)$

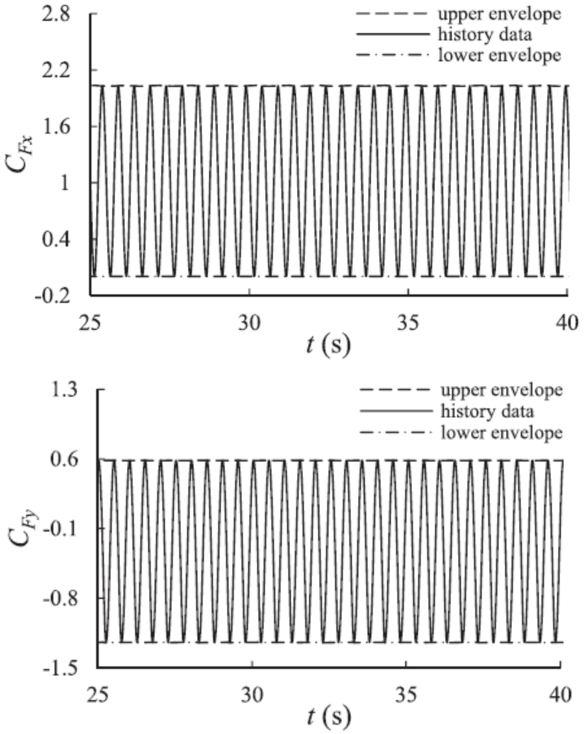
$$\begin{cases} X'_{yaw} = -\frac{D}{2} + \left(x+\frac{D}{2}\right)\cos\theta_{yaw} - y\sin\theta_{yaw} \\ Y'_{yaw} = \left(x+\frac{D}{2}\right)\sin\theta_{yaw} + y\cos\theta_{yaw} \end{cases}$$

Coordinate system

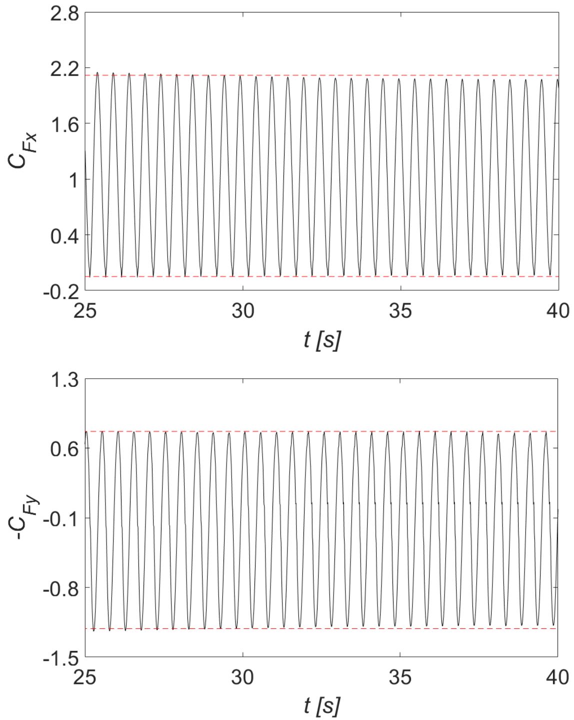


Verification – results

Only rotation motion



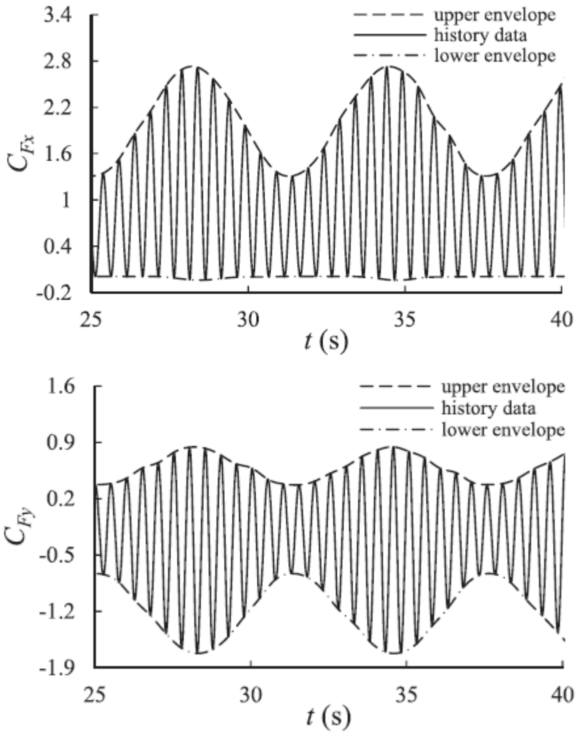
Wang et al. (2018) and Xu et al. (2019)



2D panel code

Verification – results

With surging motion



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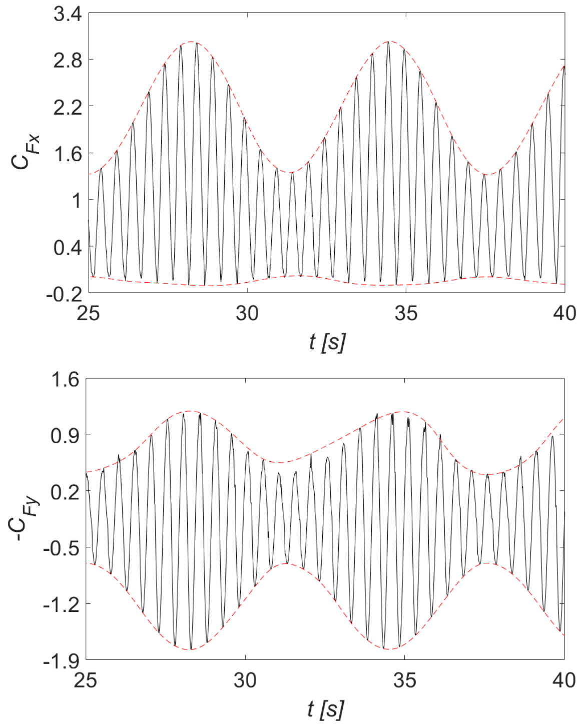
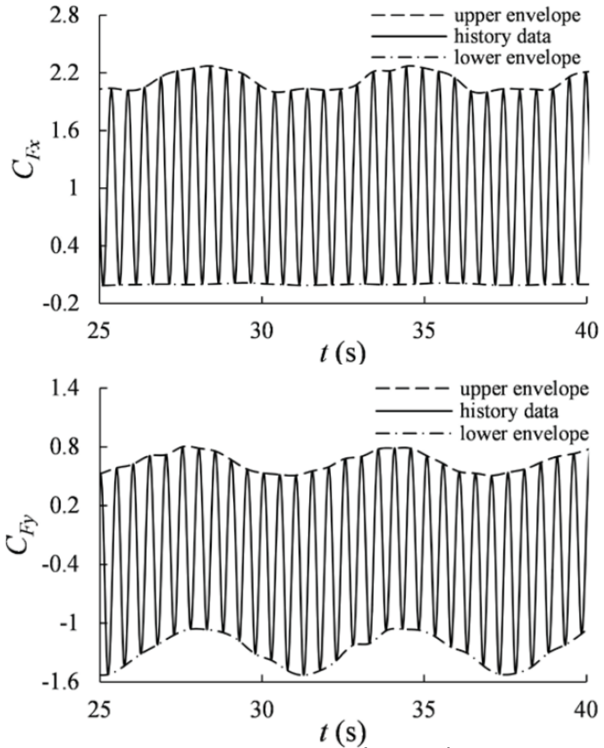


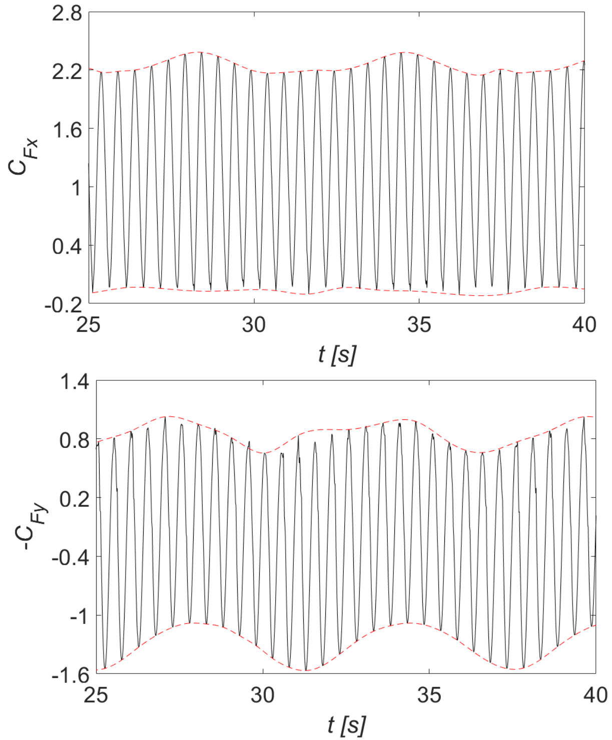
2D panel code

Verification – results

With swaying motion



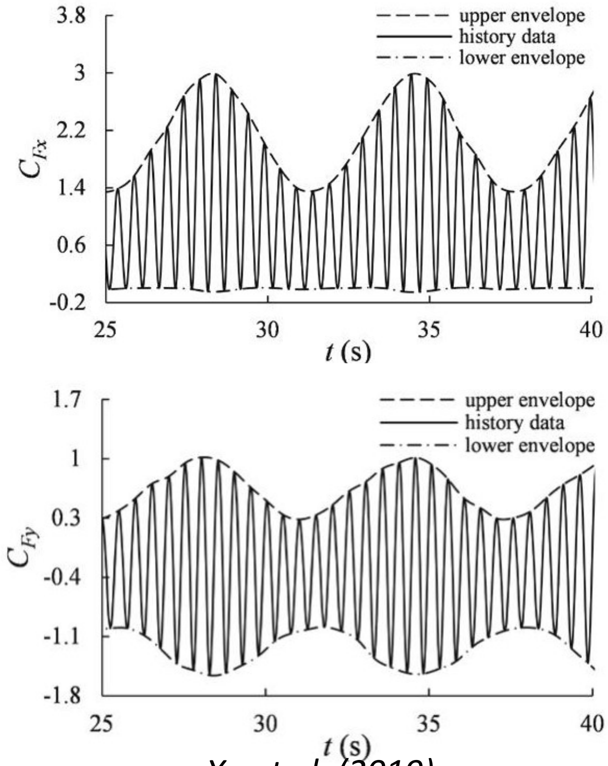
Xu et al. (2019)



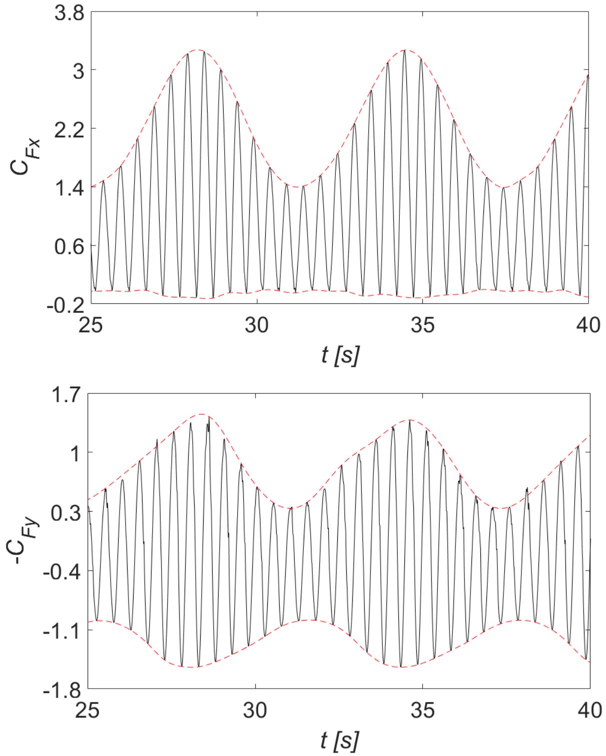
2D panel code

Verification – results

With surging & swaying coupled motions



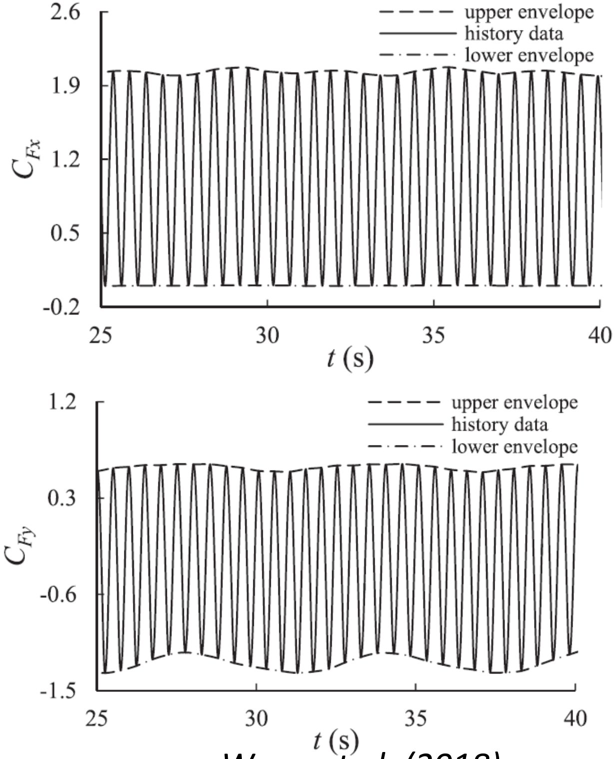
Xu et al. (2019)



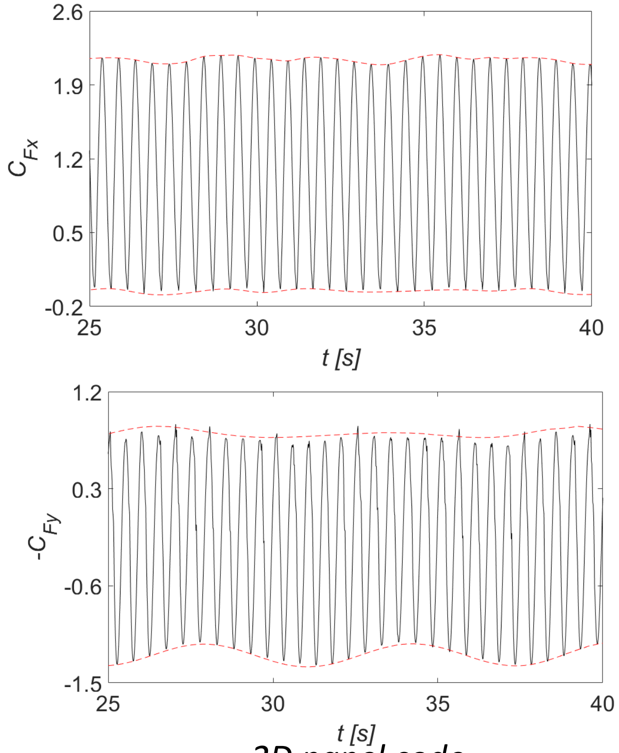
2D panel code

Verification – results

With yawing motion



Wang et al. (2018)



2D panel code

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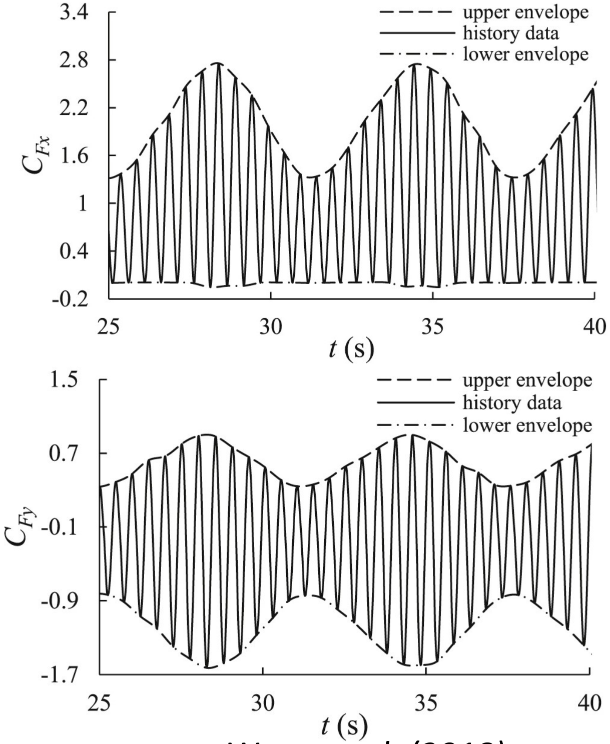
Verification – results

With surging & yawing coupled motions



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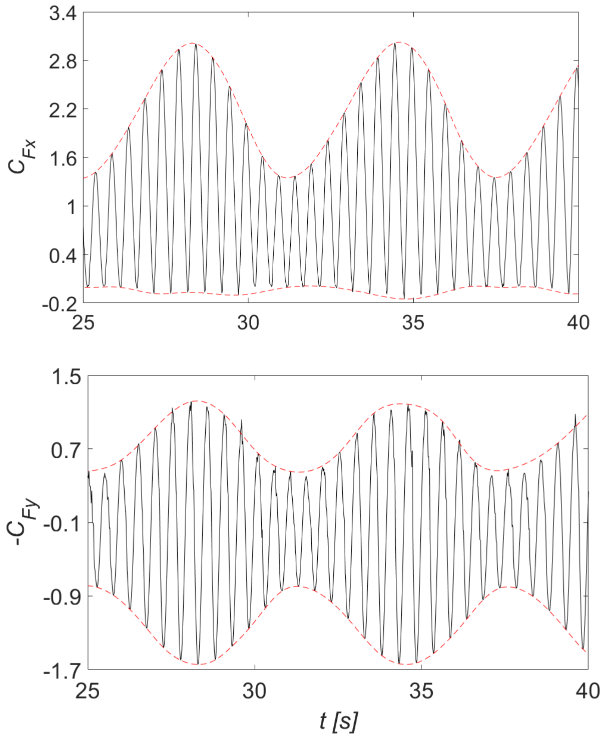

2D panel code