# Design of floating wind turbine system with DeepLines Wind

## GDR-EMR : Journée Eolien Offshore

PRINCIPIA

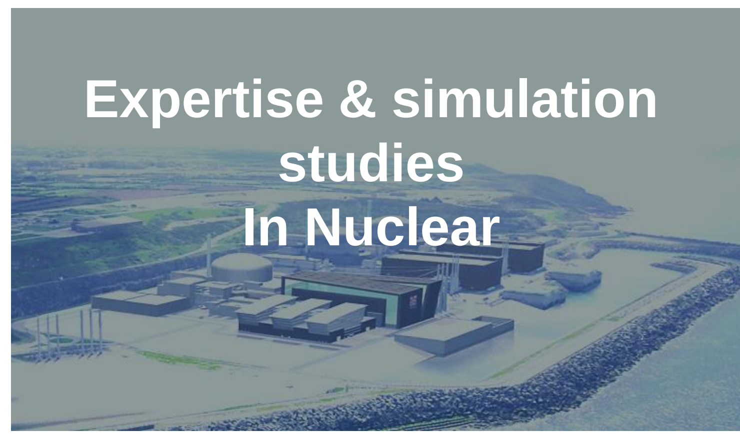
# Principia – Main activities

**Offshore engineering activity**


**Expertise & rules justification**



**R&D to basic and detailed design**




**Expertise & analysis**

# Summary

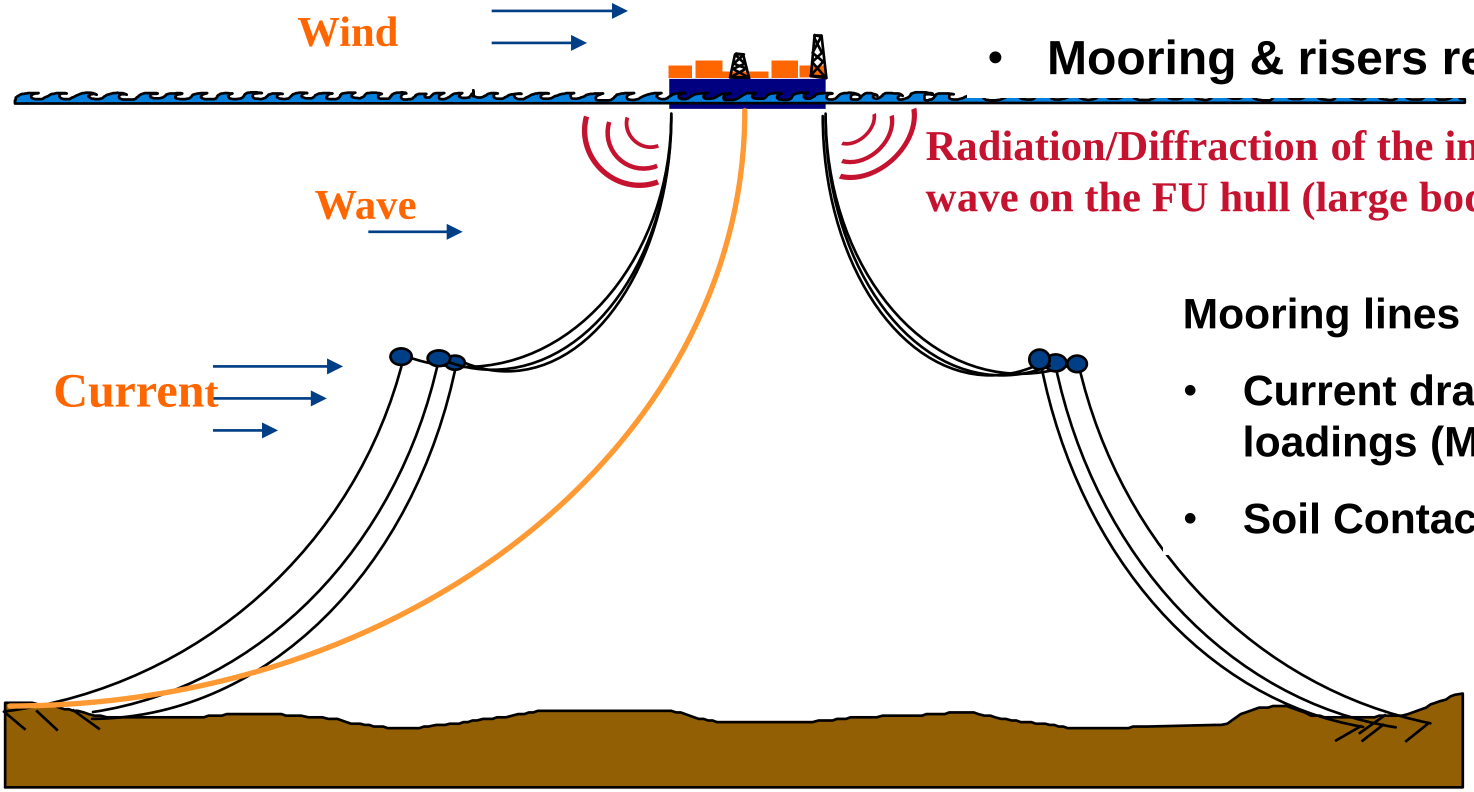
- **DeepLines Wind (in partnership with IFP Energies nouvelles)**
- **Validation**
- **Design Considerations**

# Floating system

- DeepLines

**Floater side:**

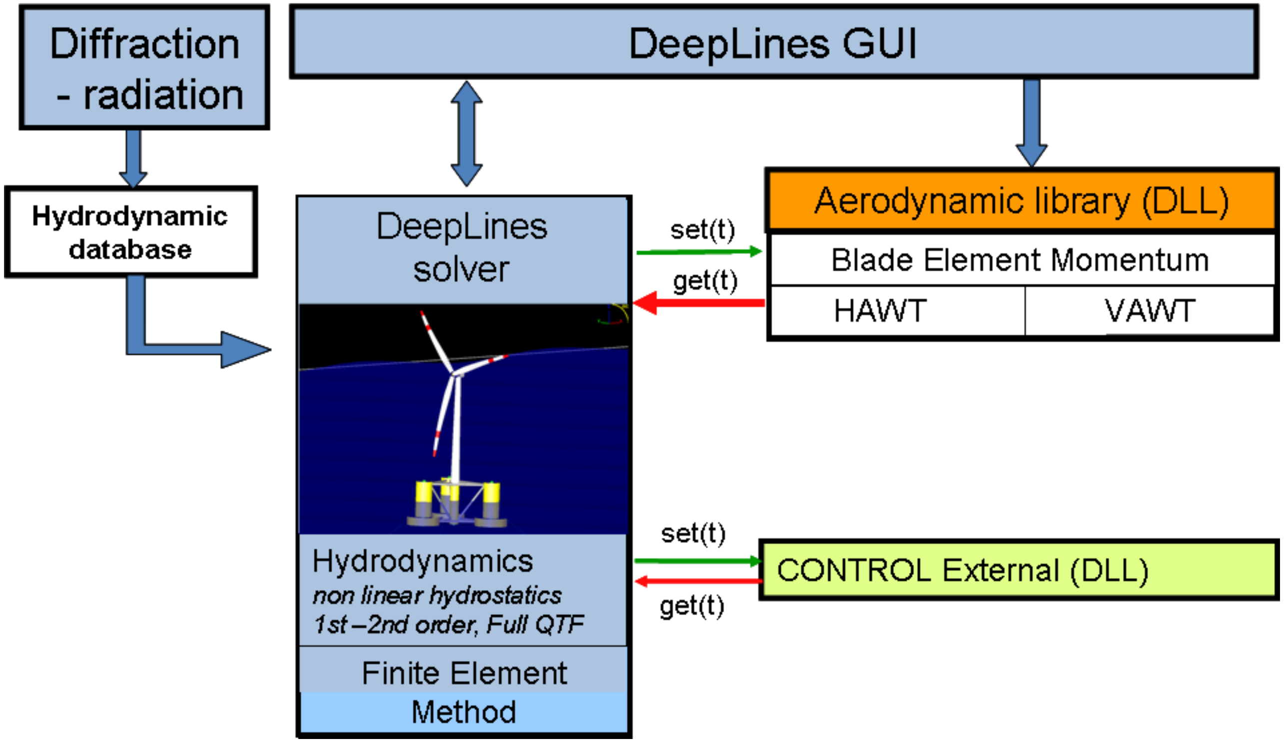
- Wind, current drag loads
- Wave loadings 1st and 2$^{nd}$ order
- Mooring & risers restoring forces




**Mooring lines & risers side:**

- Current drag loads + wave loadings (Morison)
- Soil Contact

## Wind turbine modeling software based on DeepLines solver



# New elements

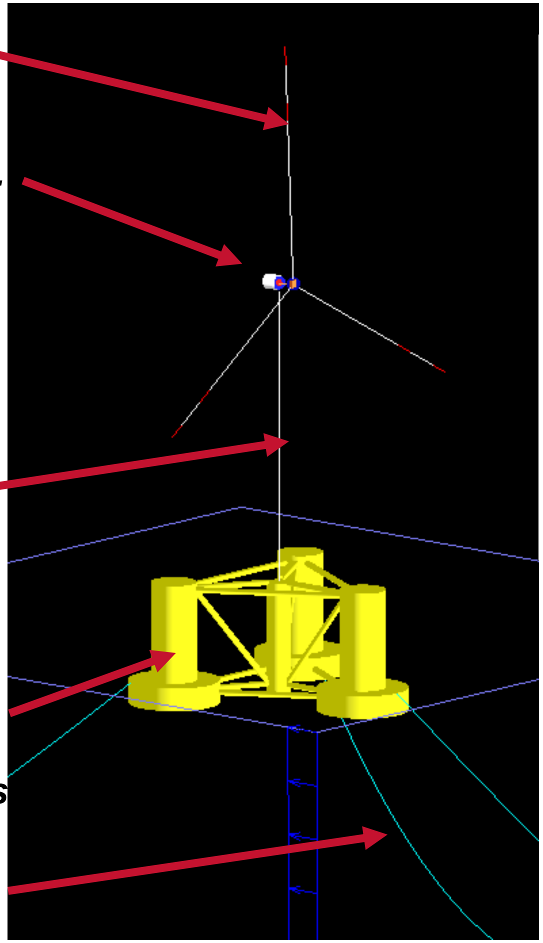
***Blades :***
***beam elements***

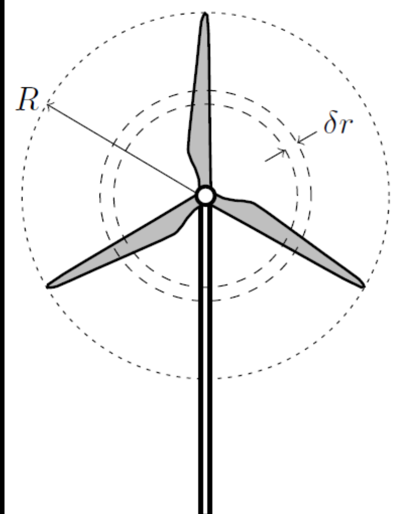
***Flexible nacelle / tower connection : flexjoint***

***Tower :***
***beam elements***

***Floater :***
***rigid floater or beam elements***

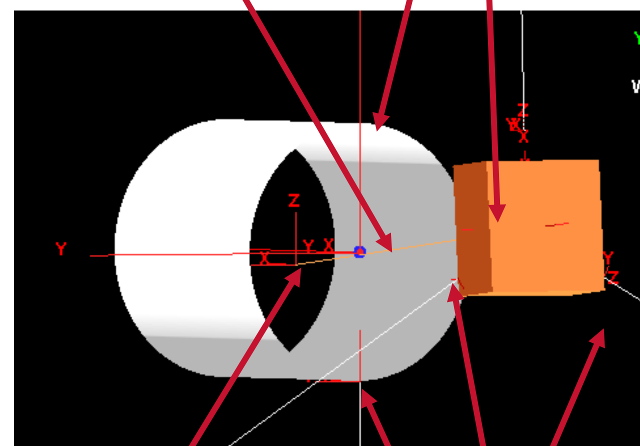
***Mooring lines***






***Hub and Nacelle :***
***rigid bodies***

***Low speed shaft :***
***beam elements***

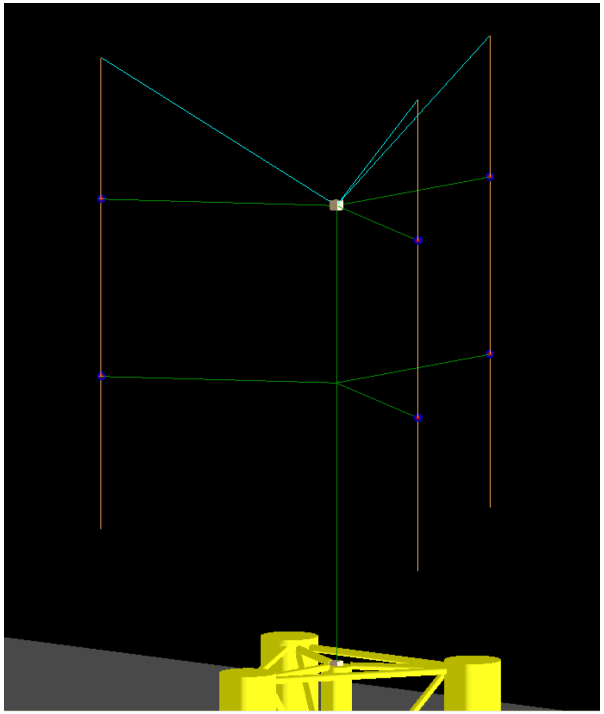


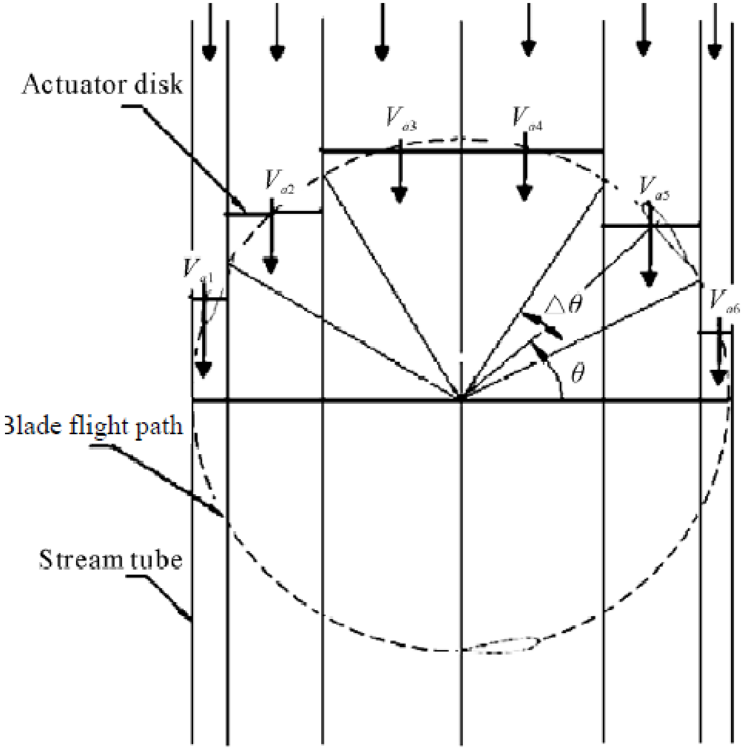
***Generator :***
***node control***

***Pitch/yaw actuators :***
***node control***

# VAWT

- **Blades, struts and tower: beam elements**
- **Control**
- **Specific aerodynamic models**



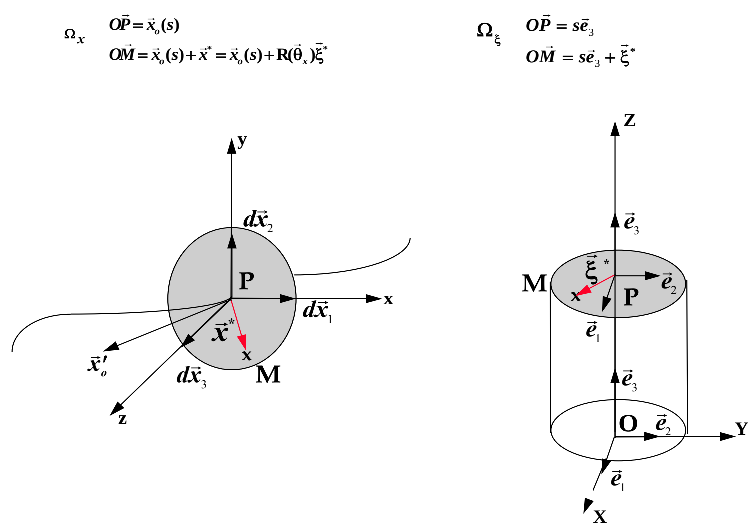


# FEM: Lagrangian Formulation

- **Defines the local reference at this node:** $\vec{d}_{xi} = \mathbf{R_x}(\vec{\theta}_x)\vec{e}_i$

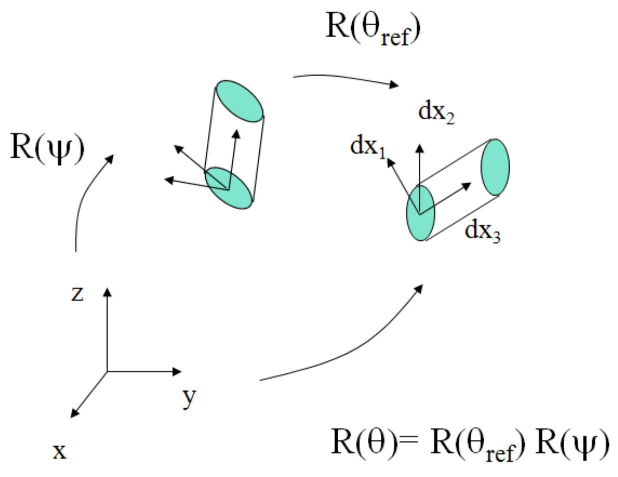
- **Let the rotation vector be** $\vec{\theta}_x = \begin{pmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \end{pmatrix}$ **and , the Rodrigues' formula is written as:**

$$\mathbf{R}_x(\vec{\theta}_x) = I_d + \frac{\sin\theta}{\theta}\begin{pmatrix} 0 & -\theta_3 & \theta_2 \\ \theta_3 & 0 & -\theta_1 \\ -\theta_2 & \theta_1 & 0 \end{pmatrix} + \frac{1-\cos\theta}{\theta^2}\begin{pmatrix} \theta_2^2+\theta_3^2 & \theta_1\theta_2 & \theta_1\theta_3 \\ \theta_2\theta_1 & \theta_1^2+\theta_3^2 & \theta_2\theta_3 \\ \theta_3\theta_1 & \theta_3\theta_2 & \theta_1^2+\theta_2^2 \end{pmatrix}$$



# Infinite rotation handling : 2 options

- **Option 1**
  - **Updated Lagrangian Formulation**
    - The reference is the previous step (static or time)
    - The unknowns are the variation from the reference position
  - **Problem : adaptation of the code**

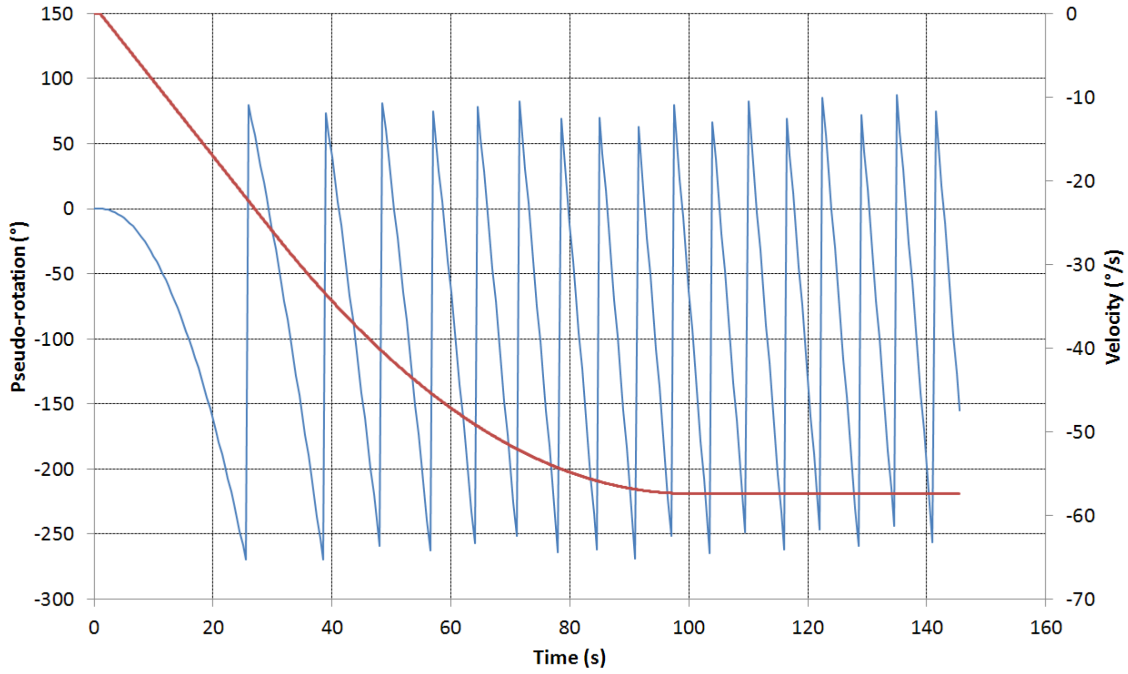



- **Option 2**
  - **Apply a transformation when necessary at the entrance of the step**
  - **Proposed by Cardona, A., Gerardin, M., 1988**
  - **Criteria on the norm of the pseudo-rotation vector to stay below 2π**
  - **Introduce an updated pseudo-rotation vector:**

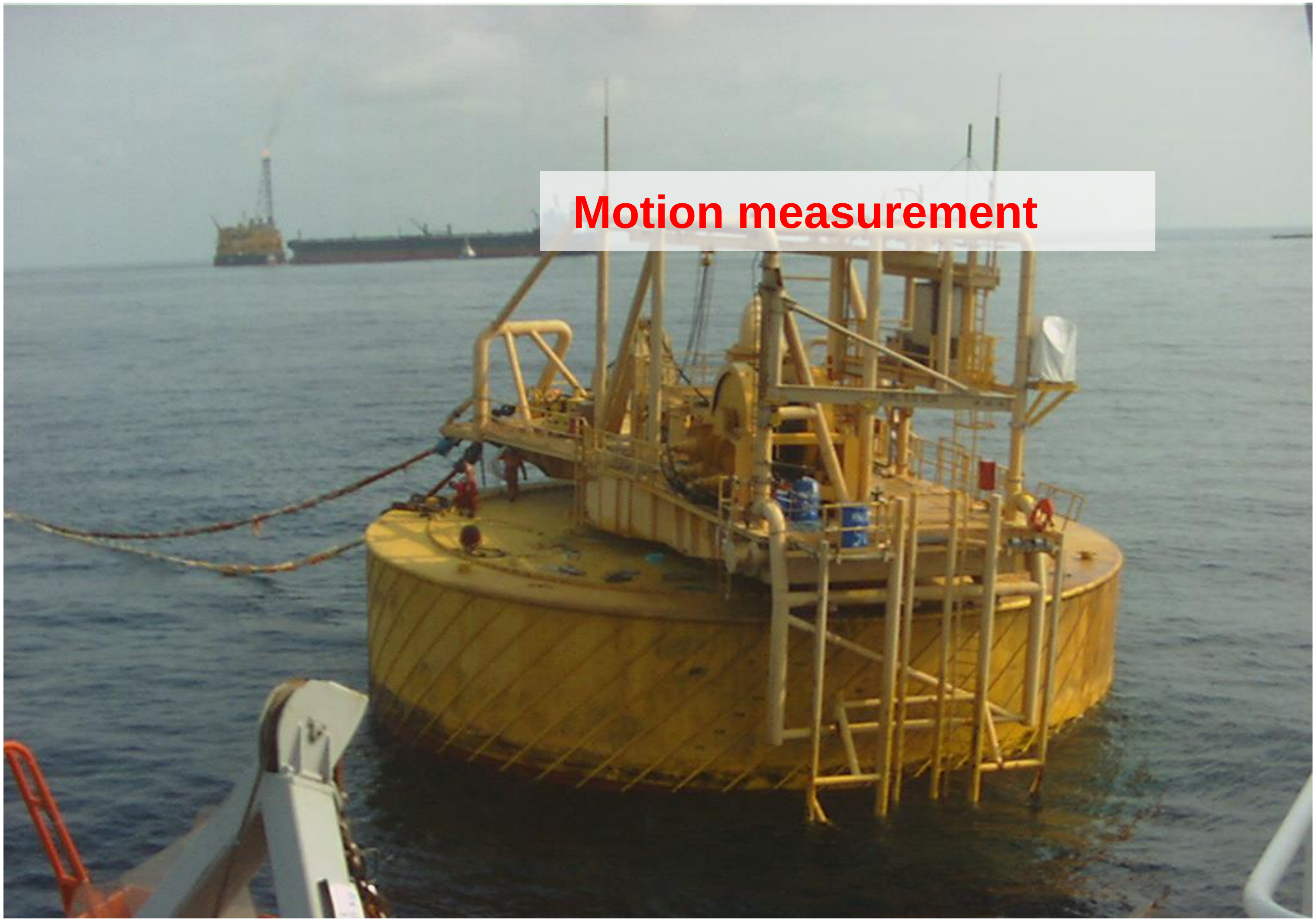
$$\vec{\theta}_x^* = \left(1 - \frac{2\pi}{\left\|\vec{\theta}_x\right\|}\right)\vec{\theta}_x$$

# Pseudo-rotation vector

- Pseudo-rotation vector becomes discontinuous with time at a given node
- The quantities rotational velocity and acceleration are continuous
- Numerical time marching scheme does not damp the results (constant rotational speed with constant moment)

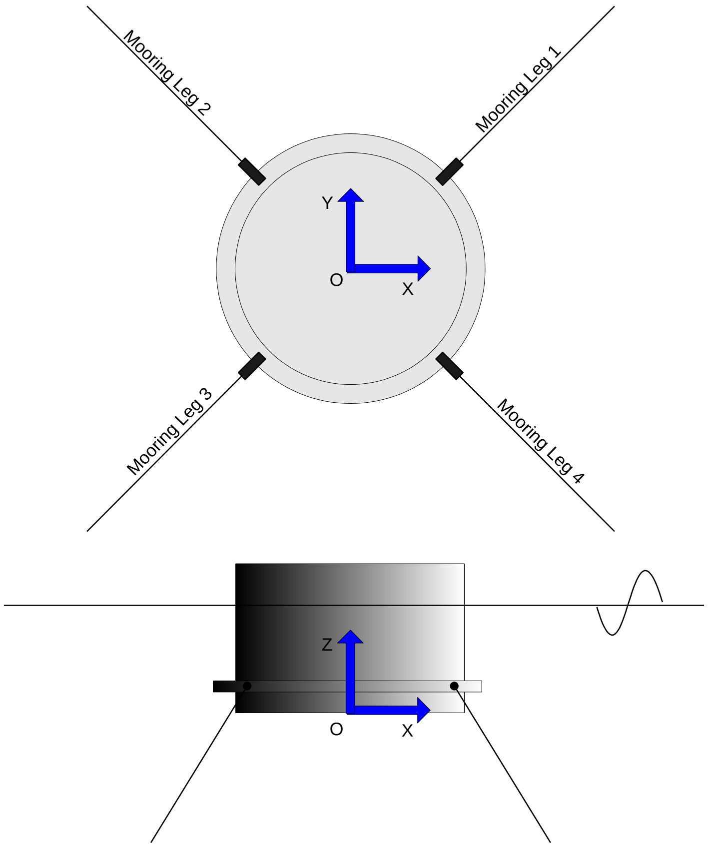


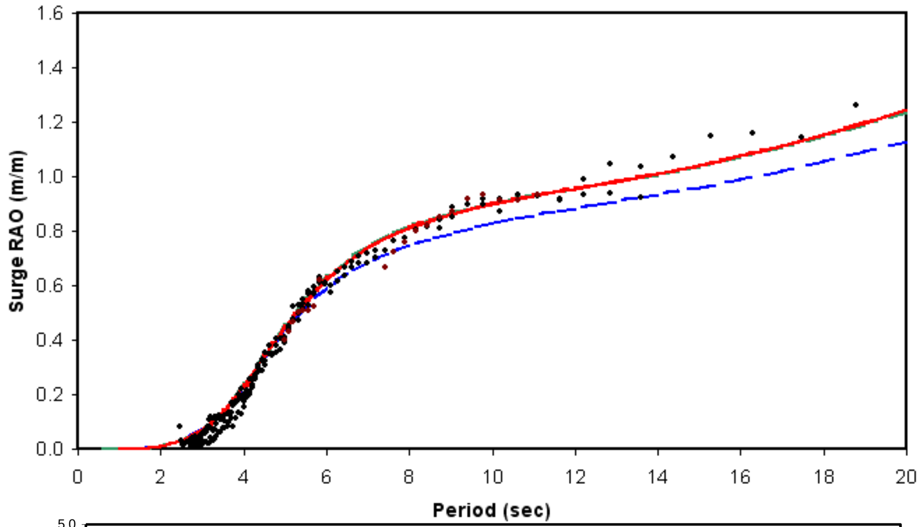
# Monitoring

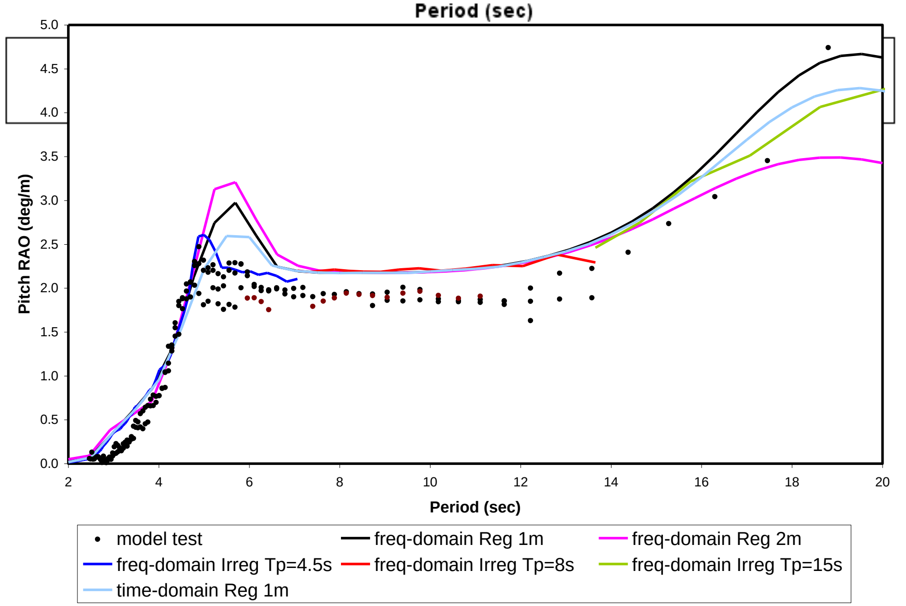


# Hydrodynamic/Mechanical coupling

- **Validation with respect to model test : anchored buoy coupled motion (2007)**

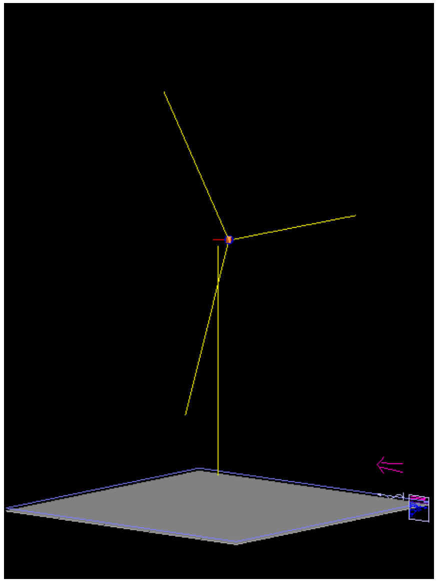


# Validation on OC3 cases Comparisons with FAST

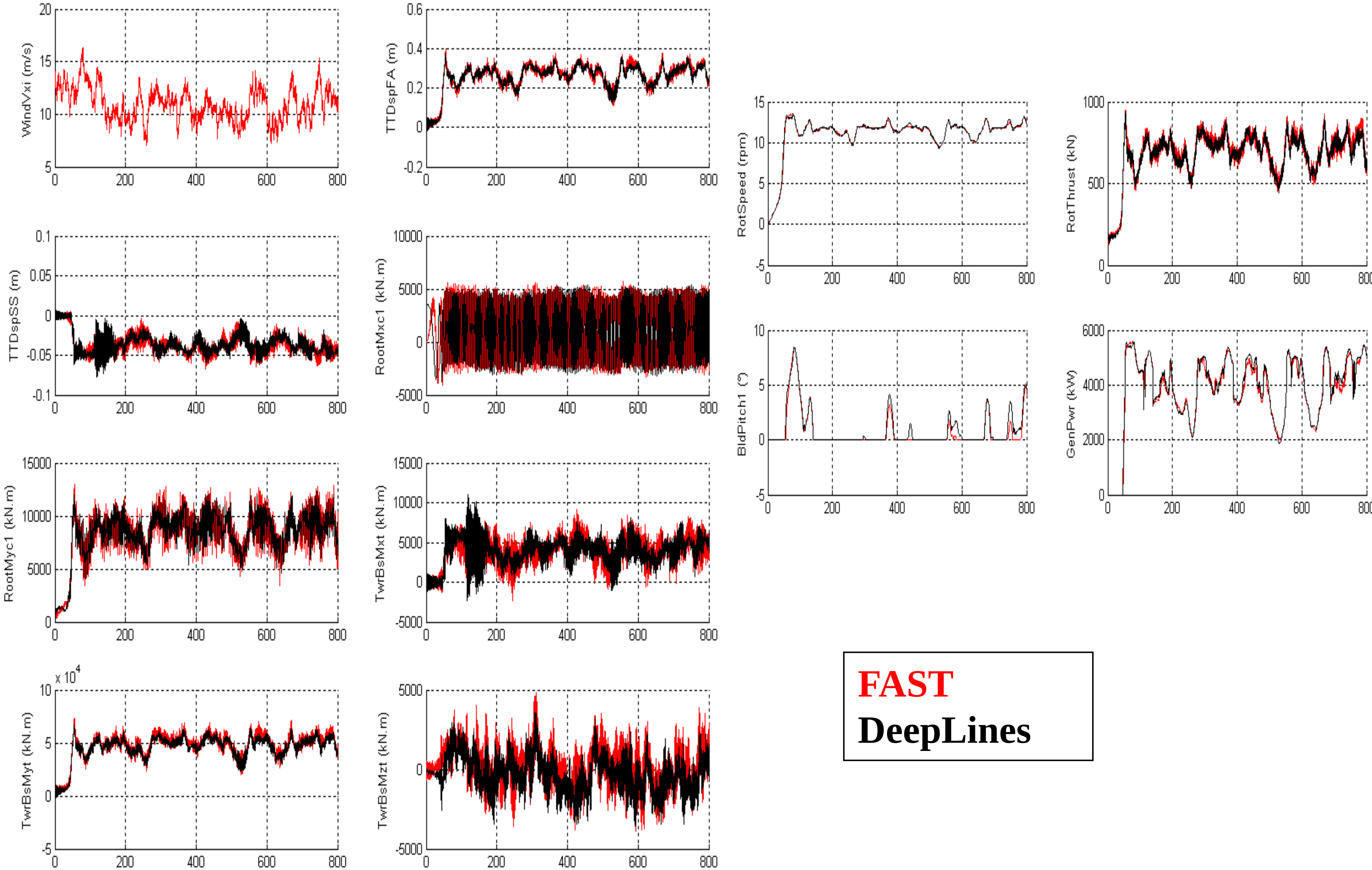
- **OC3 wind turbine with rigid foundation**
  - **Blades : 3 * 34 beam elements - damping 0.5%**
  - **Shaft : 1 beam element – damping 1%**
  - **Tower : 20 beam elements – damping 0.3%**
  - **Nacelle : rigid body (RB) with inertia matrix**
  - **Hub : RB with inertia matrix**
  - **Flexible tower / nacelle coupling**



- **Load cases**
  - **HH1: constant wind speed: 2-25 m/s – Vertical gradient 0.14**
  - **HH2: Linear ramp 5-50 m/s - yawed conditions @ 20°**
  - **HH3: Extreme operating gust 25m/s**
  - **NTM1: 3D turbulent wind - 11.2 m/s**

| Variable ID | Description | Unit |
|---|---|---|
| 'TTDspFA' | fore aft nacelle displacement | meter |
| 'TTDspSS' | side to side nacelle displacement | meter |
| 'RootMxc1' | blade root moment due to the rotor in plane forces | kN.m |
| 'RootMyc1' | blade root moment due to the rotor out of plane forces | kN.m |
| 'TwrBsMxt' | tower Base Moment due to the side to side rotor force | kN.m |
| 'TwrBsMyt' | tower Base Moment due to the rotor fore-aft force | kN.m |
| 'TwrBsMzt' | tower Base Moment in yaw | kN.m |
| 'RotSpeed' | rotor rotational speed | rpm |
| 'RotThrust' | rotor thrust | kN |
| 'BldPitch1' | blade pitch angle | ° |
| 'GenPwr' | generated power | kW |

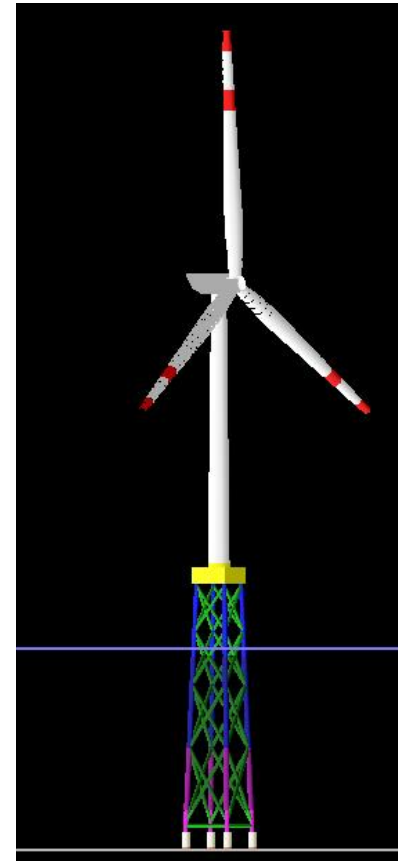
# NTM1 3D turbulent wind@11.2 m/s – time series



# OC4 phase 1 - LC 5.6

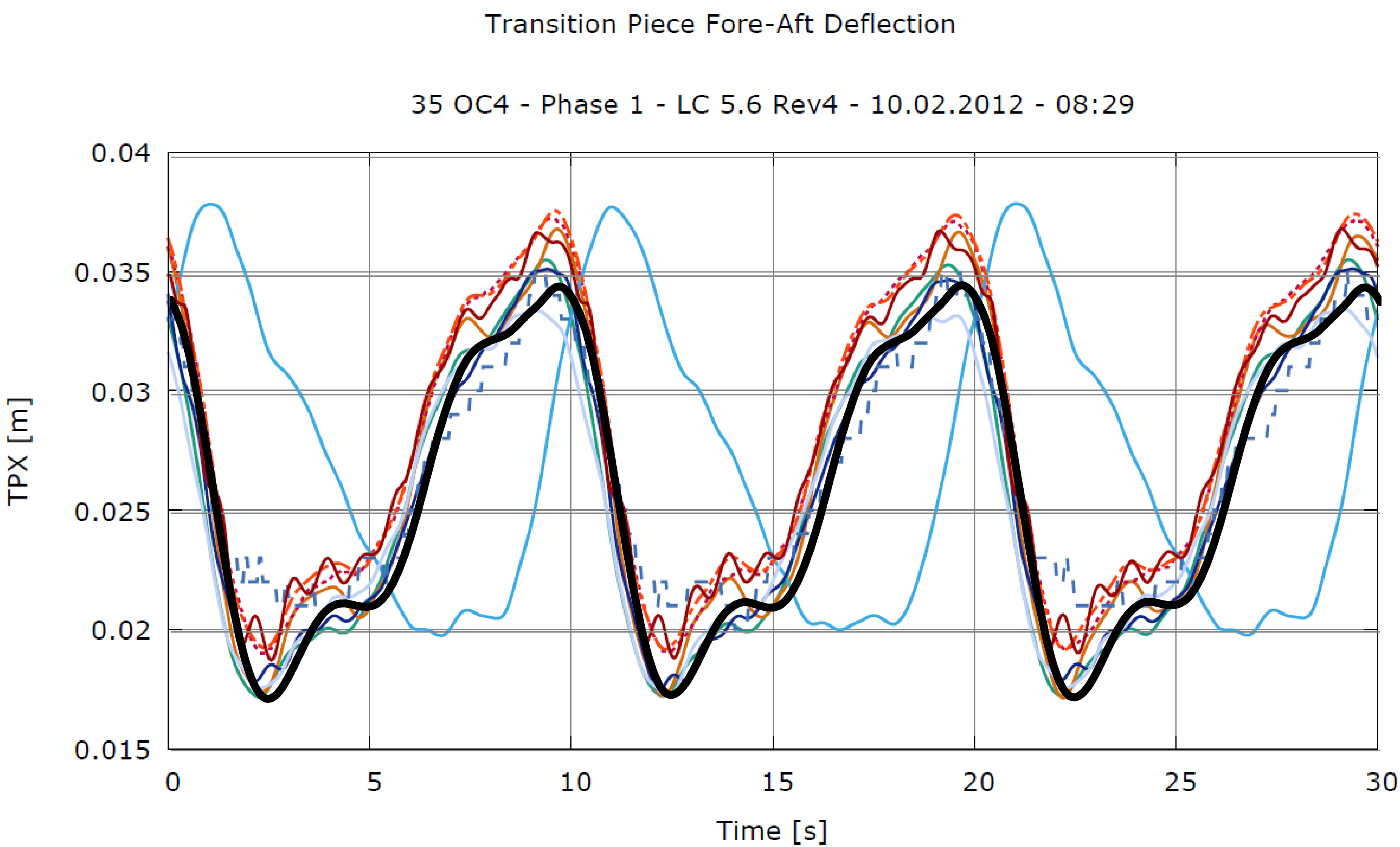
Fraunhofer IWES/ADCoS-Offshore
FEDEM/WindPower
POSTECH/Bladed V3.85
SWE/Flex5-Poseidon
CeSOS-NTNU/USFOS-vpOne
NTUA/GAST
LUH/Flex5-Poseidon-WaveLoads2
ABS/FAST-ANSYS
Risø DTU/HAWC2

**PRINCIPIA/ Deeplines WT**

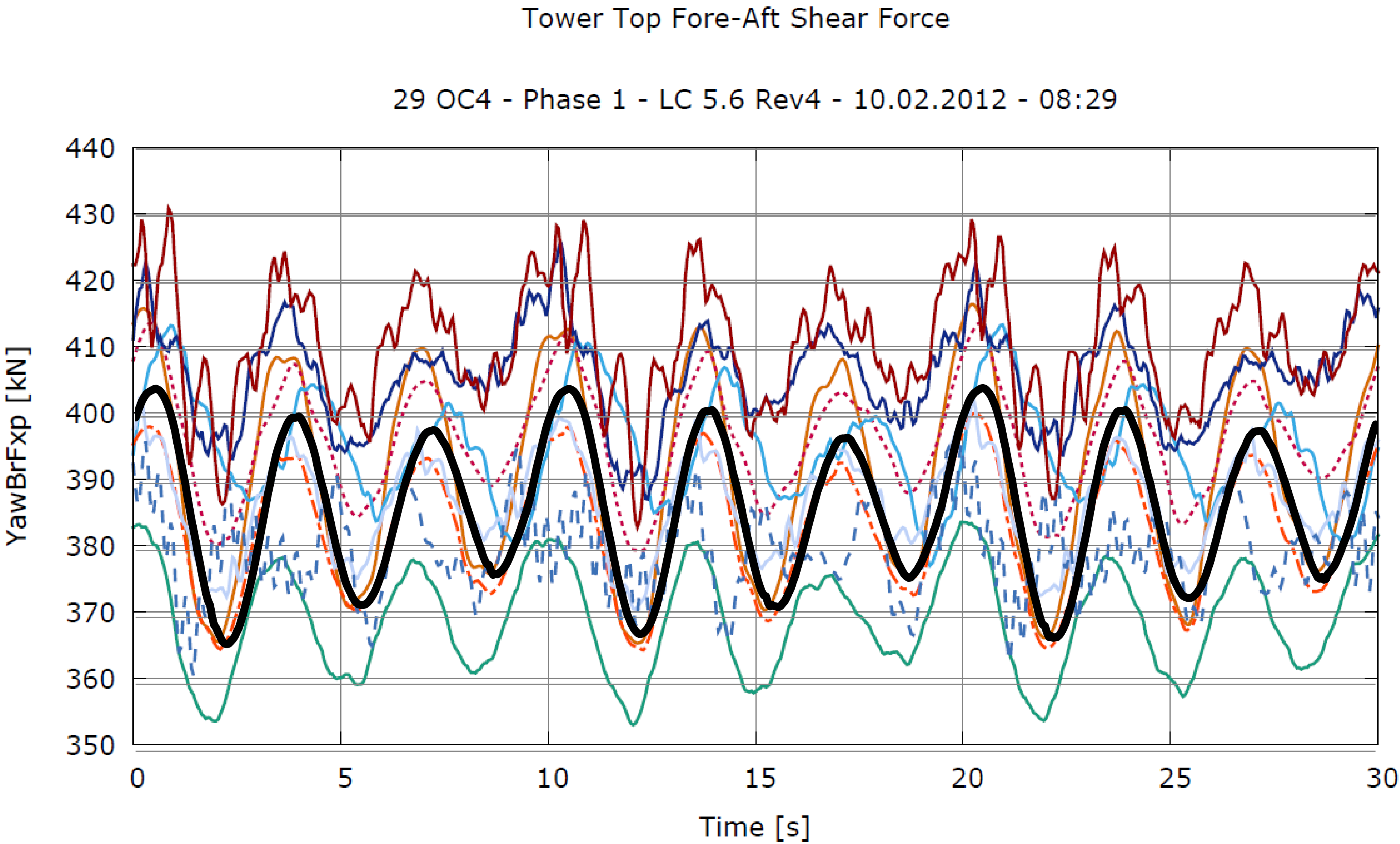


| Load Case | Enabled DOF | Wind Conditions | Wave Conditions | Analysis Type | Initial Conditions |
|---|---|---|---|---|---|
| 5.6 | All, Rotor speed and blade pitch via controller | Steady, uniform, no shear: $V_{hub} = 8\,m/s$ | Regular stream function (Dean, 9th): $H = 8\,m$, $T = 10\,s$ | Periodic time-series solution | $\Omega = 9\,rpm$<br>$\Phi = 0\,deg$<br>$\Theta = 0\,deg$<br>wave simulation starts from crest at $x = 0$, $y = 0$ (global system) |

# Structure Deflection



# Aero loads on Tower



# OC4 phase 2

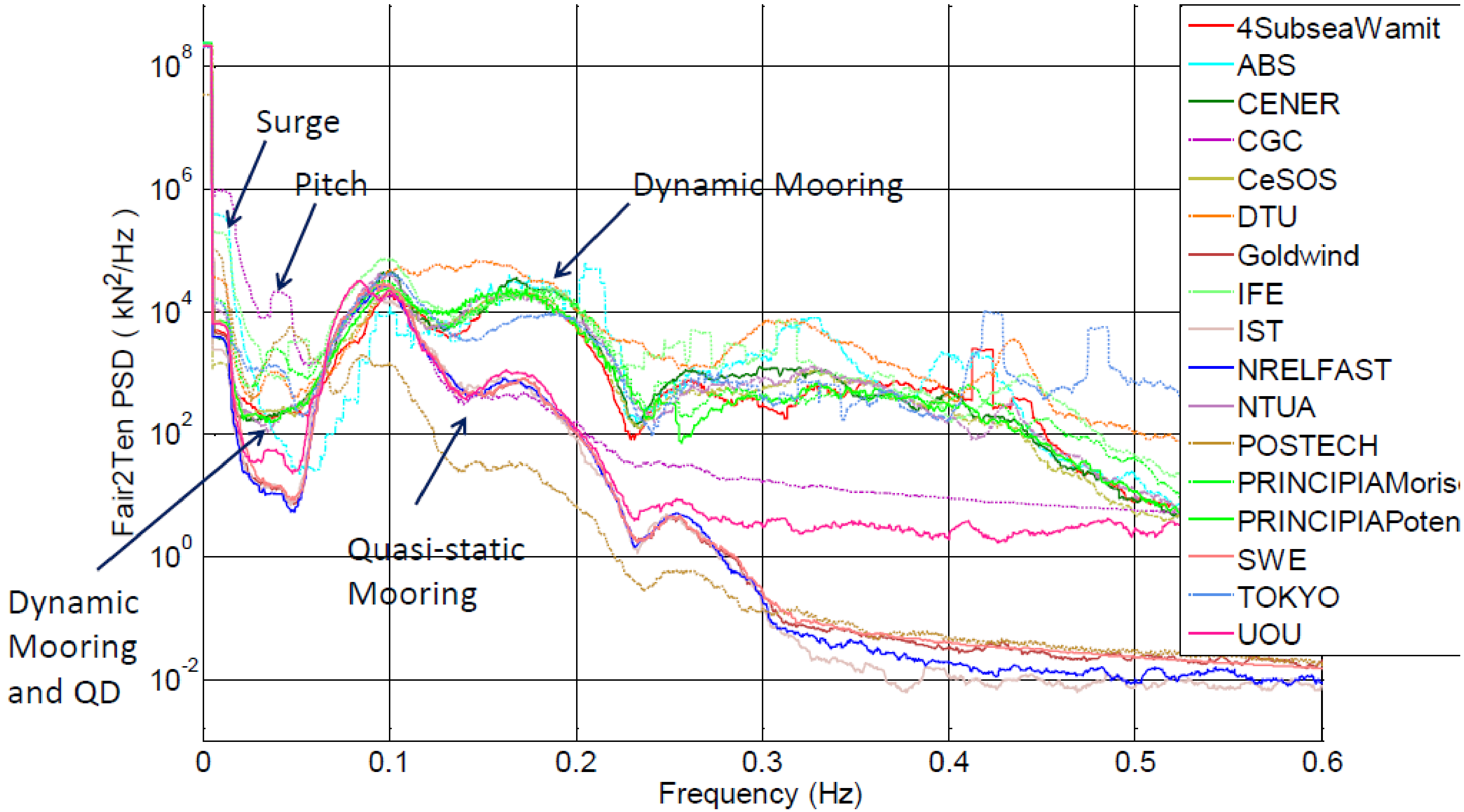
| Code |
|---|
| OrcaFlex |
| OrcaFlex |
| OrcaFlex |
| CHARM3D + FAST |
| OPASS + FAST |
| |
| Simo+Riflex+Aerody |
| Bladed 4.3 |
| WAMSIM |
| HAWC2 |
| Bladed 4.3 |
| FAST |
| 3DFLOAT |
| FAST |
| SWT |
| hydro-GAST |
| FAST |
| FAST + OrcaFlex |
| GH Bladed |
| DeepLinesWT |
| DeepLinesWT |
| SIMPACK |
| CAST |
| UOU + FAST |
| Wavec2Wire |

**Table 4: Load-Case Set 2, Inverted Pendulum**

| Load Case | Description | Enabled DOFs | Sim. Length | Wind Condition | Wave/Current Condition | |
|---|---|---|---|---|---|---|
| 2 | **Inverted pendulum** (flexible support structure; rigid nacelle, drivetrain, and rotor; generator locked) | | | | | |
| 2.1 | Deterministic waves | Support structure | 60 s | No air | Regular Airy: $H$ = 6 m, $T$ = 10 s | Time series |
| 2.2 | Stochastic waves | Support structure | 60 min | No air | Irregular Airy: $H_s$ = 6 m, $T_p$ = 10 s, $\gamma$=2.87, JONSWAP spectrum | Time-series-generated PDFs and PSDs |
| 2.3 | Current only | Support structure | N/A | No air | Surface = 0.5 m/s, 1/7$^{th}$ power law decrease with depth | Quasi-steady equilibrium position and loads |
| 2.4 | Current and deterministic waves | Support structure | 60 s | No air | Regular Airy: $H$ = 6 m, $T$ = 10 s waves; Current at surface = 0.5 m/s, 1/7$^{th}$ power law decrease with depth | Time series |
| 2.5 | 50-year extreme wave | Support structure | 60 min | No air | Irregular Airy: $H_s$ = 15.0 m, $T_p$ = 19.2, $\gamma$=1.05, JONSWAP spectrum | Time-series-generated PDFs and PSDs |
| 2.6 | RAO estimation, no wind | Support structure | 60 min | No air | White noise, $H_s$ = 6m | Time-series-generated "effective RAOs" |

# OC4 phase 2

## LC 2.2 – Irregular Wave – Mooring Response

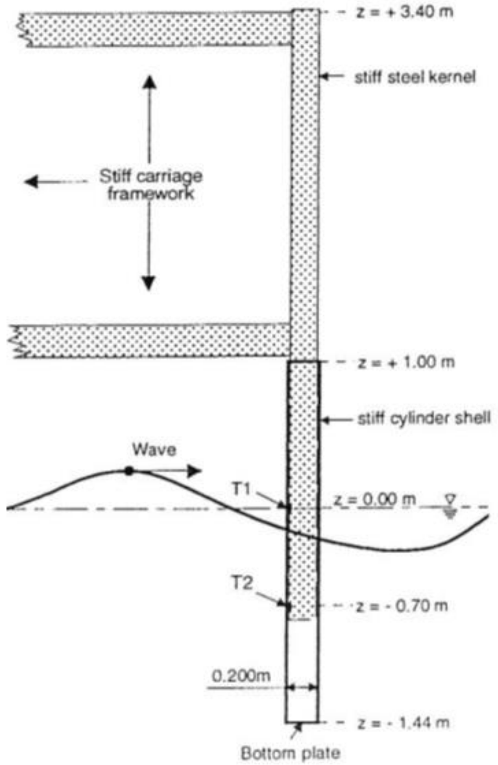


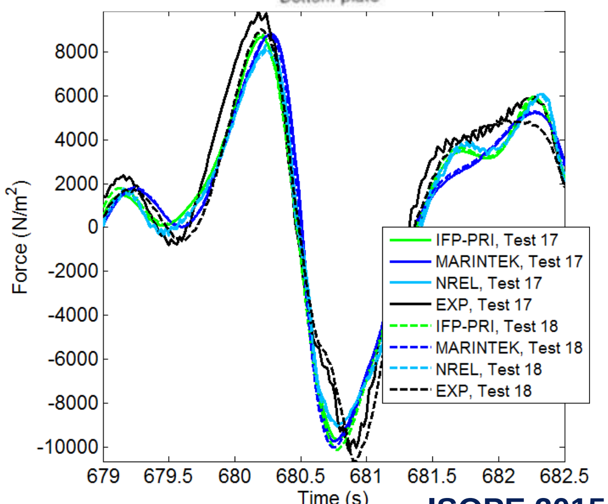

- Larger response for dynamic mooring models – excitation of mooring natural frequencies?
- Below wave frequency, Morison-based models show more response at platform frequencies
- At pitch frequency, see separation into three groups: QS+QD, Dyn+QD, Dyn+Mor

# OC5 phase 1 and 2

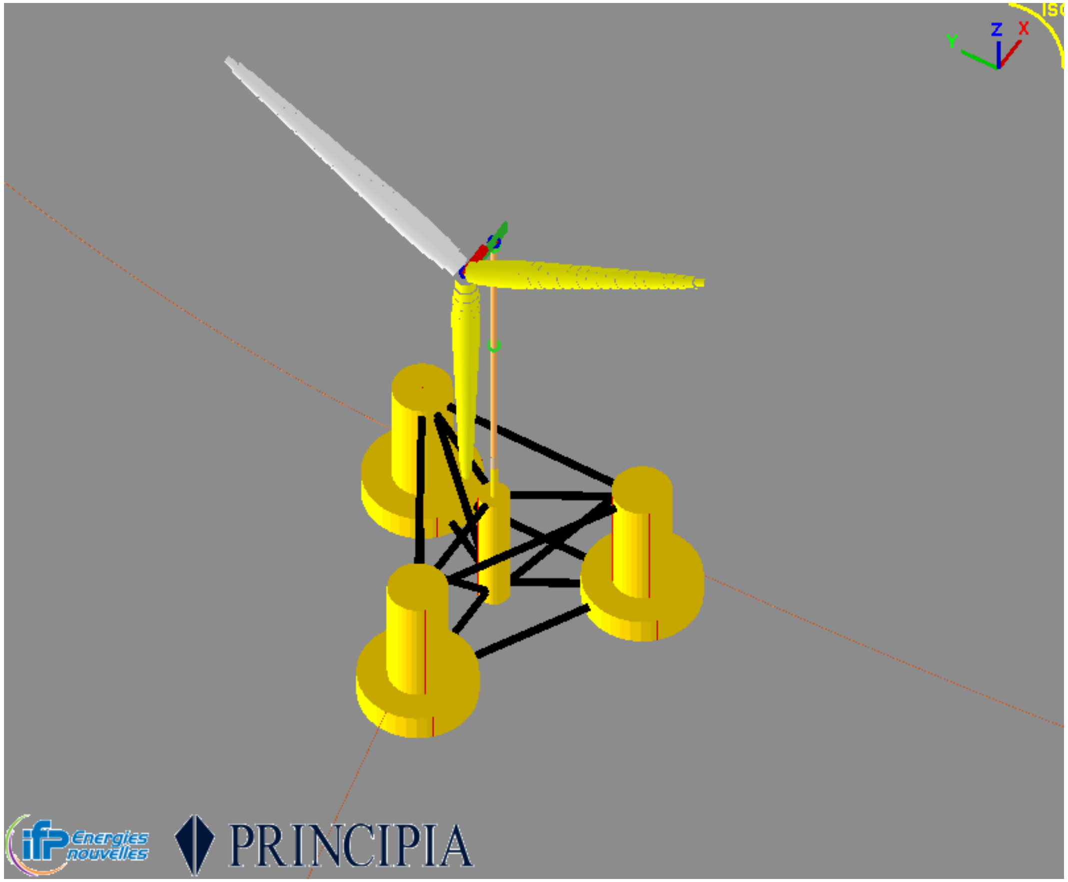
## Model test:

- **Wave Forces**
- **Floating windturbine**



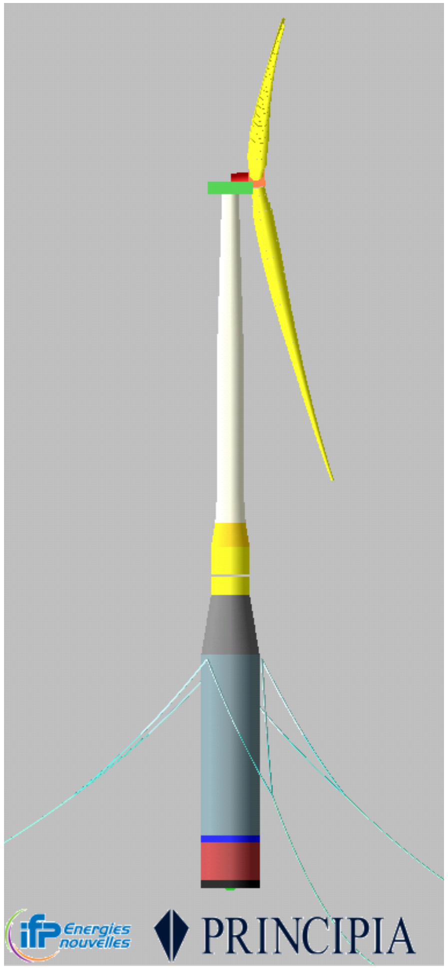




ISOPE 2015



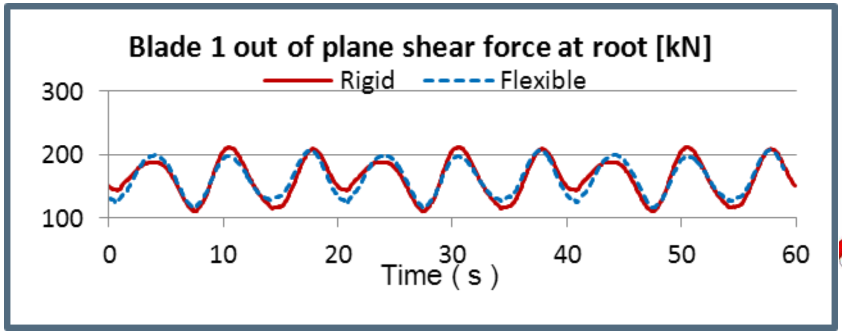
# Statoil Hywind

- Beam model: mooring lines, floater, tower, blades, shaft,…
- Floater beam modeling calibrated with a potential model
- Time domain simulation of the whole coupled system (hydro/aerodynamic loadings and turbine controller)
- Large number of ULS, FLS & ALS analyses
- Verification of design criteria (acceleration, pitch, offset, angles, etc…)
- Mooring design (extreme and fatigue)
- Floater, Tower design (extreme and fatigue)
- Comparison and verification of the simulations with Company and turbine manufacturers' software.

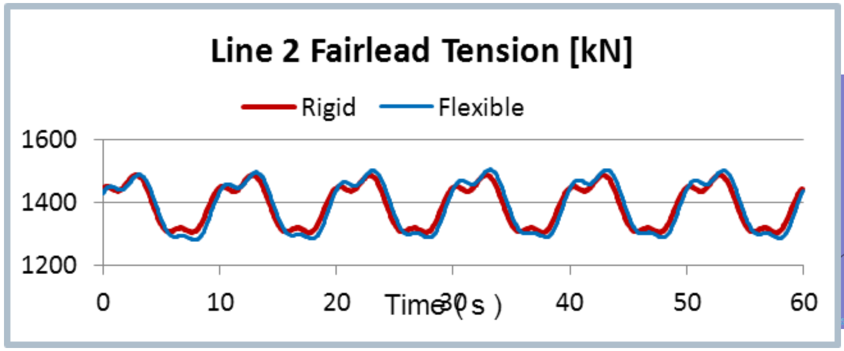


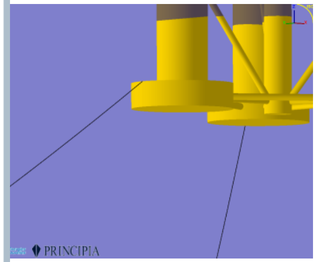
# Hydrodynamic

Low impact on blade loads



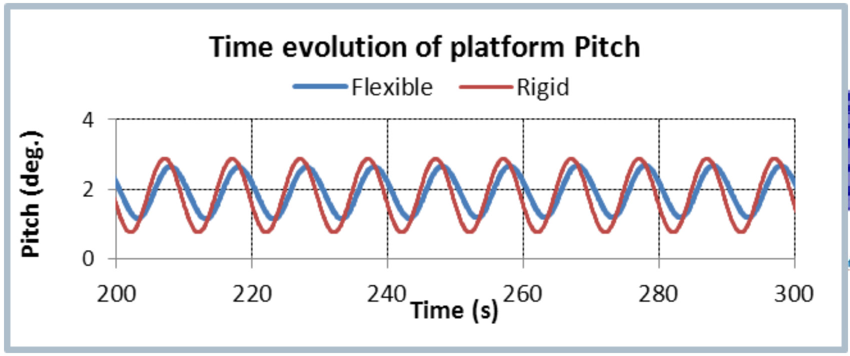

Low impact on Mooring lines

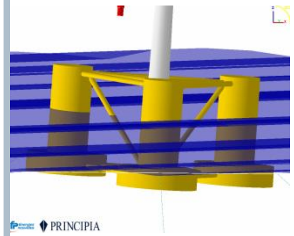


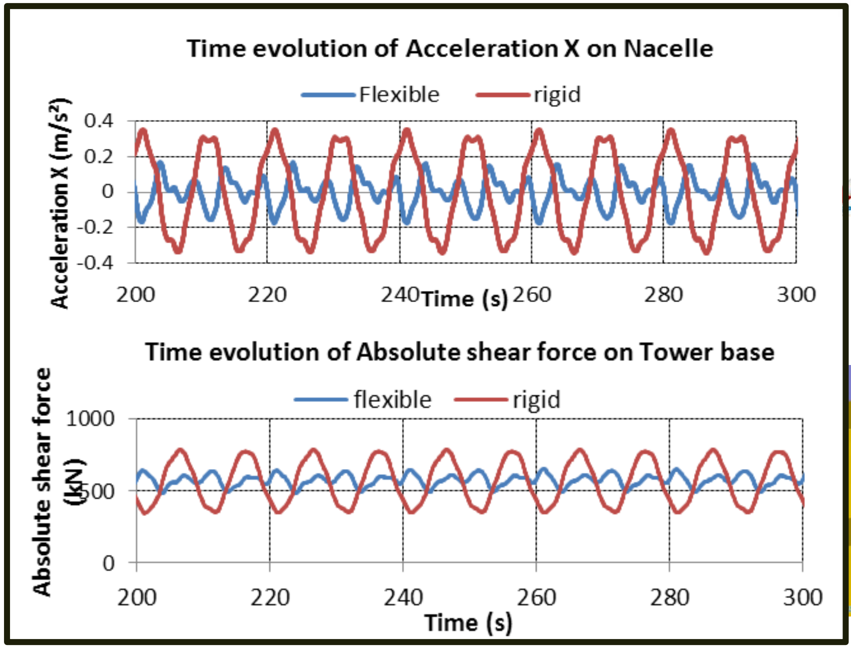
# Hydrodynamic

**Low impact on platform motions** (for usual wave loadings)

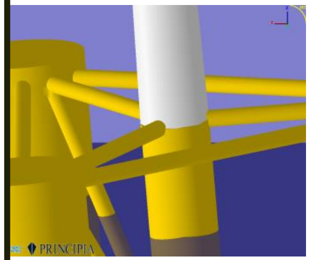



**Considerable impact on**
**Nacelle acceleration**
**Tower loads**
**platform loads**







# Control

- Bladed Interface
- Specificity of floating turbine
- IT issues

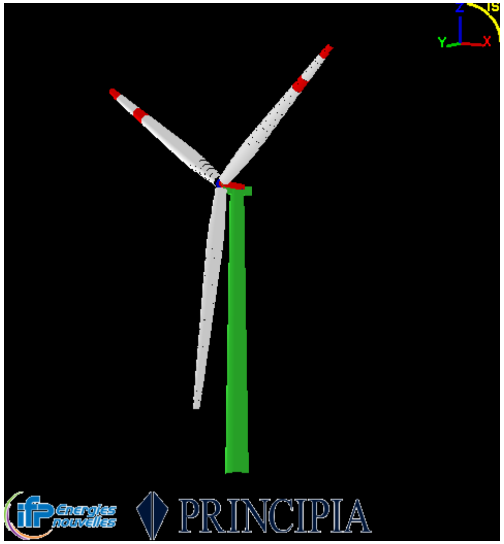
# Cross Validation

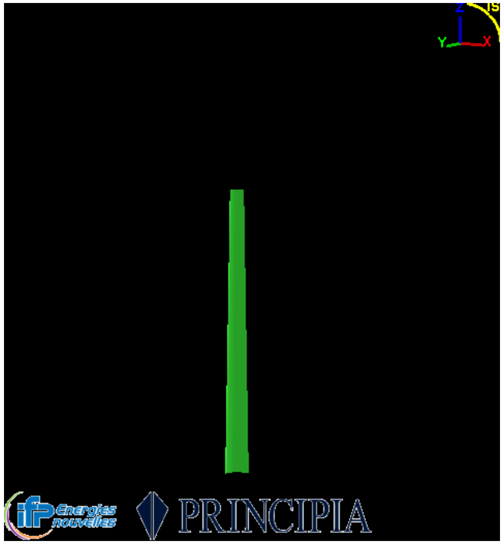
- Aerodynamic / Controller
  - Onshore cases
  - Offshore cases
- Hydrodynamic
  - Model Tests
  - Prototypes

- Hydrodynamic simplified model

# Simplified aerodynamic model

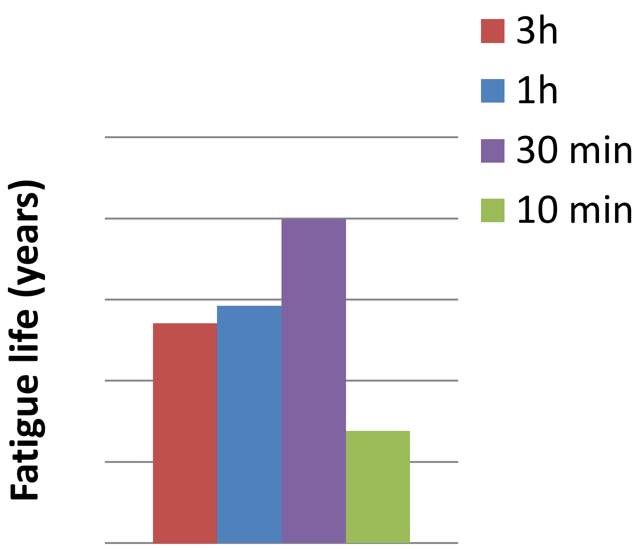
- Turbine / Cd / Constant load
- Extreme / Fatigue analysis

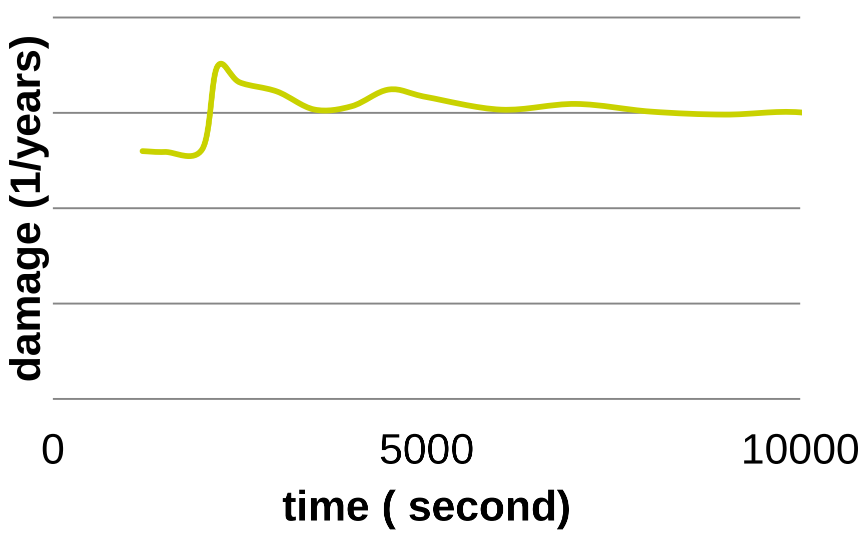




# Load Cases

- Turbine vs Mooring / Structure design
- 10 min / 3 hours



# Conclusion

- **Floating wind turbine**
  - **Interaction of two disciplines**
  - **Two designs in one with their own focus**
  - **Communication / Feedback**
- **Model**
  - **Keep in mind the objective of your model**
  - **Choose the proper simplifications**