AERODYNAMIC DAMPING OF A HAWT ON A SEMISUBMERSIBLE

Effect of aerodynamic loading on the motions of the OC4-semi in waves

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OUTLINE

- How MARIN is helping developers of floating wind turbines?
  - Model-tests
  - Simulations
- From 'concept design' to validated model 'Model of the model'
  - Example of the OC4-semisubmersible
  - Sensitivity to change in inertia
  - Sensitivity of the model to rotor force coefficients
- Conclusions
- Further work

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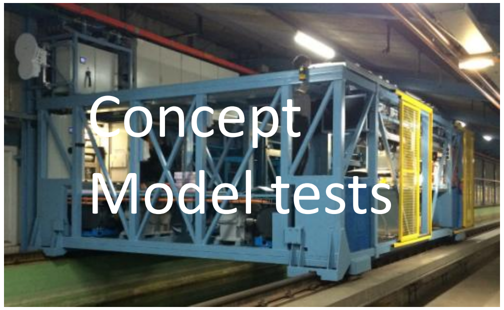
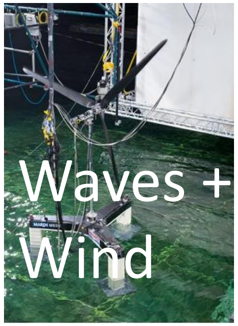
FLOATING WIND AT MARIN

Model tests





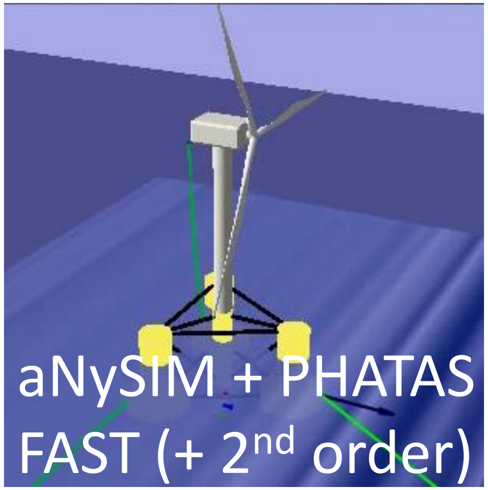
Scaled wind

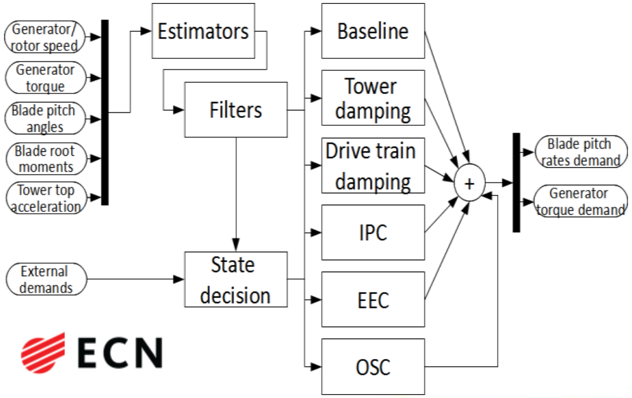
Scaled thrust

Model of the model

Numerical studies

CFD for wind set-up, blades





My objectives:

- R&D: What does matter for the floater?
- BU: Verification => Concept study

‘MODEL OF A MODEL’

- A concept design evolves before and after the model-tests (different mass distribution, different turbine, etc…)
- A turbine is available for model-testing in wave and wind (but the actual wind turbine may be slightly different)
- While modeling wind & waves, a new scaling approach is followed (‘performance scaling for the rotor’). This has an impact an the aerodynamic performance of the turbine.

⇒ Use model-test data to calibrate a numerical model = ‘Model of the model’

⇒ What is the influence on the motions of a OFWT of all these differences?

MODEL OF THE OC4 SEMISUBMERSIBLE

- Differences?
  - (Design) OC4-SEMI
  - (Built) OC5-SEMI

⇒ "Model of the model"

Designation	Symbol	Unit	Values	
			OC4 Calculated	OC5 As-built
Draft	T	m	20.0	20.0
Mass	M	ton	14,260	13,958
Centre of Gravity above keel	KG	m	9.96	11.93
Longitudinal metacentric height	GM_L	m	7.34	5.29
Roll radius of gyration in air	k_{xx}	m	32.07	32.63
Pitch radius of gyration in air	k_{yy}	m	32.94	33.38
Yaw radius of gyration in air	k_{zz}	m	31.83	31.32
Natural pitch period (moored)	T_θ	s	25.1	32.1
Natural heave period (moored)	T_z	s	17.0	17.2

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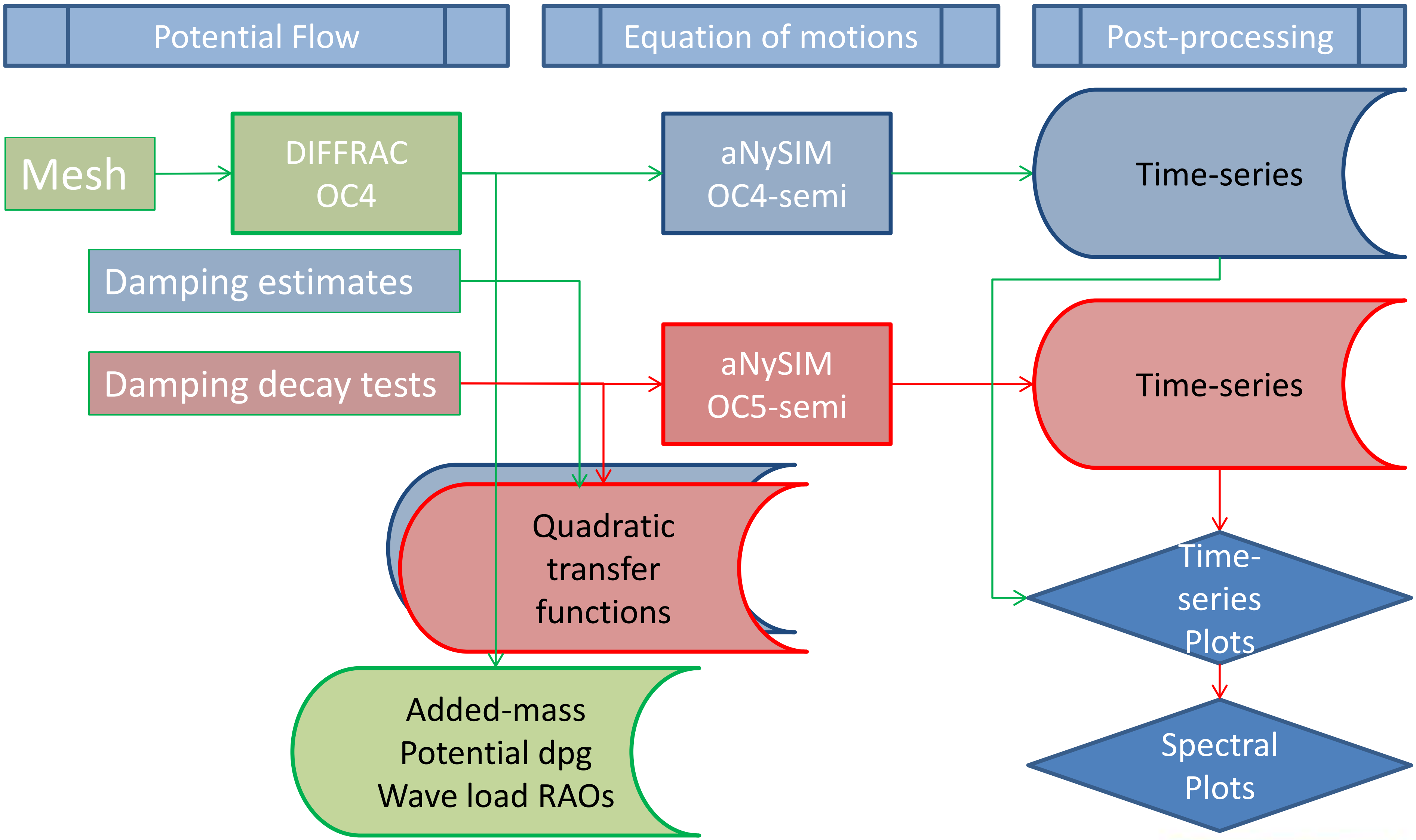
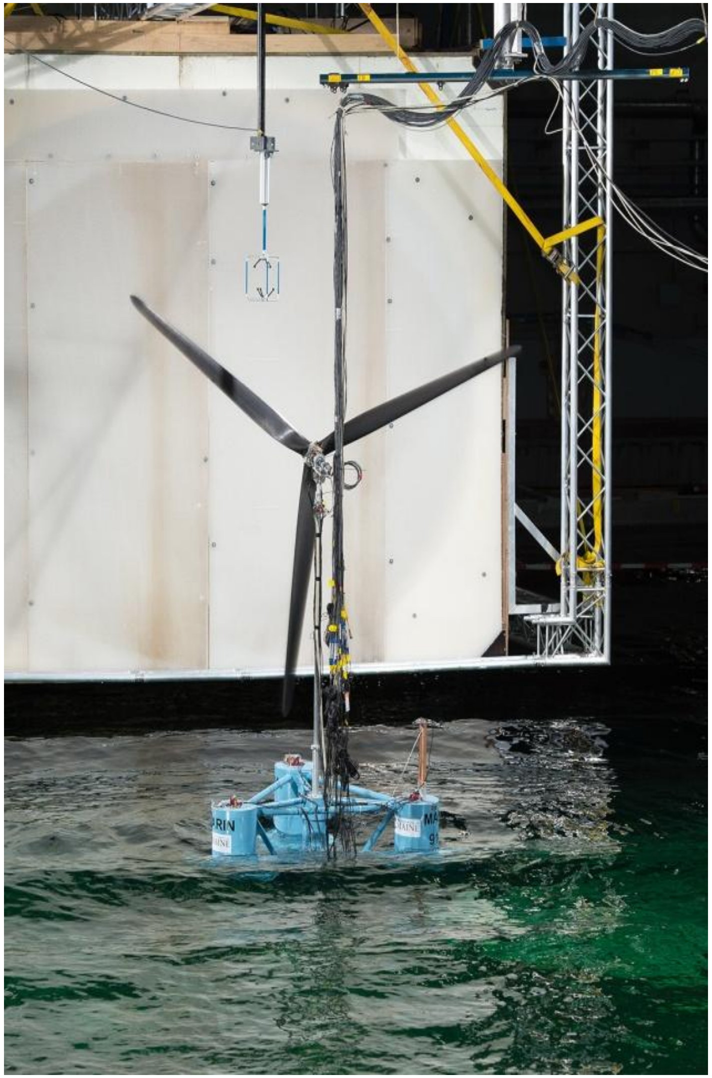
CALCULATION PROCESS & POST-PROCESSING



POTENTIAL THEORY RESULTS IN WAVES



Load case:

- Long-crested waves
- JONSWAP Hs = 7.1 m Tp = 12.1 s

Comparison of simulations for:

A. *OC5 = calibrated model*
B. *OC4 = original 5MW*
C. *Measurements*

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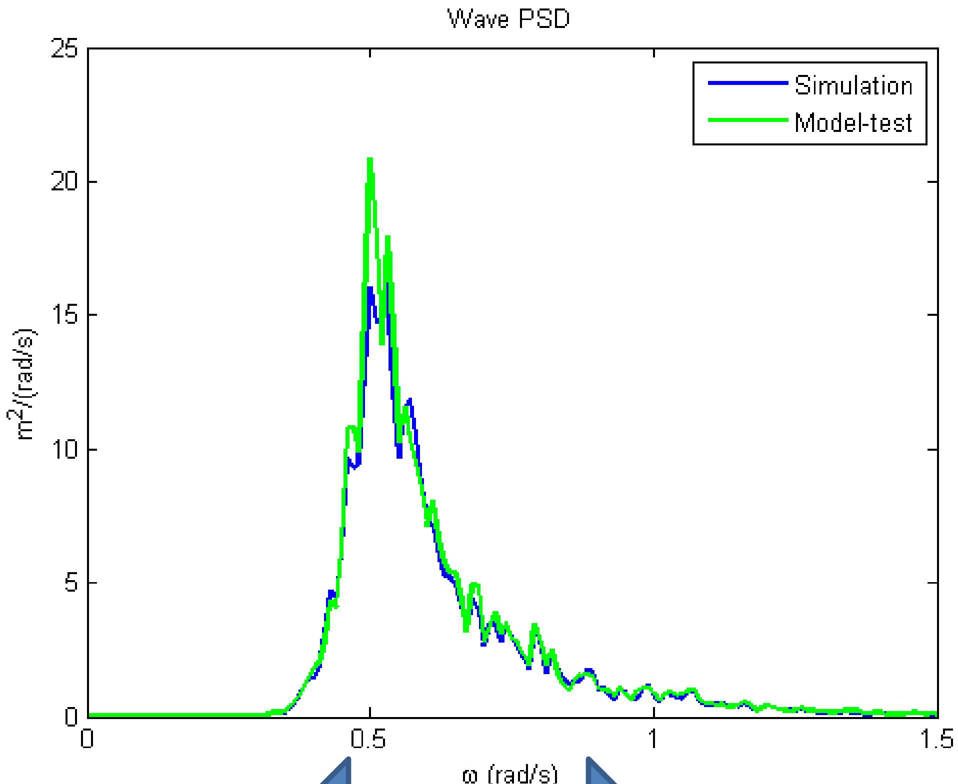
VERIFICATION OF HYDRODYNAMIC RESPONSE

- Operational sea, head waves



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VERIFICATION OF HYDRODYNAMIC RESPONSE

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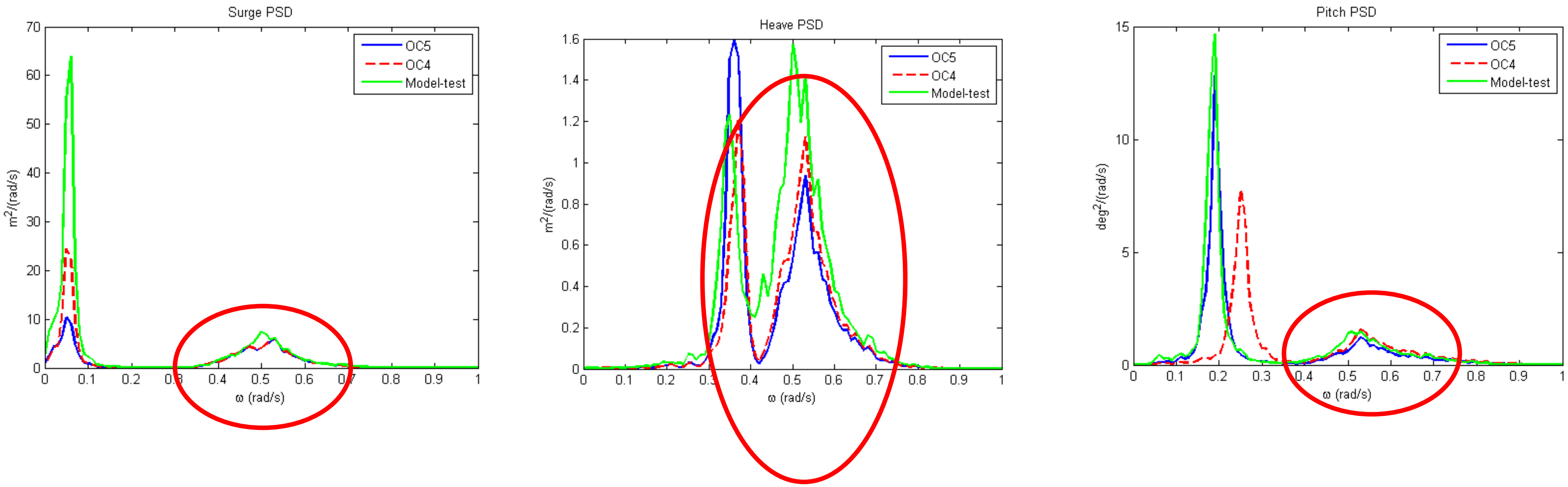
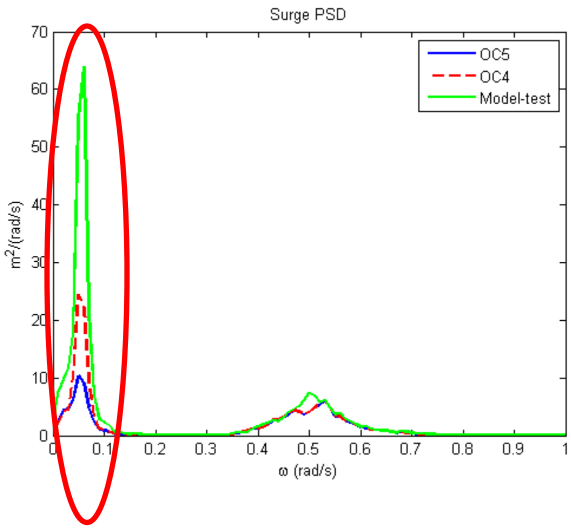
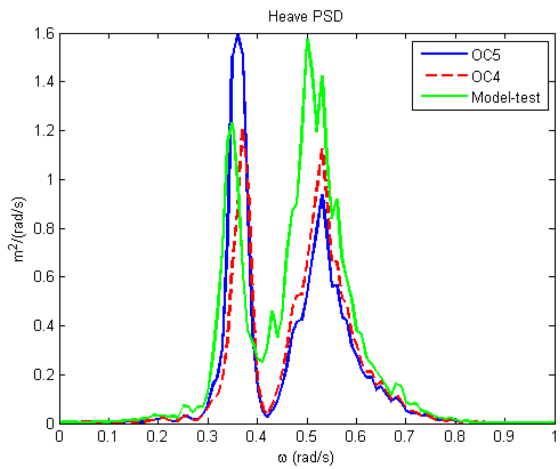


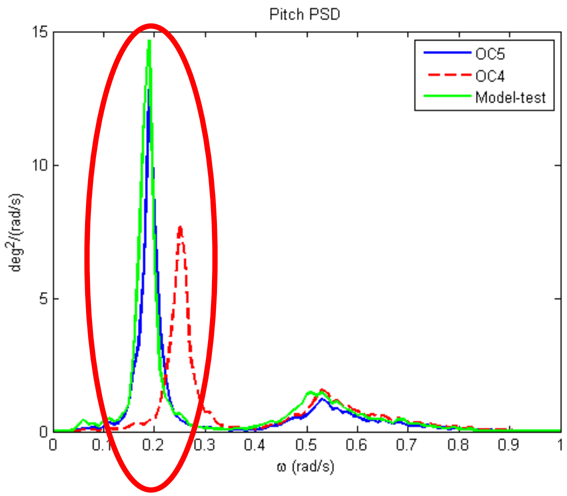
- Response in wave energy range (1st order) are similar

VERIFICATION OF HYDRODYNAMIC RESPONSE

- Operational sea, head waves



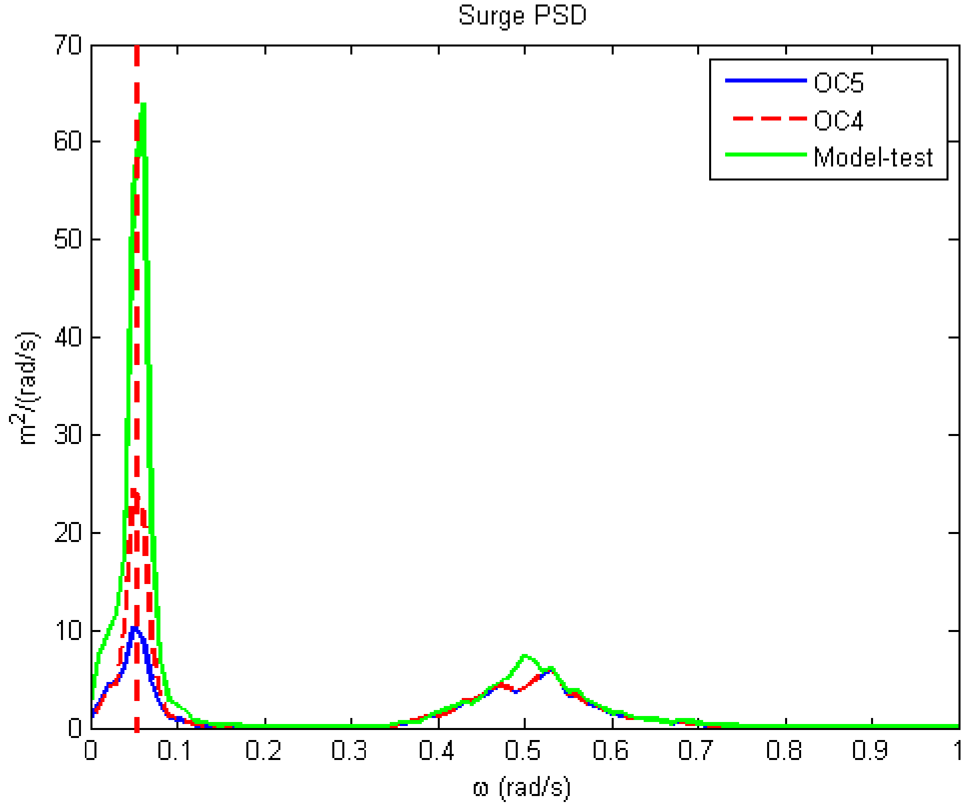




- Response in low frequency range (2nd order) are different
- Difference at resonance (surge, heave & pitch)

COMPARISON: MODEL OF THE MODEL

- OC5 Calibrated / OC4 Design / Model-test data



- Surge resonance peak of simulations are different and much smaller than in the model-test data.

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COMPARISON: MODEL OF THE MODEL

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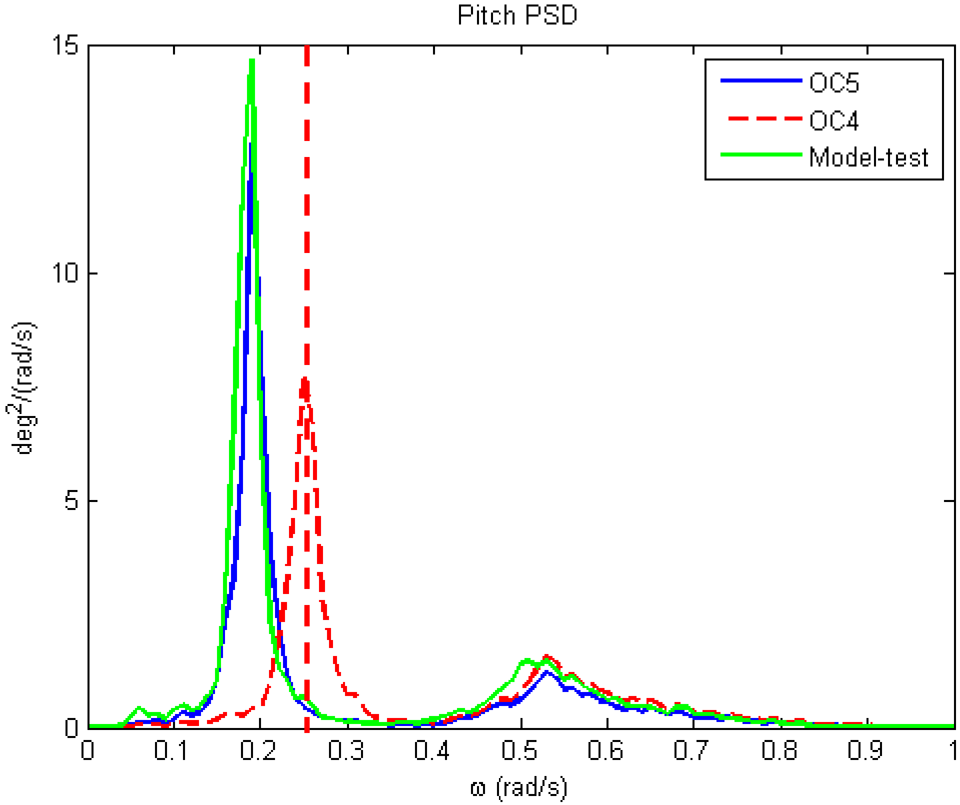
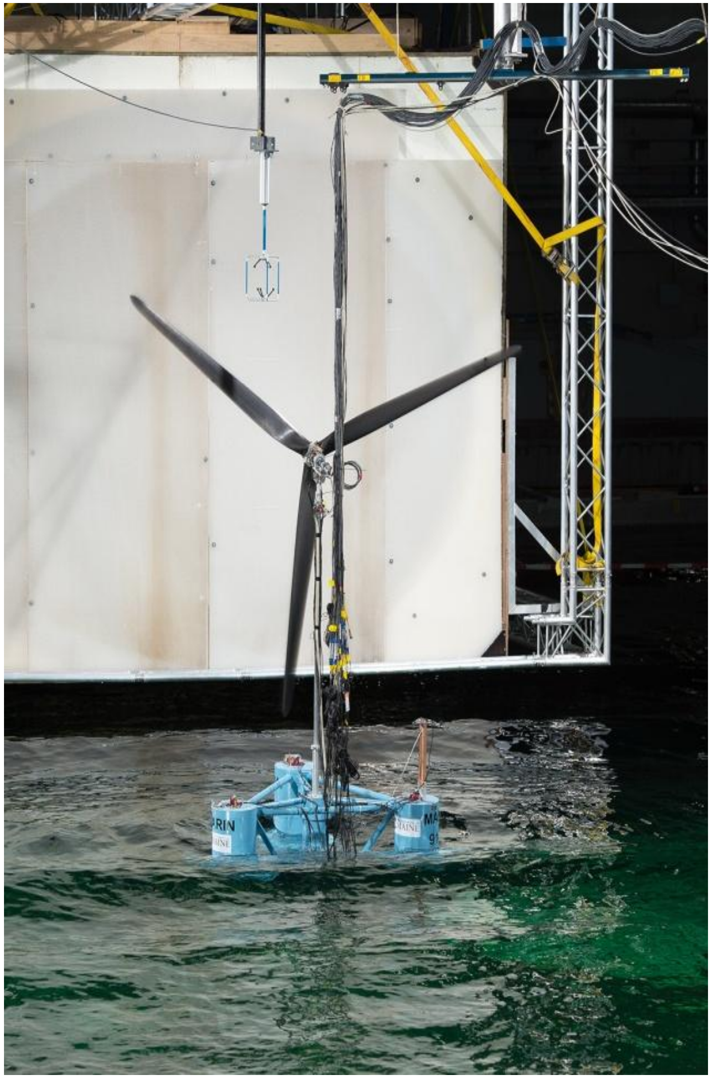


- Pitch resonance peak are different:
  - OC4 < model-test

BEMT RESULTS IN WAVES & WIND



Load case:

- Co-linear waves and wind
- JONSWAP Hs = 7.1 m Tp = 12.1 s
- Wind speed V = 13 m/s
- Rotor fixed rpm = 12.1
- Blade pitch angle = 1 deg

  => TSR = 6.156

Comparison of simulations for:

A. OC4 design (XFOIL @ FS)
B. OC5 model (UMaine @ MS)
C. OC5 model (ECN RFOIL @ MS)

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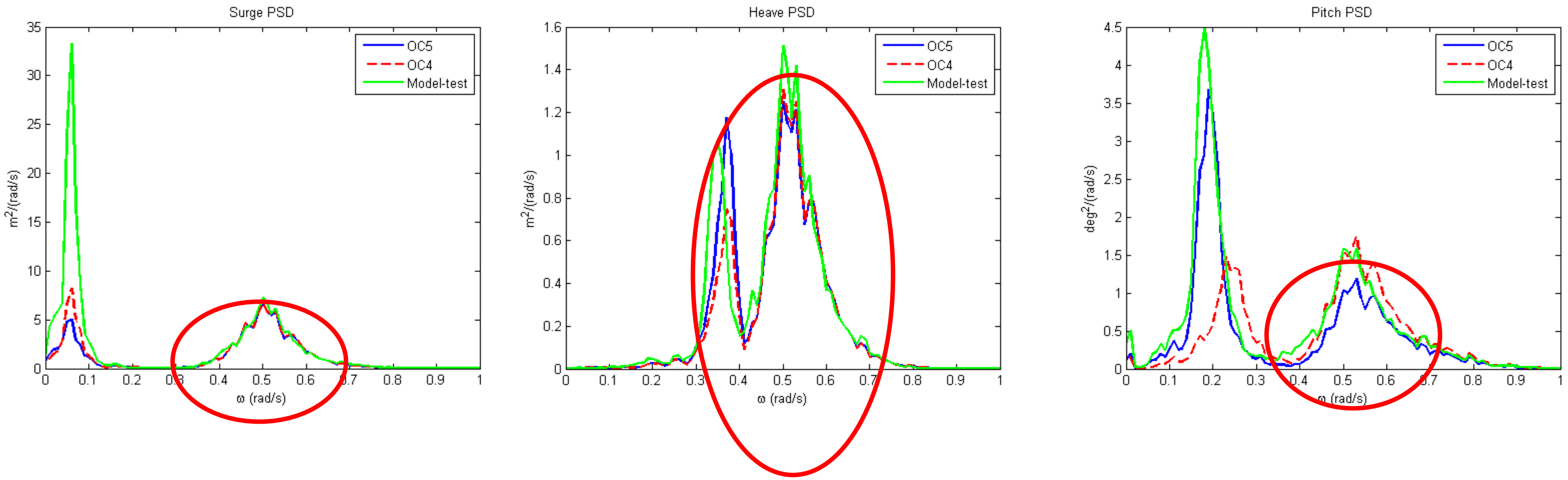
VERIFICATION OF RESPONSE IN WIND & WAVES

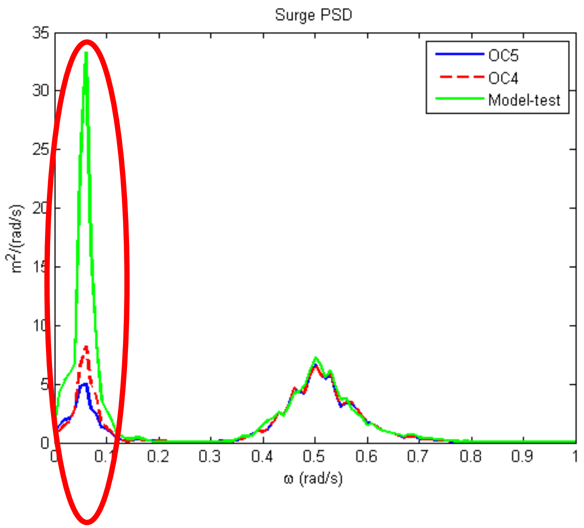
- Operational sea + steady wind, head waves

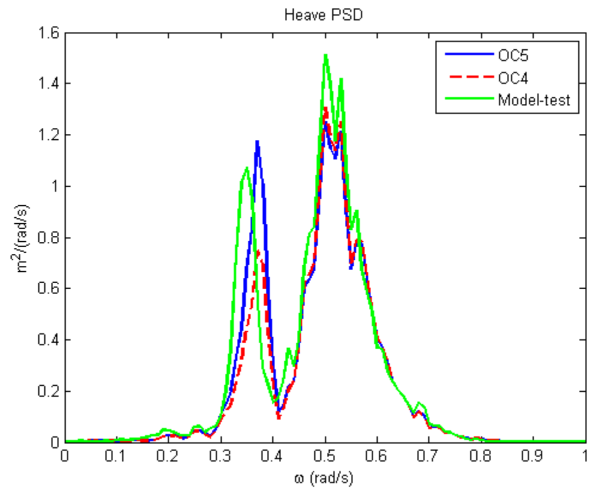


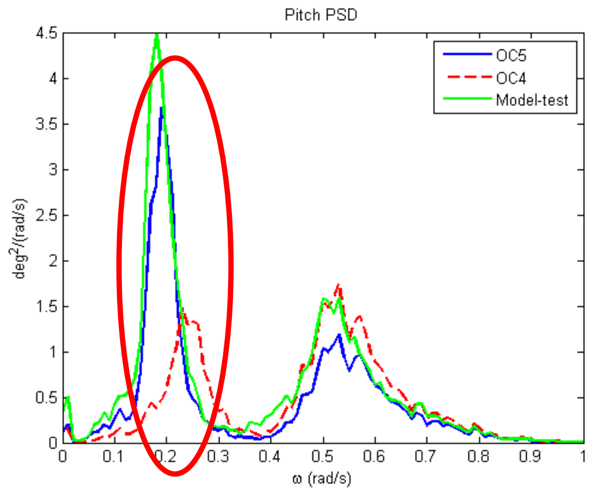
- Response in wave energy range (1st order)

VERIFICATION OF RESPONSE IN WIND & WAVES

- Operational sea + steady wind, head waves







- Response in low frequency range (2^{nd} order)

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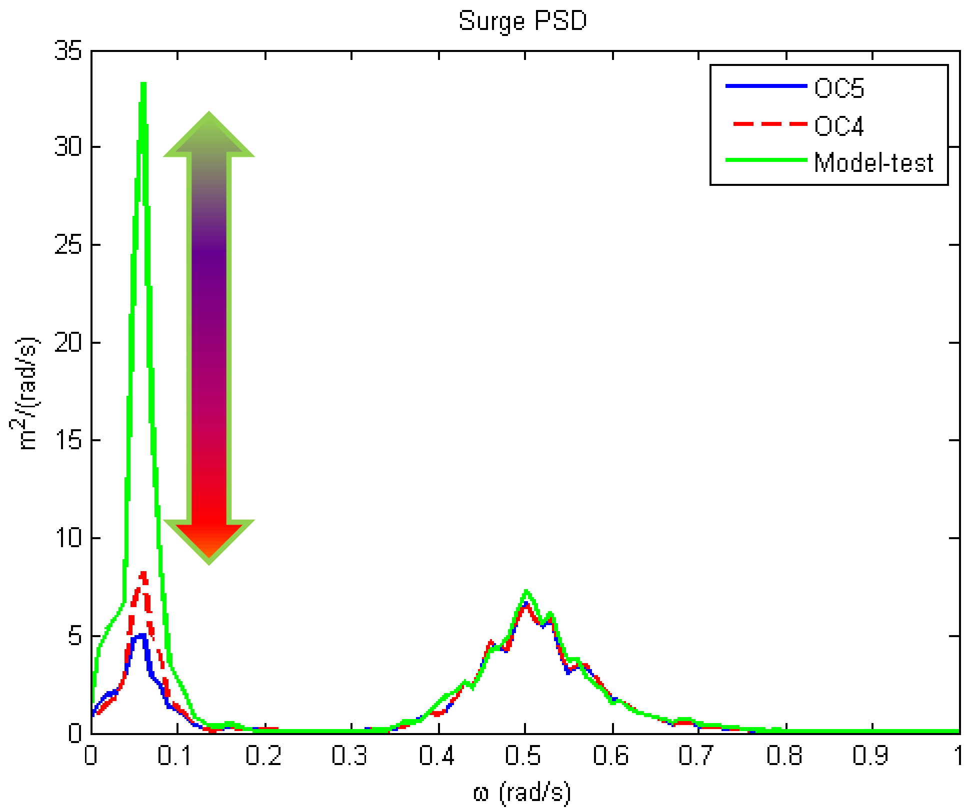
COMPARISON: MODEL OF THE MODEL

- OC5 Calibrated / OC4 Design / Model-test data



⇒ Less damping for the model-tests than the simulations

⇒ Effect mainly visible at resonance (slow drift 2^{nd} order response)

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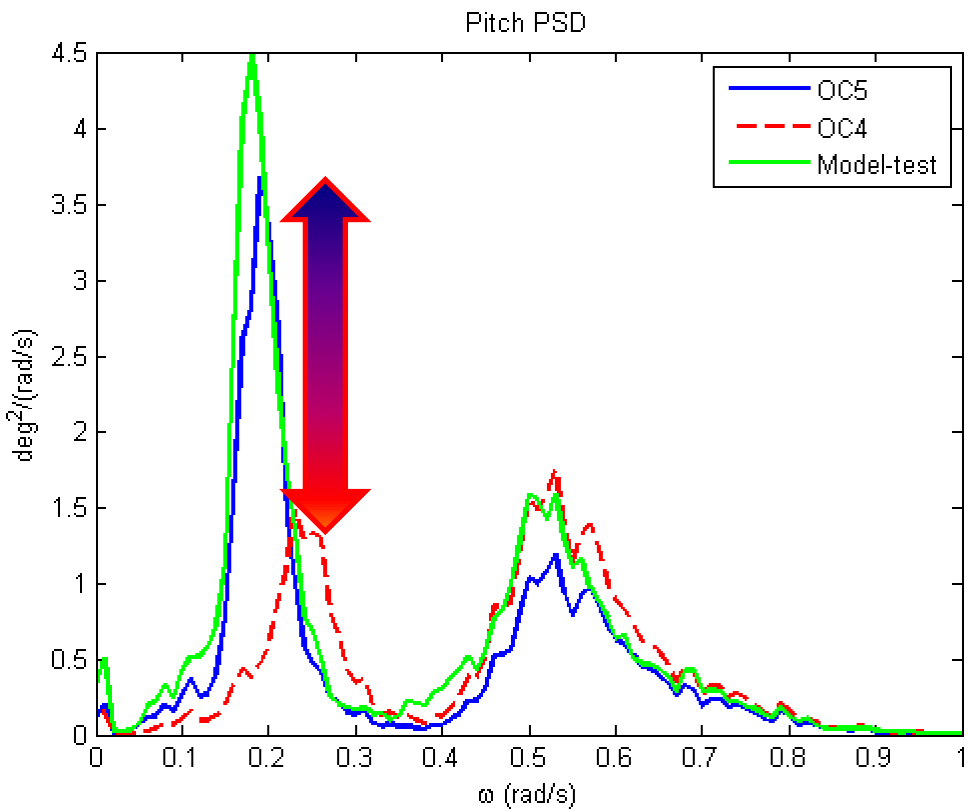
COMPARISON: MODEL OF THE MODEL

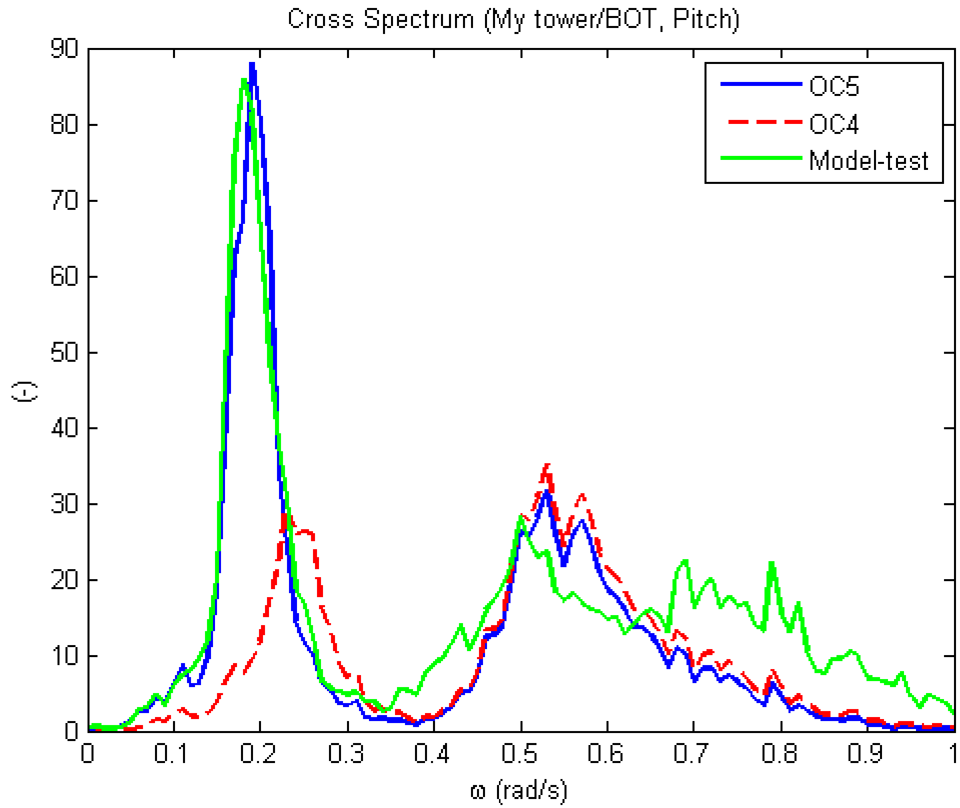
- OC5 Calibrated / OC4 Design / Model-test data



=> Less damping for the 'Model of the model' than the 'Design' case

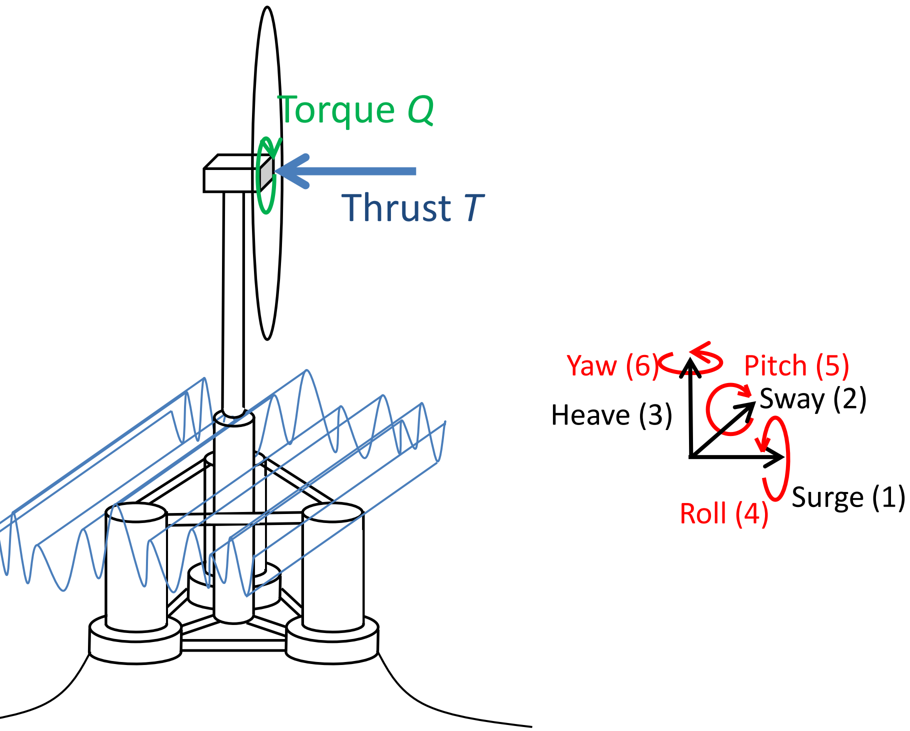
COMPARISON: MODEL OF THE MODEL

- OC5 Calibrated / OC4 Design / Model-test data



⇒ Correlation of pitch moment at tower foot and pitch motion

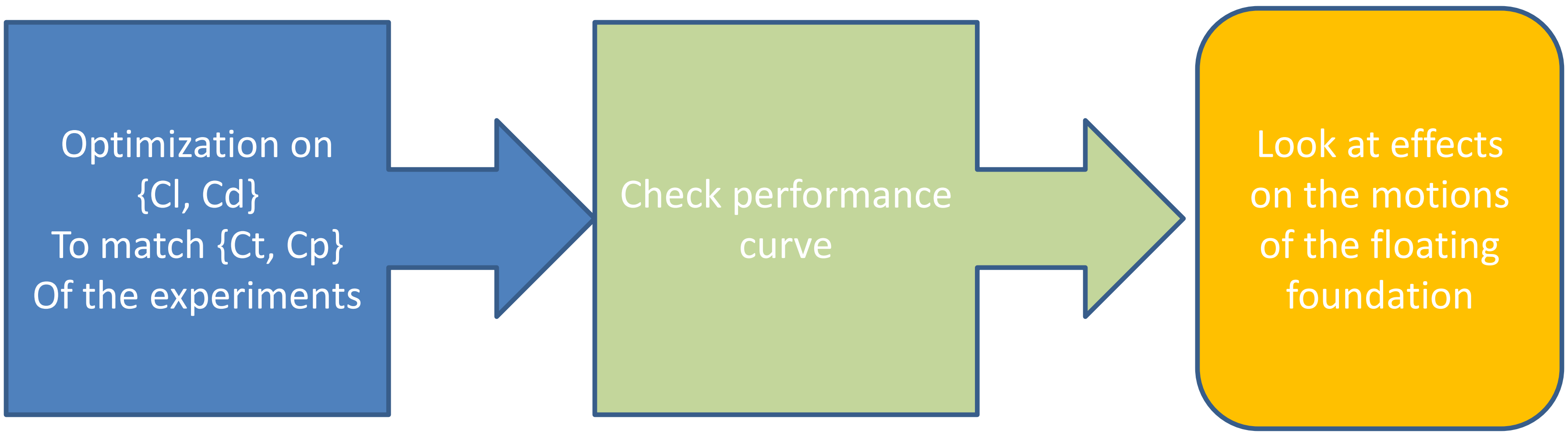
CALIBRATION OF THE ROTOR OF THE WIND TURBINE



- Parallel wind and wave, no yaw
- Thrust acts mainly on
  - Surge
  - Pitch
- Test in a basin at scale 1/50 with a re-designed rotor that mimics the full scale rotor {Ct, (Cp)} for a range of TSR
- What are the {Cl, Cd}?

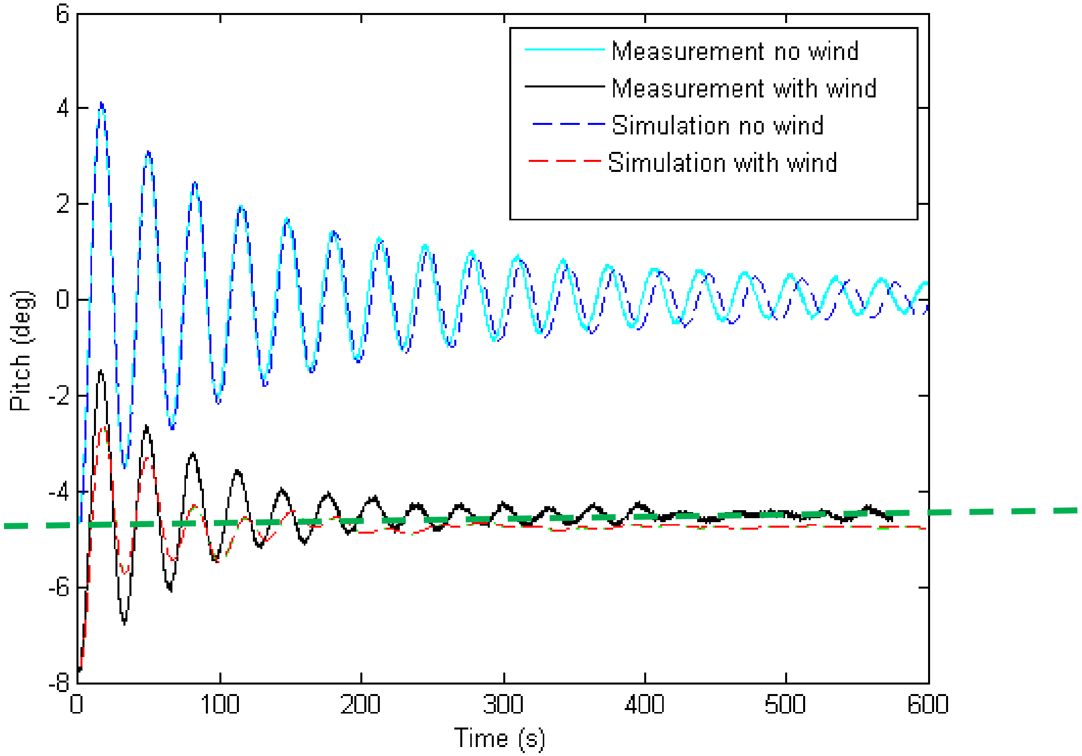
CALIBRATION OF AERODYNAMIC LOAD COEFFICIENTS

- Optimization = vary {Cl, Cd} to match measured {Ct, Cp}



LOOK AT THE DYNAMIC RESPONSE

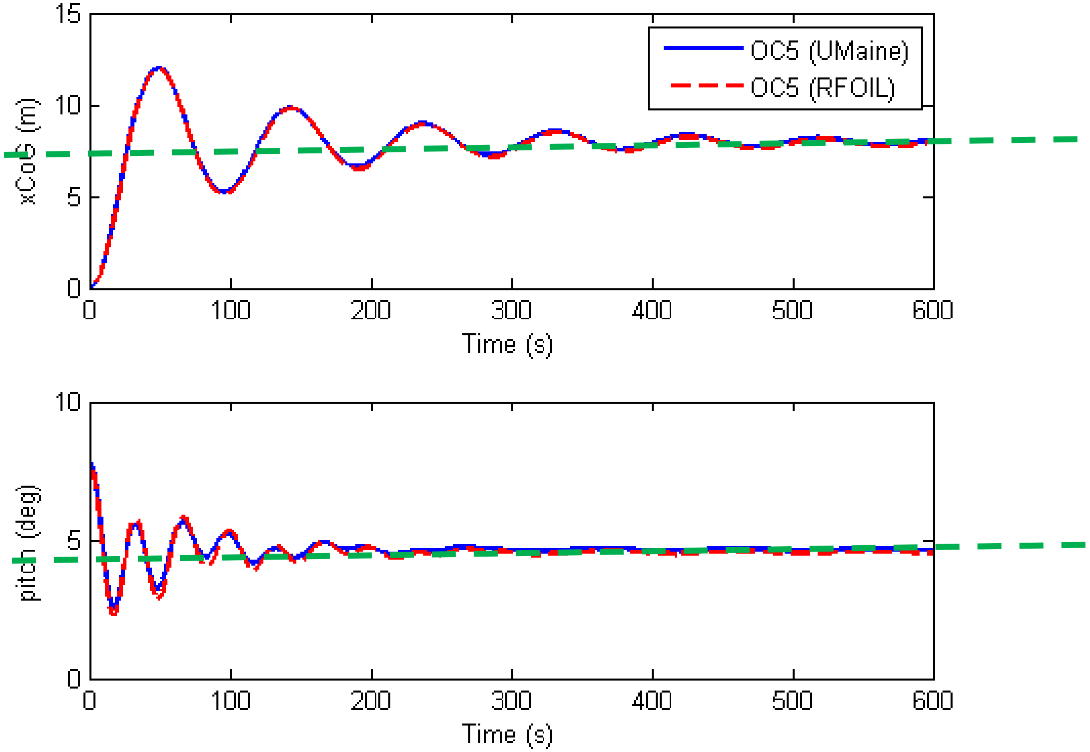
- Simulation of a pitch decay test in steady wind (13 m/s)



=> More damping for the 'Model of the model' than the model-test

LOOK AT EFFECT OF {CL,CD} ON THE RESPONSE

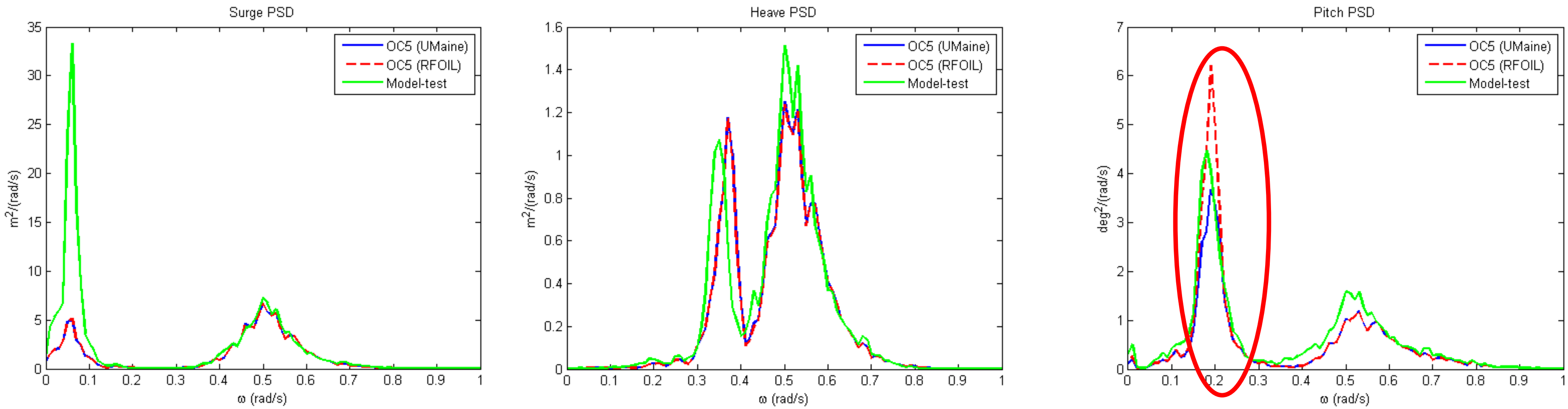
- Simulation of a pitch decay test in steady wind (13 m/s) with other {Cl, Cd}



- Surge (and heave) are identical
- Less damping with **RFOIL** than **UMaine**

LOOK AT EFFECT OF {CL,CD} ON THE RESPONSE

- Operational sea + steady wind (13 m/s), head waves
- **RFOIL** versus **UMaine** coefficients



- Surge and heave are identical
- Different amplitudes of pitch resonance peak
- Less damping with **RFOIL** than **UMaine**

CONCLUSIONS

Lessons learnt:

- OC5 and OC4 behave in similar ways (small differences)
- 'Model of the model' => learn about main physics at play
- Response to 2nd order wave loads in surge and pitch
- Rotor loads acts primarily on resonance peaks
- Aerodynamic damping is mainly effective on surge and **PITCH**
- Level of damping (aero + hydro) is important to know if a numeric model is conservative or not
- Further work necessary on the determination of the damping:
- Horizontal (hydrodynamics)
- Pitch (aerodynamics)
- Also on the wave loads (surge)

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THANK YOU

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