MODELLING CHALLENGES IN SIMULATING THE COUPLED MOTION OF A SEMI-SUBMERSIBLE FLOATING VAWT

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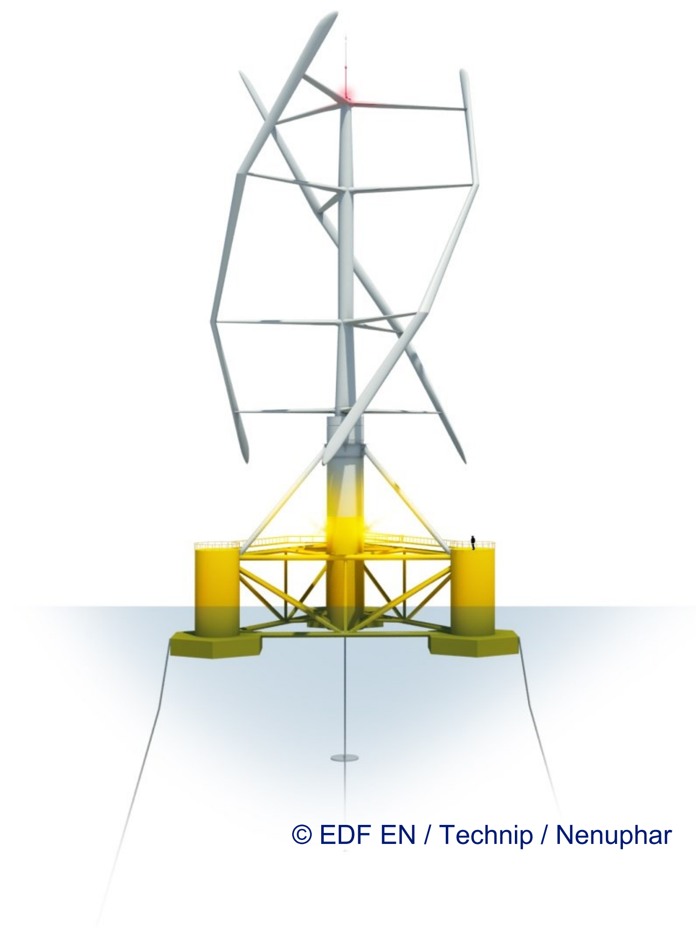
SUMMARY

- The VertiWind project
- Coupled dynamic simulation methodology
- Viscous damping modelling study
- Coupled hydro-aerodynamic study
- Conclusions
- Future work

THE VERTIWIND PROJECT

CONTEXT

- Onshore reduced scale turbine model
- VertiFloat: Onshore full scale turbine prototype
- **VertiWind: Offshore full scale turbine prototype**
- INFLOW: Design optimisation & supply chain
- VertiMED: 26 MW floating offshore windfarm



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THE VERTIWIND PROJECT

PARTNERS AND FUNDING

Project partners:

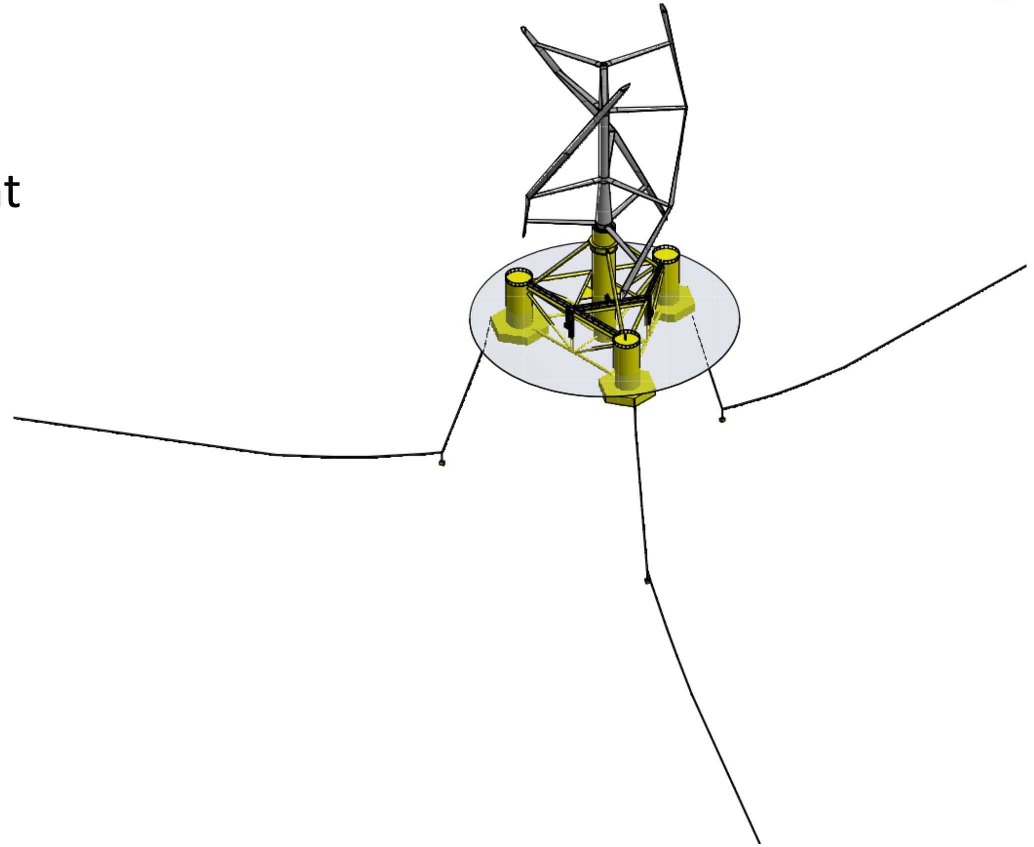
- **Technip**
Project leader. Substructure, mooring and installation design + procurement
- **Nénuphar**
VAWT design + procurement
- **EDF EN**
Pilot site utility client. Definition of maintenance strategy
- Seal Engineering
- Bureau Veritas
- Oceanide
- IFP EN
- Arts & Métiers
- USTV

Governmental funding:

ADEME
Agence de l'environnement et de la maîtrise de l'énergie
(Agency for the environment and management of energy)

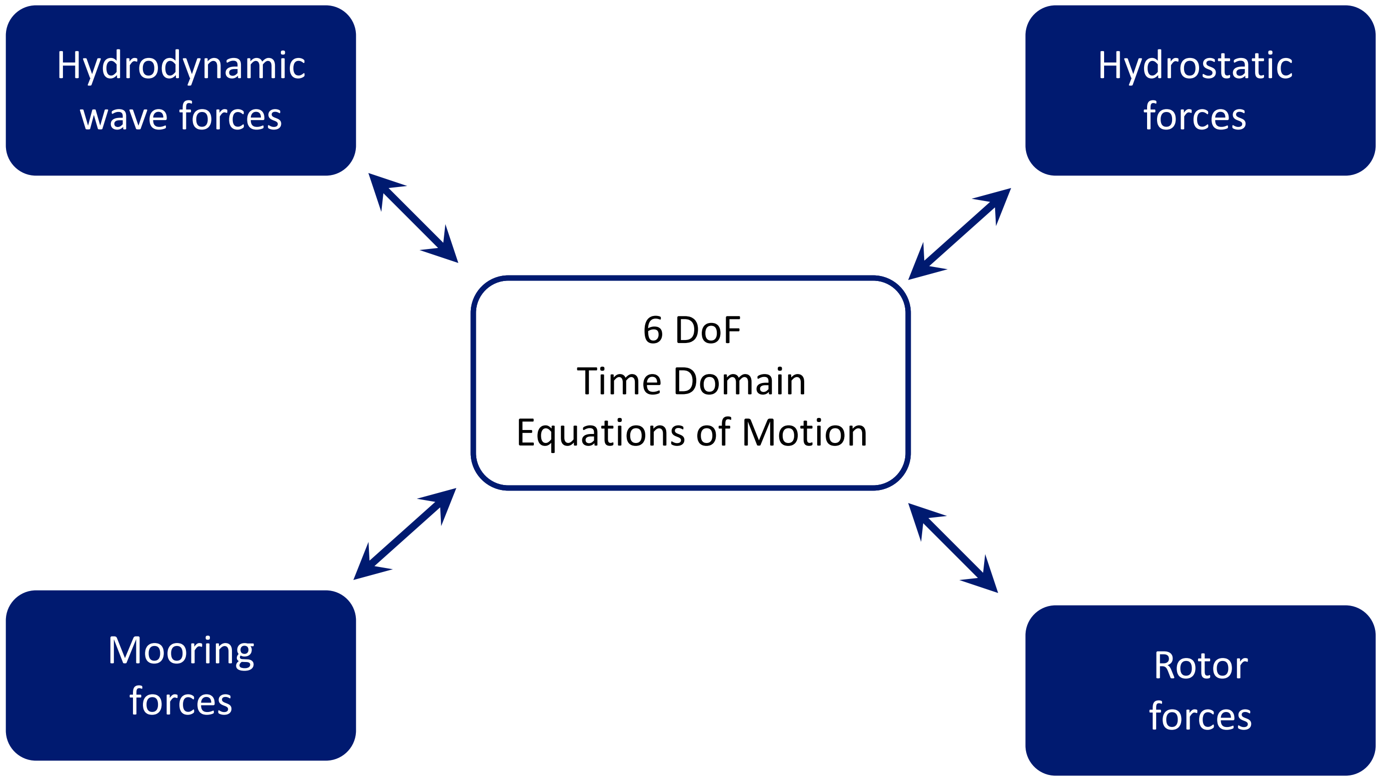
THE VERTIWIND PROJECT
TECHNOLOGY

- Bespoke VAWT design
- Direct drive 2MW permanent magnet generator
- Column-stabilised semisubmersible platform
- Catenary moorings



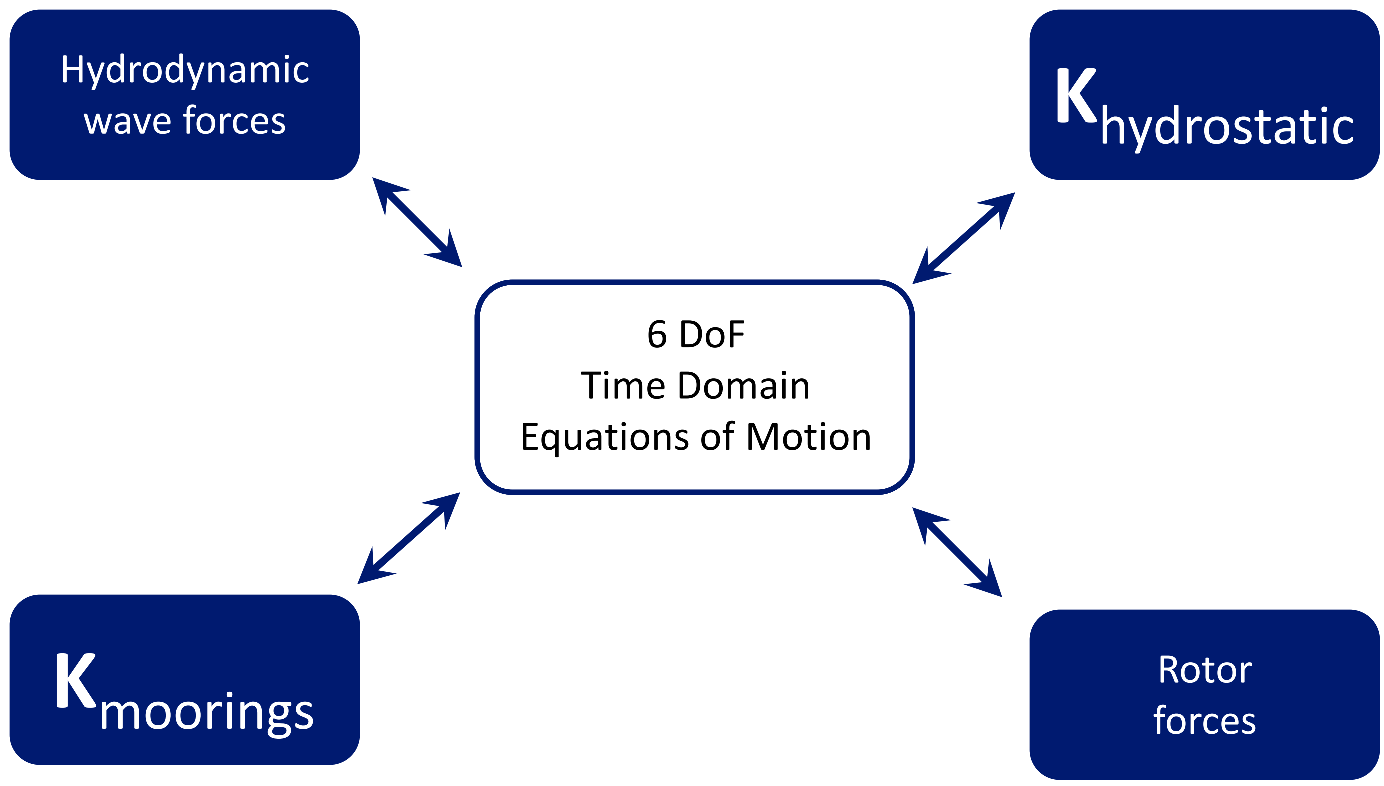
COUPLED DYNAMIC SIMULATION METHODOLOGY

GENERAL

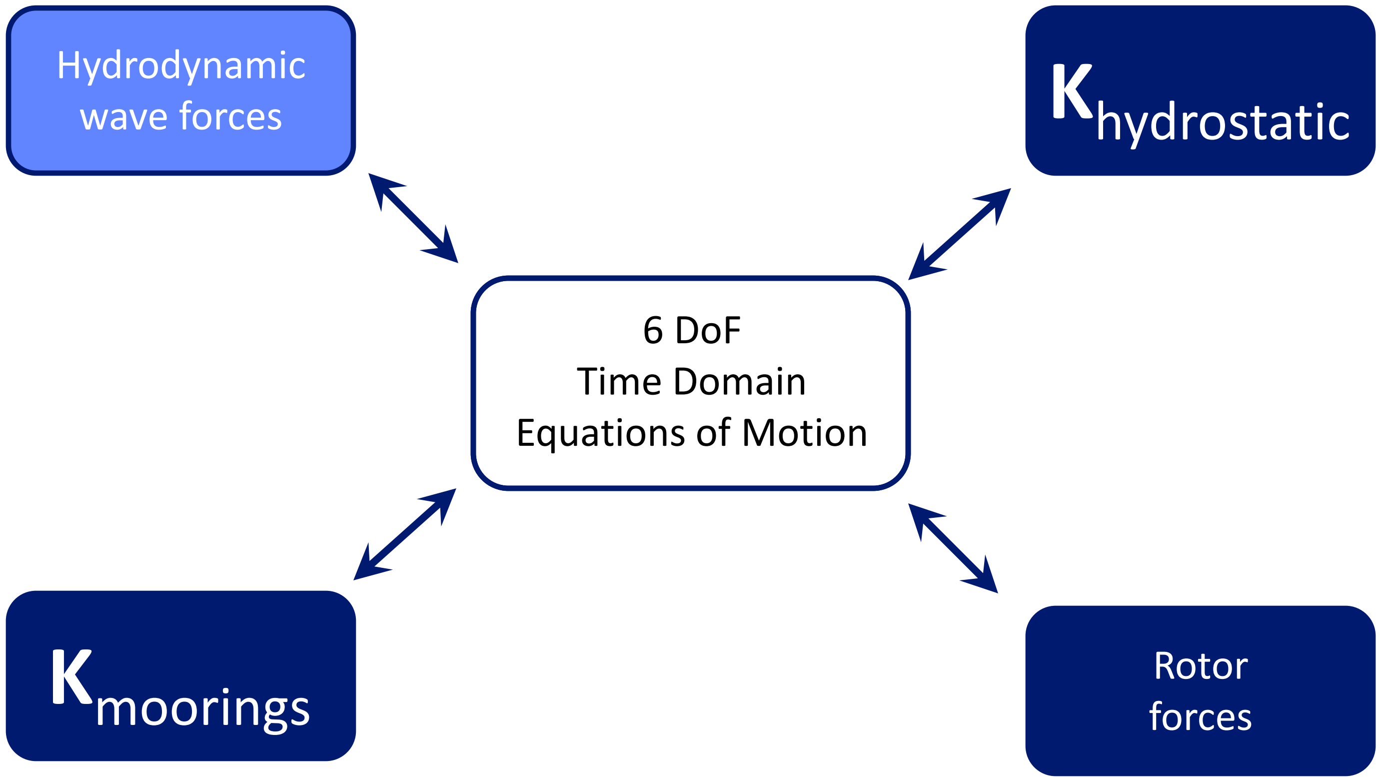


COUPLED DYNAMIC SIMULATION METHODOLOGY

GENERAL

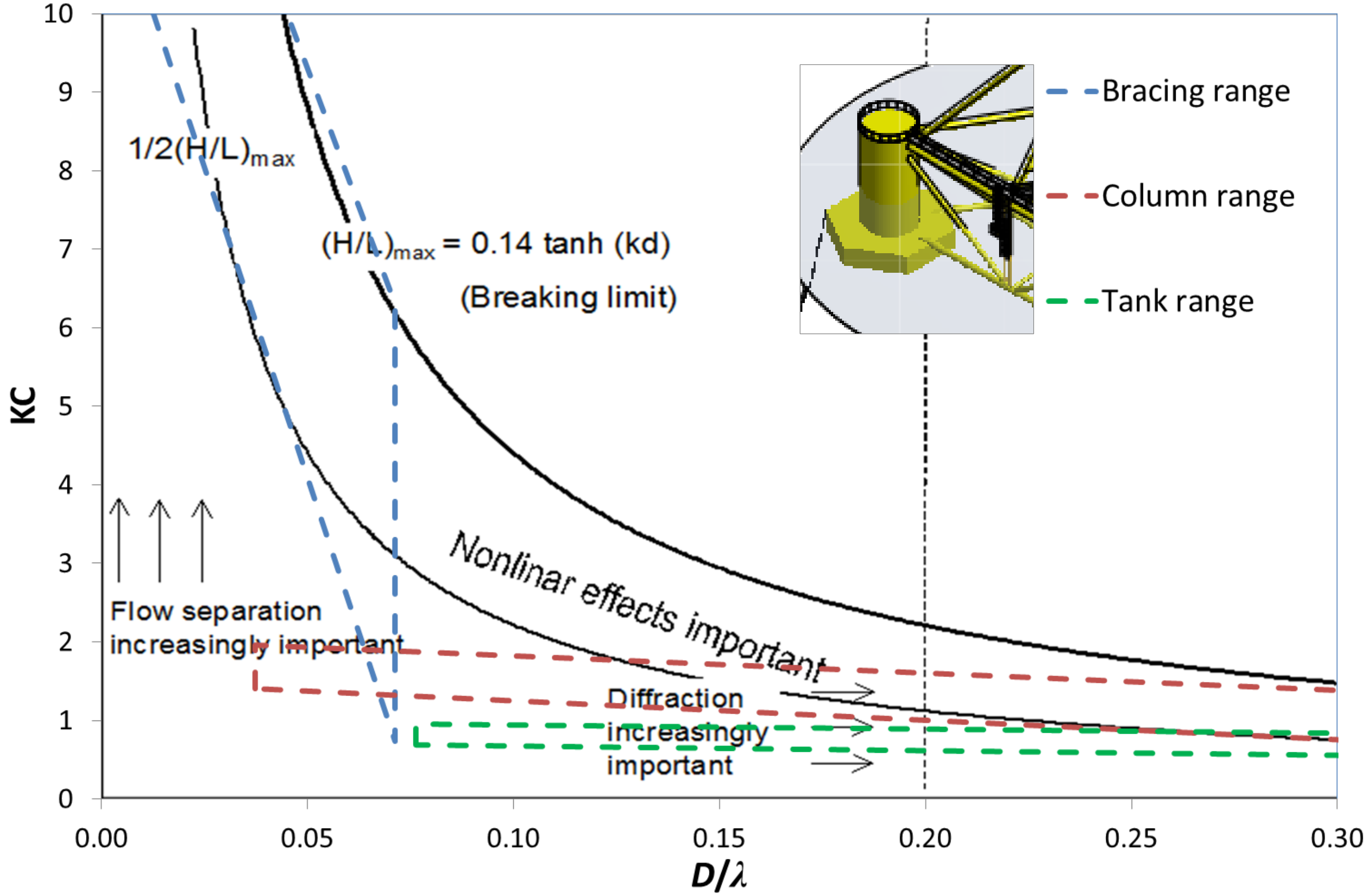


COUPLED DYNAMIC SIMULATION METHODOLOGY
HYDRO-MECHANICS



COUPLED DYNAMIC SIMULATION METHODOLOGY
HYDRO-MECHANICS (1)

Wave loading regime

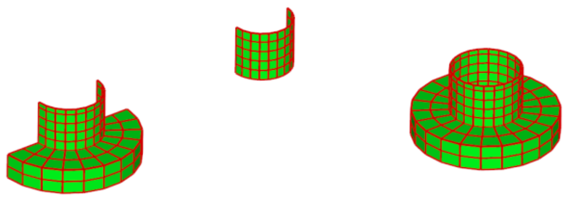


L. Johanning and J.M.R. Graham, *Dynamic Response of Wind Turbine Structures in Waves and Current*, 2003

COUPLED DYNAMIC SIMULATION METHODOLOGY

HYDRO-MECHANICS (2)

Inertial loads on large members



Linear diffraction-radiation solution via *Aquaplus* (École Centrale de Nantes)

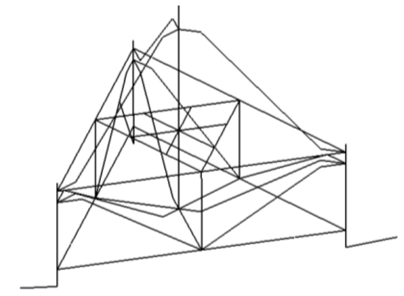
↓

Time-domain representation following Cummins method

↓

Inertial wave forces

Drag loads on all members



Option 1:

Reconstruct global 6 DoF quadratic drag matrix $\boldsymbol{B_Q}$

↓

Global drag forces $\boldsymbol{f_d} = \boldsymbol{B_Q}\,\boldsymbol{x}'(t)|\boldsymbol{x}'(t)|$

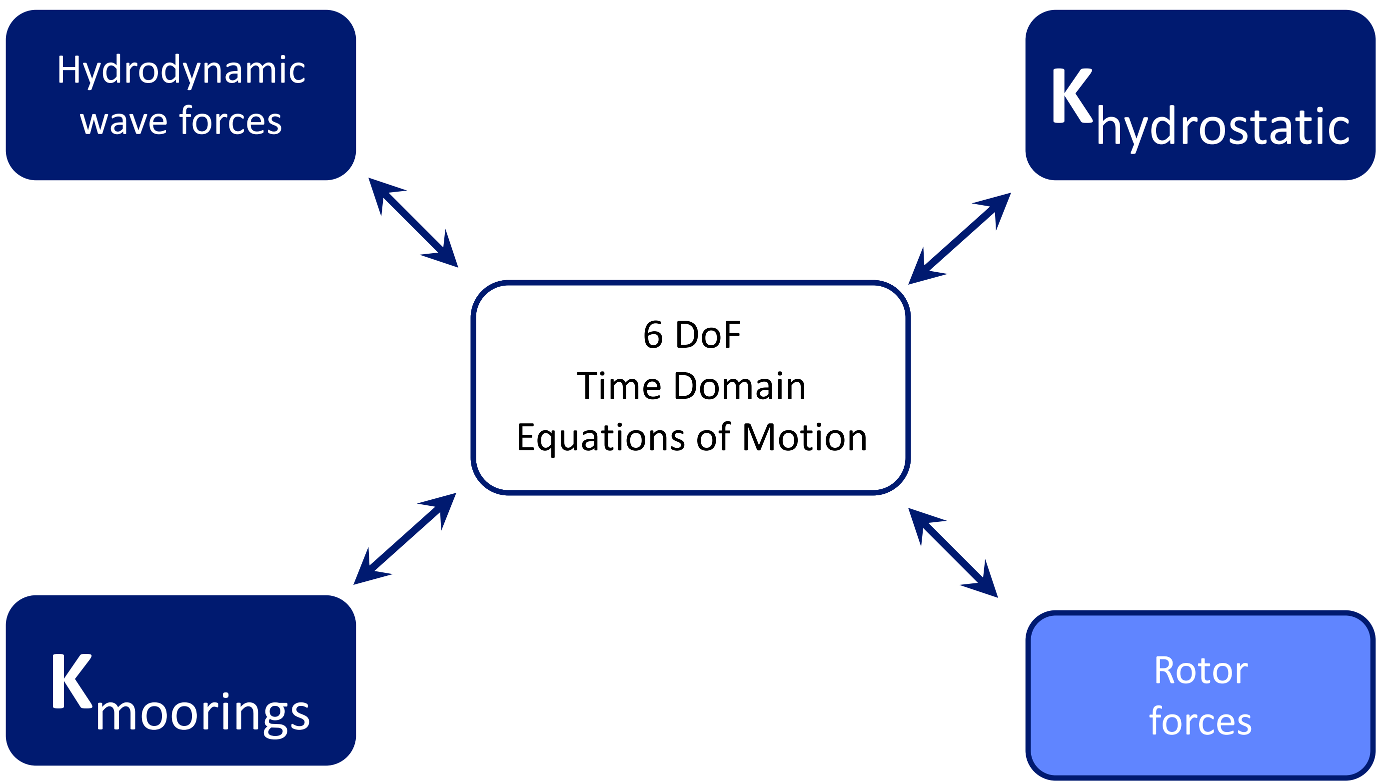
Option 2:

Integrate local drag forces over wetted hull at each time step

↓

Local drag forces $\boldsymbol{f_d} = \boldsymbol{f_d}(t)$

COUPLED DYNAMIC SIMULATION METHODOLOGY
AERO-MECHANICS

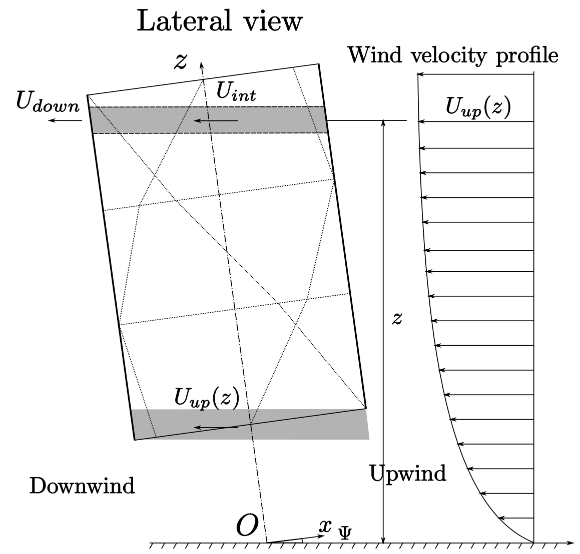


COUPLED DYNAMIC SIMULATION METHODOLOGY

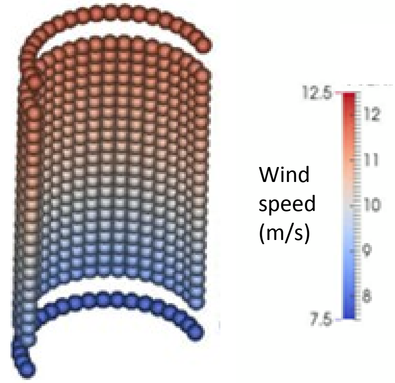
AERO-MECHANICS (1)

VAWT library

- Rigid rotor, gyro forces
- Time domain BEMT using DMST
- Dynamic stall: Gormont + Berg correction
- Punctual computation of flow skew and relative speed under platform oscillations
- PID controller
- NO stream tube expansion
- NO dynamic inflow

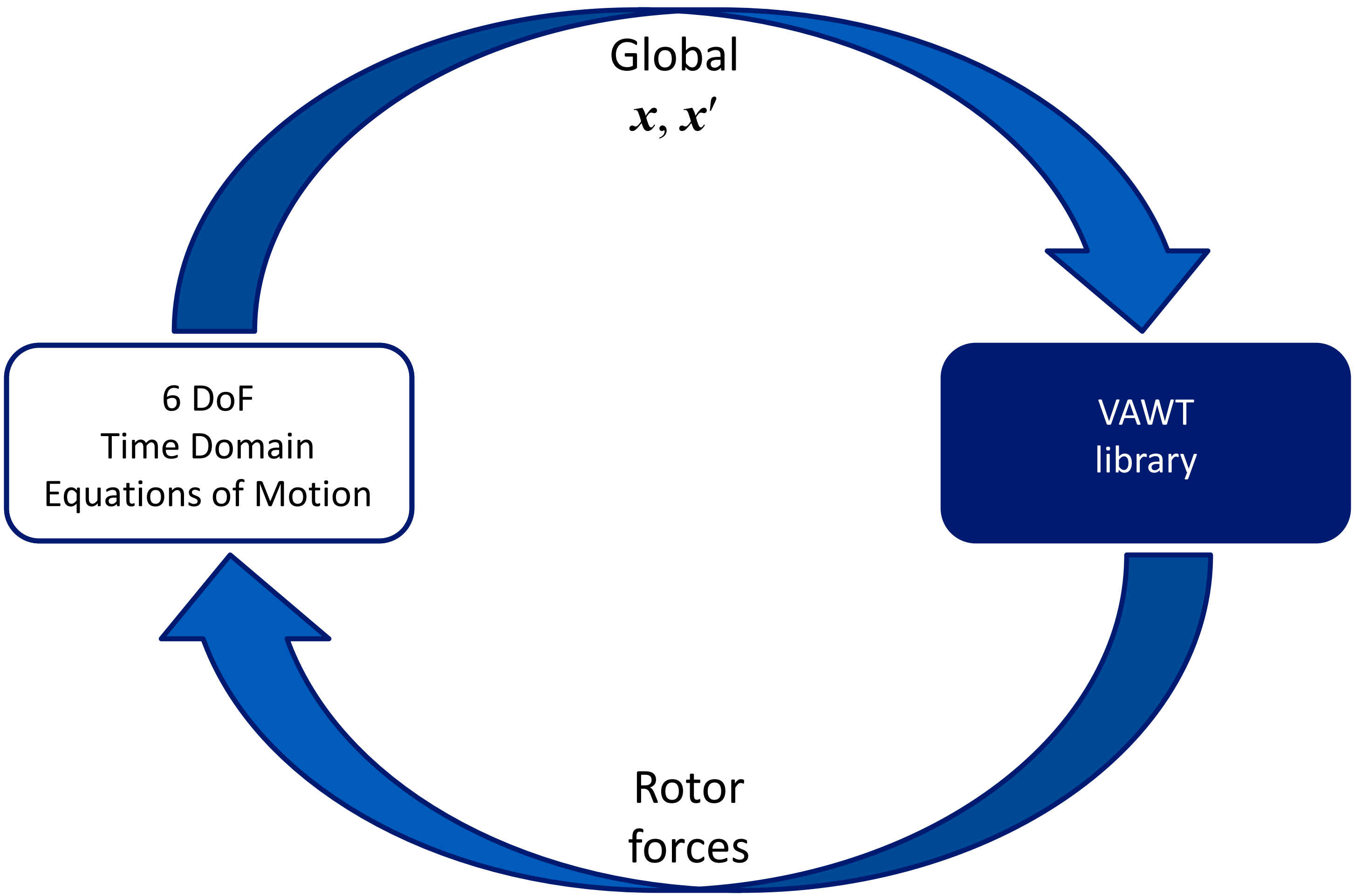


Inspired by: I. Paraschivoiu, *Wind Turbine Design*, 2002



COUPLED DYNAMIC SIMULATION METHODOLOGY

AERO-MECHANICS (2)



VISCOUS DAMPING MODELLING STUDY

MODELLING OPTIONS

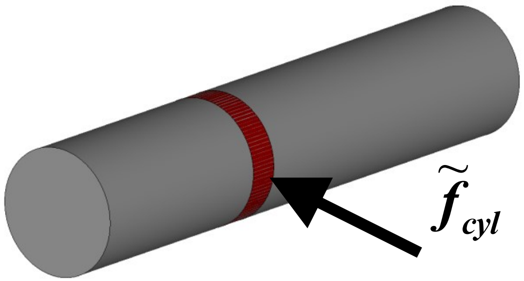
a) Quadratic viscous damping matrix $\boldsymbol{B_Q}$

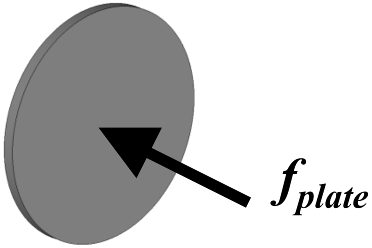
$$\boldsymbol{f_d} = \boldsymbol{B_Q}\, \boldsymbol{x}'(t)\, |\boldsymbol{x}'(t)|$$

b) Integration of drag forces over wet hull

$$\boldsymbol{f_d} = \sum_{n=1}^{N_{cylinders}} \int_{Span} \widetilde{\boldsymbol{f}}_{\boldsymbol{cyl}}\, ds + \sum_{n=1}^{N_{plates}} \boldsymbol{f_{plate}}$$

Using relative flow speed with linear wave kinematics





VISCOUS DAMPING MODELLING STUDY

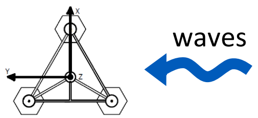
SIMULATION RESULTS (PARKED ROTOR)

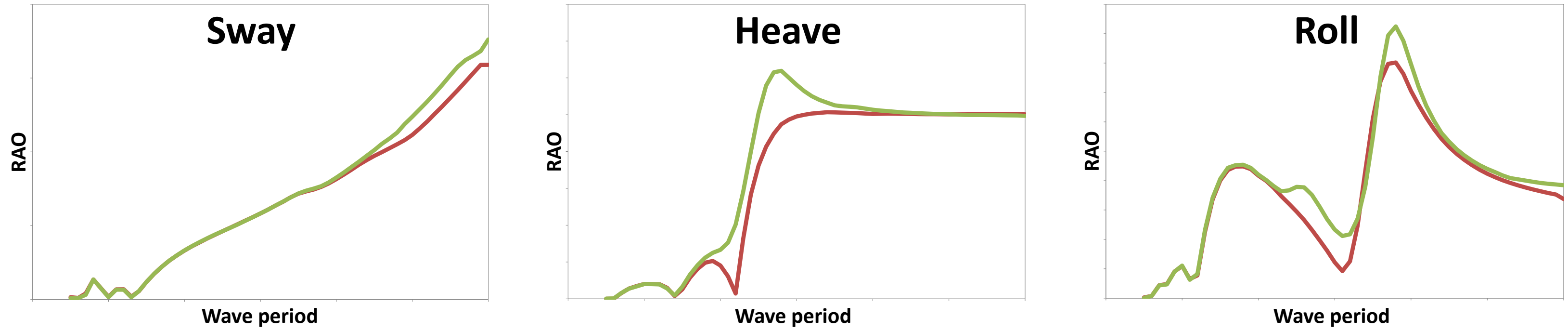
Legend

Viscous damping modelled with: a) Quadratic matrix; b) Integration

Decay simulations

Synthetic RAOs





COUPLED HYDRO-AERODYNAMIC STUDY
ENVIRONMENTAL/OPERATIONAL CONDITIONS (1)

a) Waves + standstill

V_w = 0 m/s
Turbine parked

b) Waves + spinning (reference case)

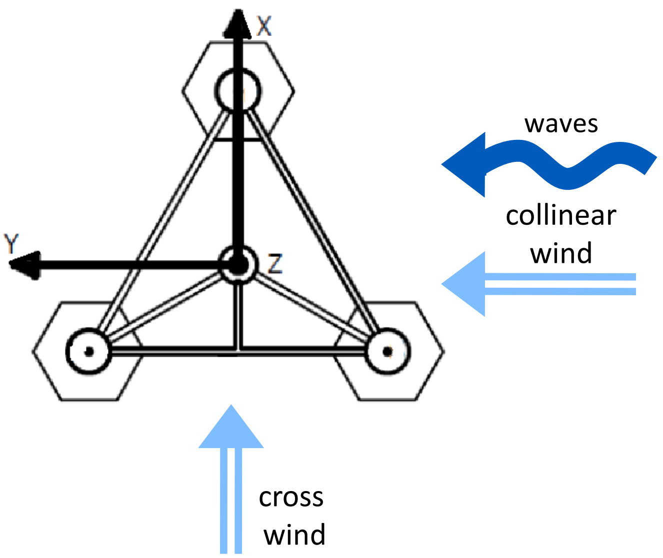
V_w = 0 m/s
Turbine spinning at same speed as c) and d)

c) Waves + collinear wind

V_w = 80% cut-out wind speed
Turbine operating at prescribed speed

d) Waves + cross wind

V_w = 80% cut-out wind speed
Turbine operating at prescribed speed



COUPLED HYDRO-AERODYNAMIC STUDY
ENVIRONMENTAL/OPERATIONAL CONDITIONS (2)

a) **Waves + standstill**

V_w = 0 m/s
Turbine parked

Blade Element Theory only

b) **Waves + spinning (reference case)**

V_w = 0 m/s
Turbine spinning at same speed as c) and d)

BEMT
TSR $\longrightarrow \infty$

c) **Waves + collinear wind**

V_w = 80% cut-out wind speed
Turbine operating at prescribed speed

BEMT
Low TSR

d) **Waves + cross wind**

V_w = 80% cut-out wind speed
Turbine operating at prescribed speed

BEMT
Low TSR

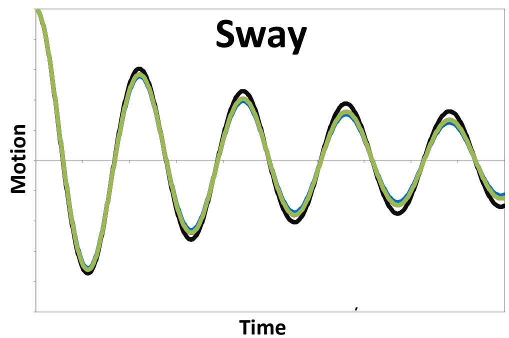
COUPLED HYDRO-AERODYNAMIC STUDY

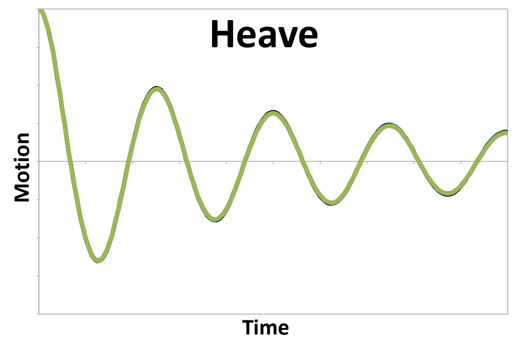
SIMULATION RESULTS

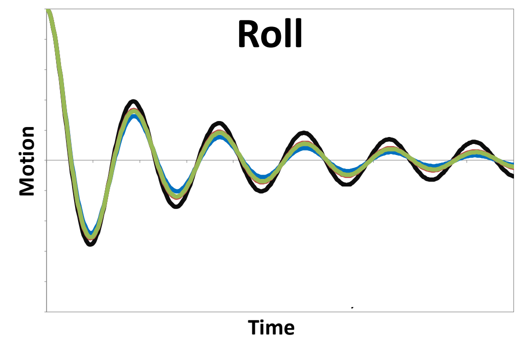
Legend

Environmental & operational conditions:
- a) Standstill
- b) Spinning
- c) Collinear wind
- d) Cross wind

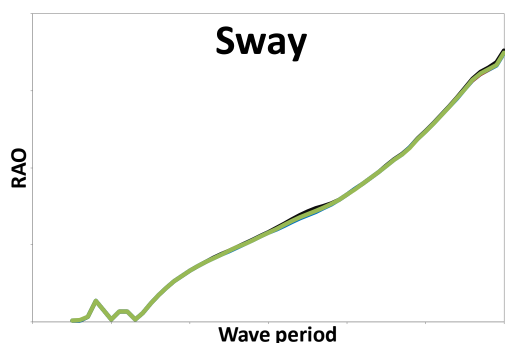
Decay simulations

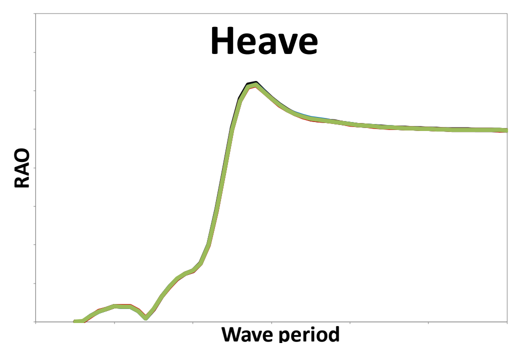


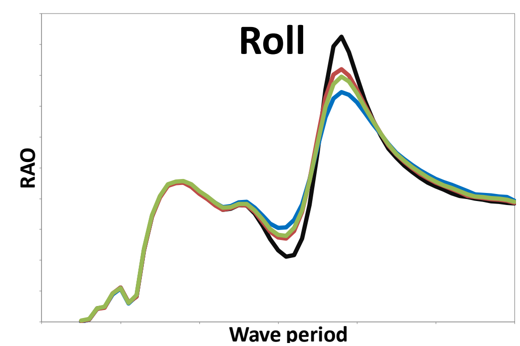




Synthetic RAOs about modified equil. pos.







CONCLUSIONS

Viscous hydro damping

Global quadratic matrix representation $\boldsymbol{B_Q}$:

- fits well experimental decay tests BUT
- does not explain extra motion response in resonance band

⇩

<u>integration of drag forces over wetted hull allows to include viscous excitation</u>

Aero-hydrodynamic coupling

Operating VAWT rotor provides aerodynamic damping:

- significant for roll & pitch
- function of TSR
- relatively insensitive to wind direction relative to motion

FUTURE WORK

- Further improvements of BEMT solver (including validation)
- Turbulent, unsteady wind input
- Rotor elasticity
- Nonlinear hydrostatics
- Nonlinear potential hydrodynamics
- Dynamic moorings model

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ADEME Agence de l'Environnement et de la Maîtrise de l'Energie