Real-time hybrid model testing of floating wind turbines: sensitivity to limited actuation

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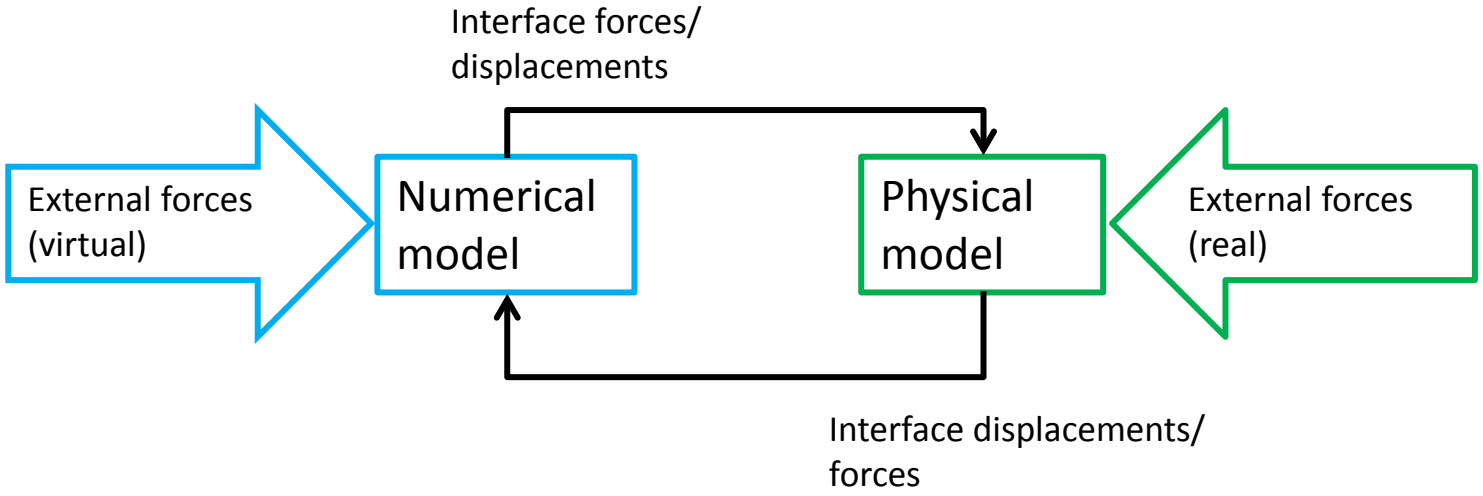
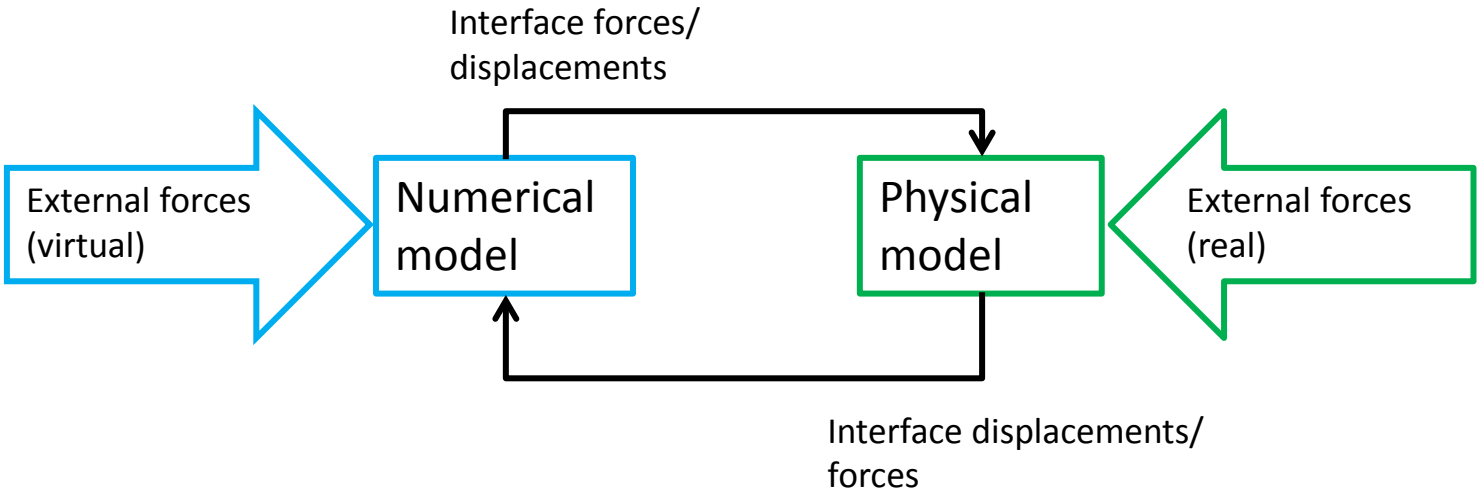
Real-time hybrid model testing (ReaTHM)

- Also called Hardware-in-the-Loop (HiL) or Model-in-the-Loop (MiL)
- The test specimen is part real and part virtual
- Only the key component with unknown dynamics is physically tested
- Some conditions may be more accurately represented by a computer model than by laboratory conditions
- Characteristics of the simulated system can be easily varied



Plummer (2006)
Chabaud et al. (2013
Hall et al. (2014)



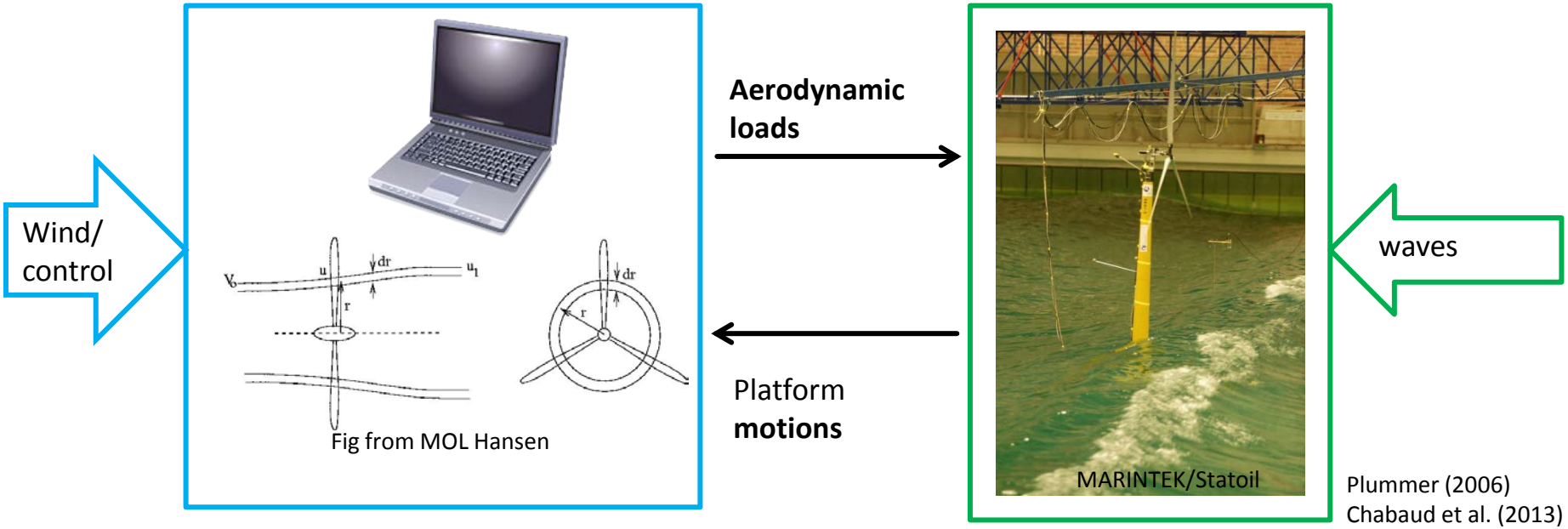
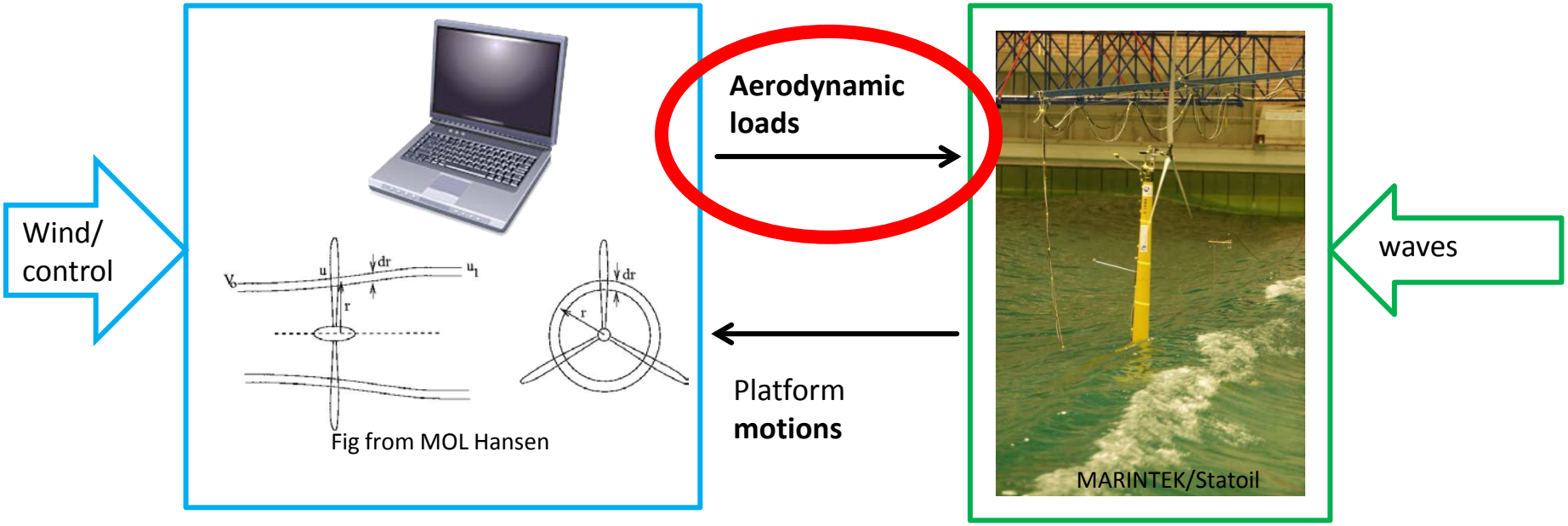


Fig from MOL Hansen

Plummer (2006)
Chabaud et al. (2013)
Hall et al. (2014)

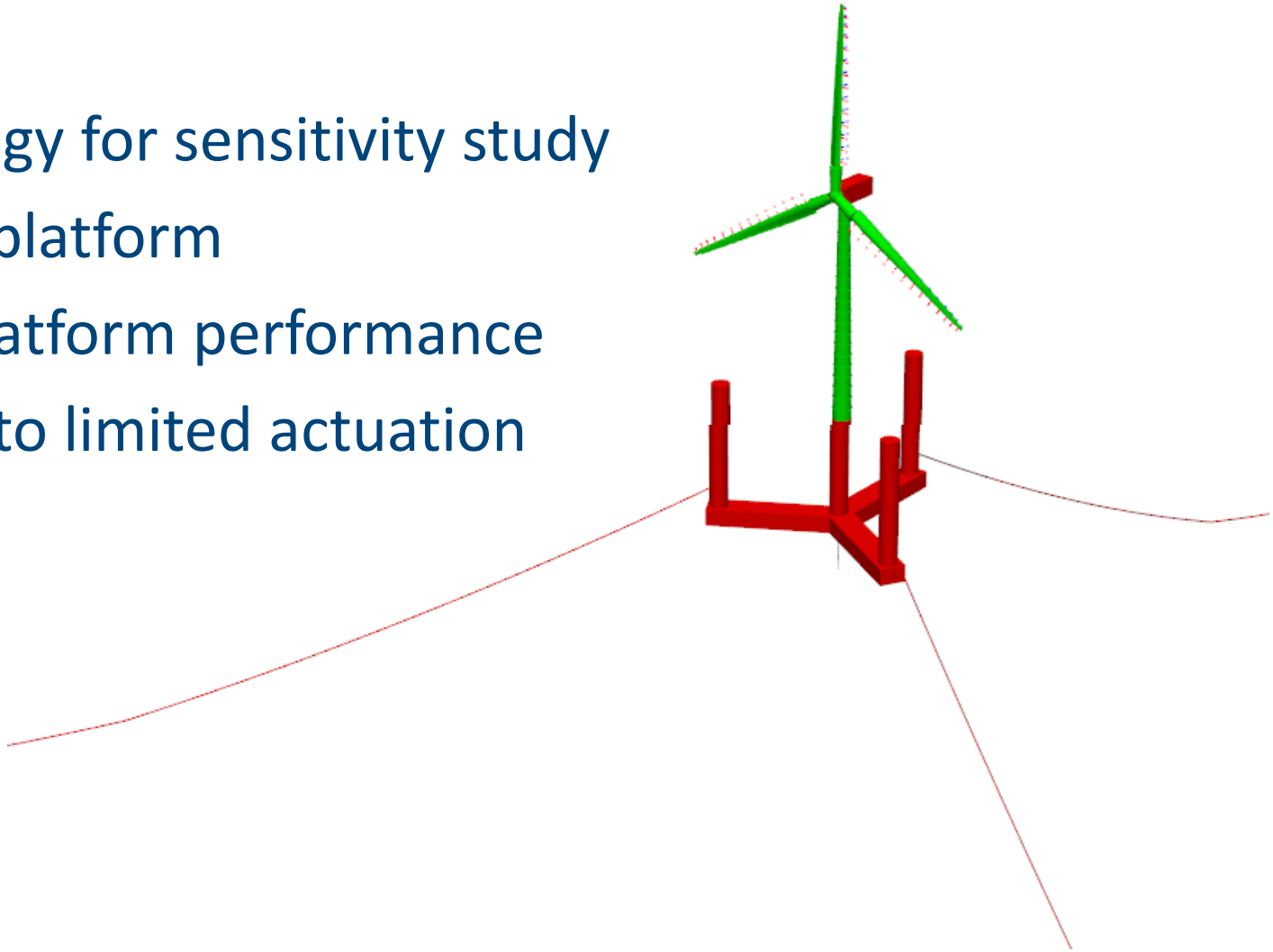
Real-time hybrid model testing of floating wind turbines: sensitivity to limited actuation

- What happens if we are not able to actuate all of the forces and moments?

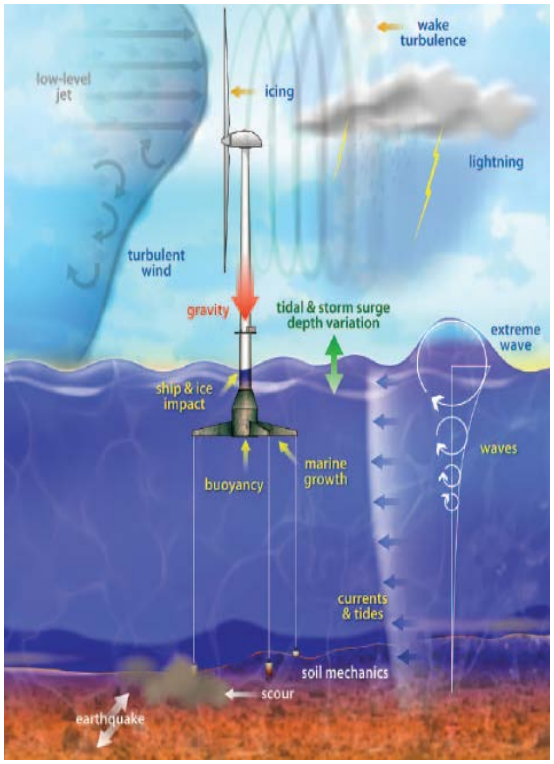


Outline

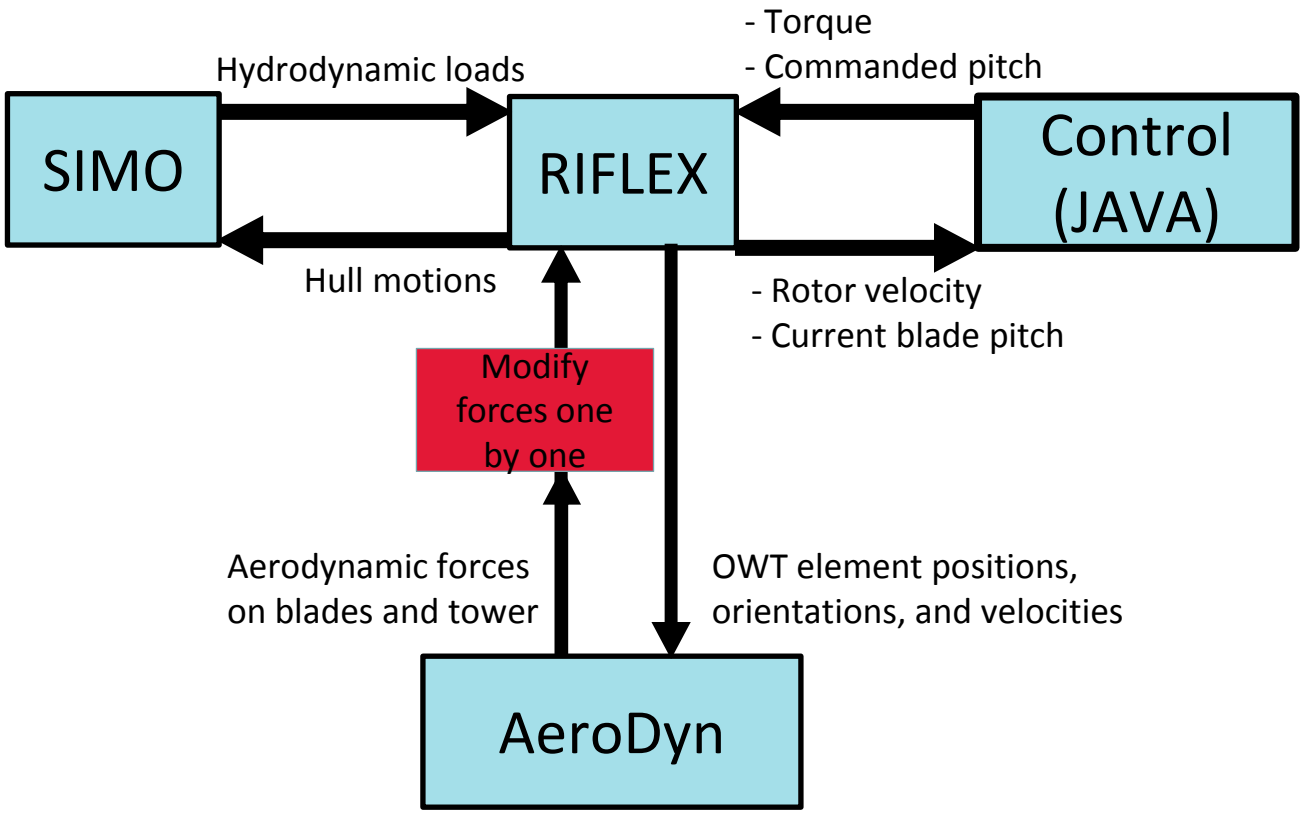
- Methodology for sensitivity study
- 5MW-CSC platform
- Baseline platform performance
- Sensitivity to limited actuation



Computational methodology



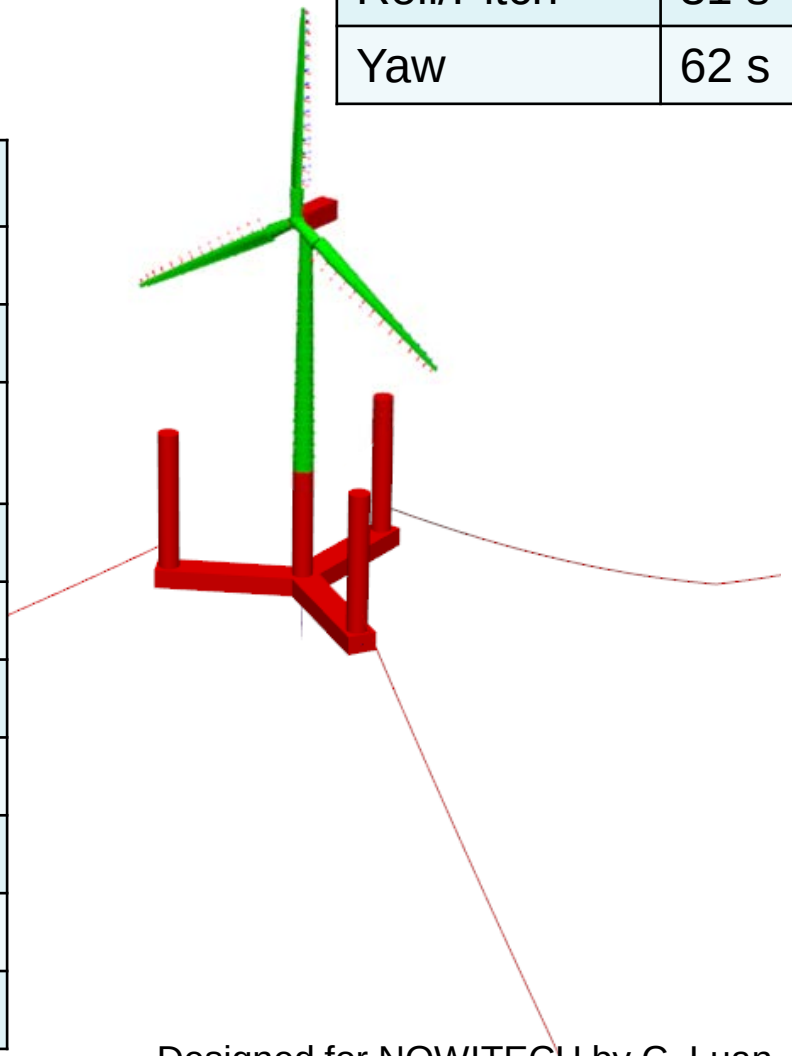
Source: NREL/Wind power today, 2010.



5MW-CSC platform

Surge/Sway	80 s
Heave	26 s
Roll/Pitch	31 s
Yaw	62 s

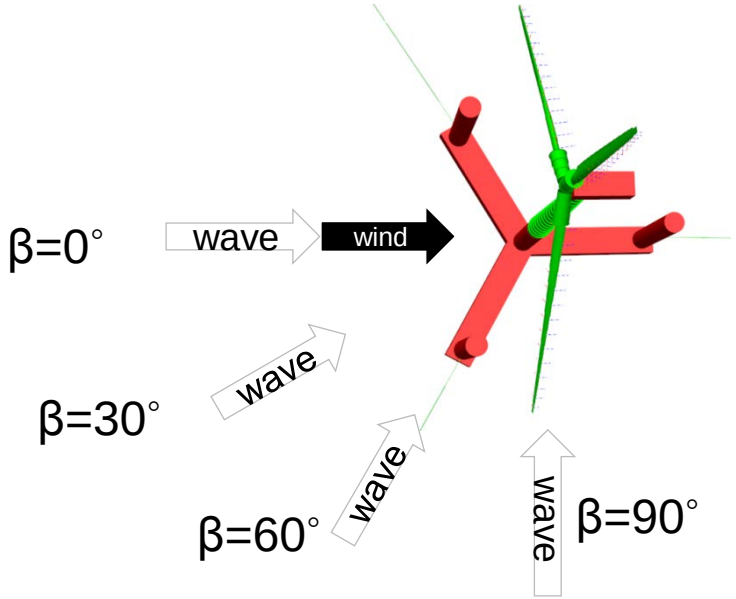
Diameter of center and offset columns	6.5 m
Pontoon height	6.0 m
Pontoon width	9.0 m
Distance from center column midpoint to pontoon edge	45.5 m
Draft	30.0 m
Freeboard	20.0 m
Water depth	200 m
Anchor point radius	884 m
Mooring line weight (total)	258 tonnes
Hull steel mass	1686 tonnes
Turbine	NREL 5MW



Designed for NOWITECH by C. Luan

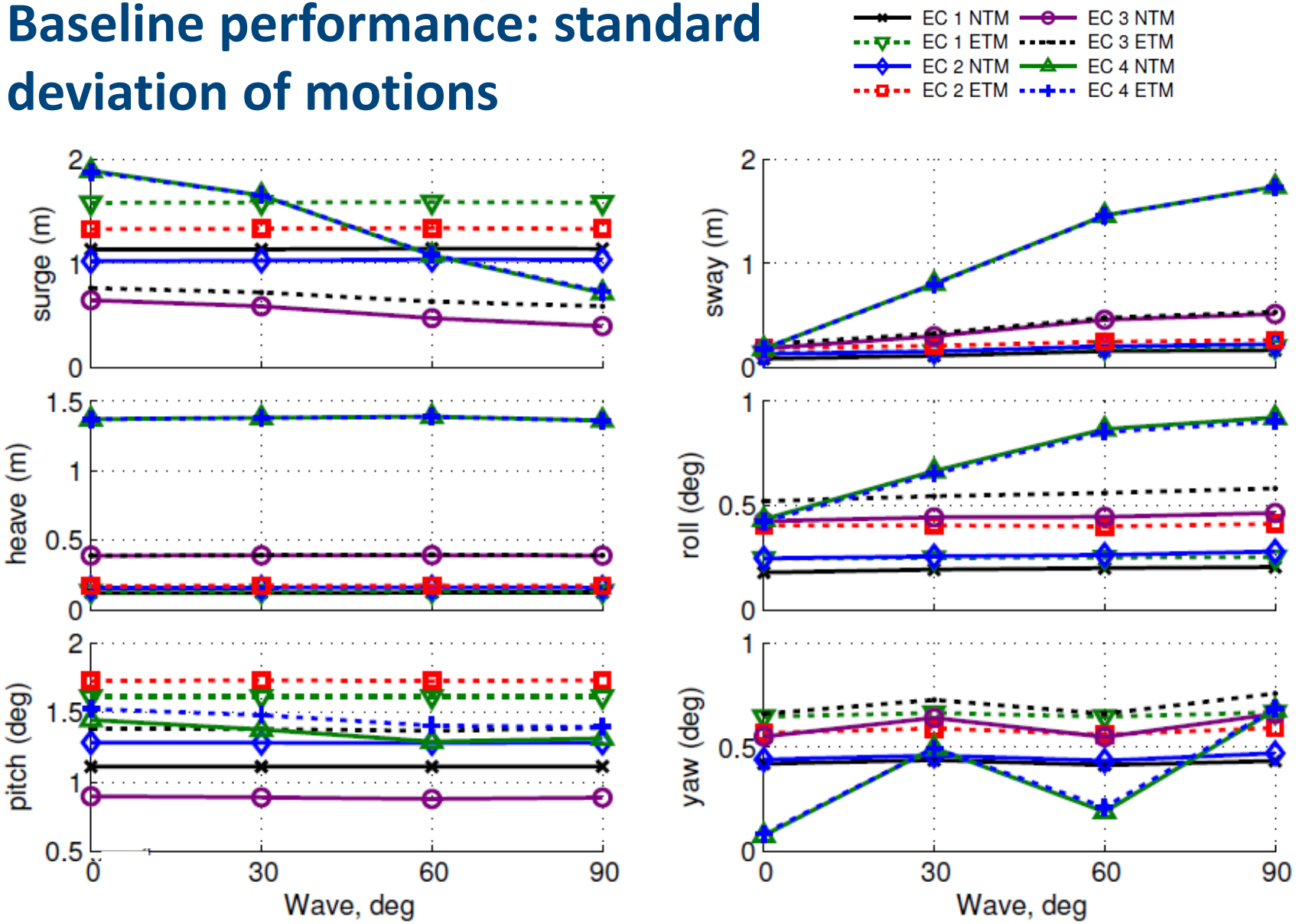
Environmental Conditions

	EC 1	EC 2	EC 3	EC 4
U (m/s)	8.0	11.4	20.0	49.0
H_s (m)	2.5	3.0	5.9	14.4
T_p (s)	9.8	10.1	11.3	13.3
I (%) (NTM)	17.1	14.0	11.5	10.0
I (%) (ETM)	28.1	23.2	15.7	10.7

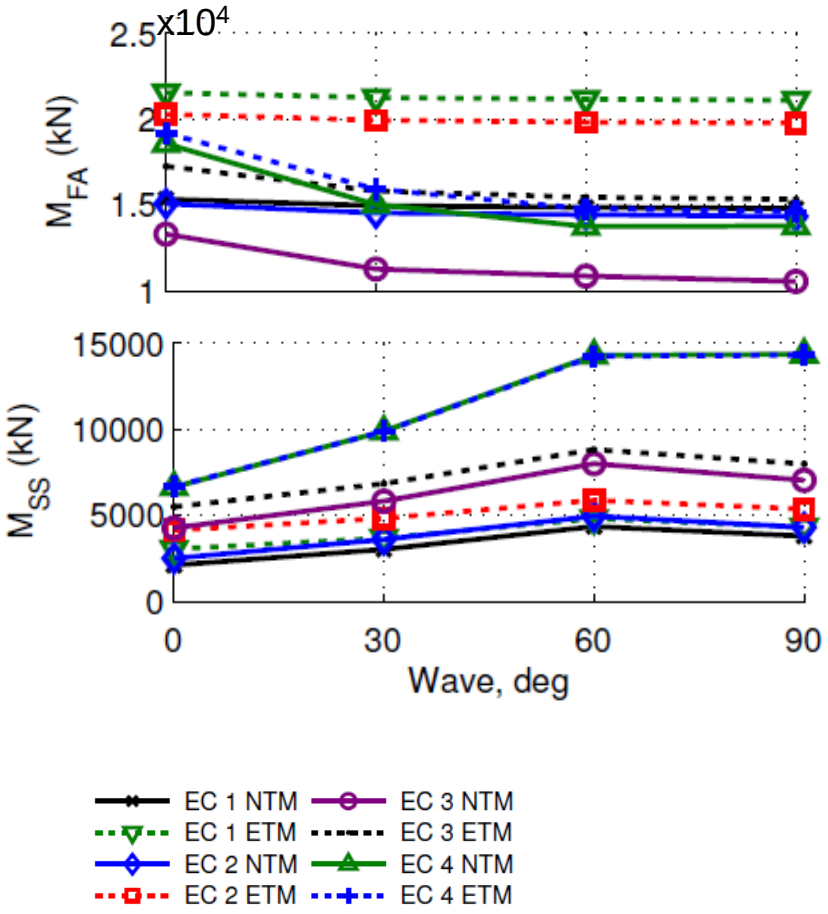


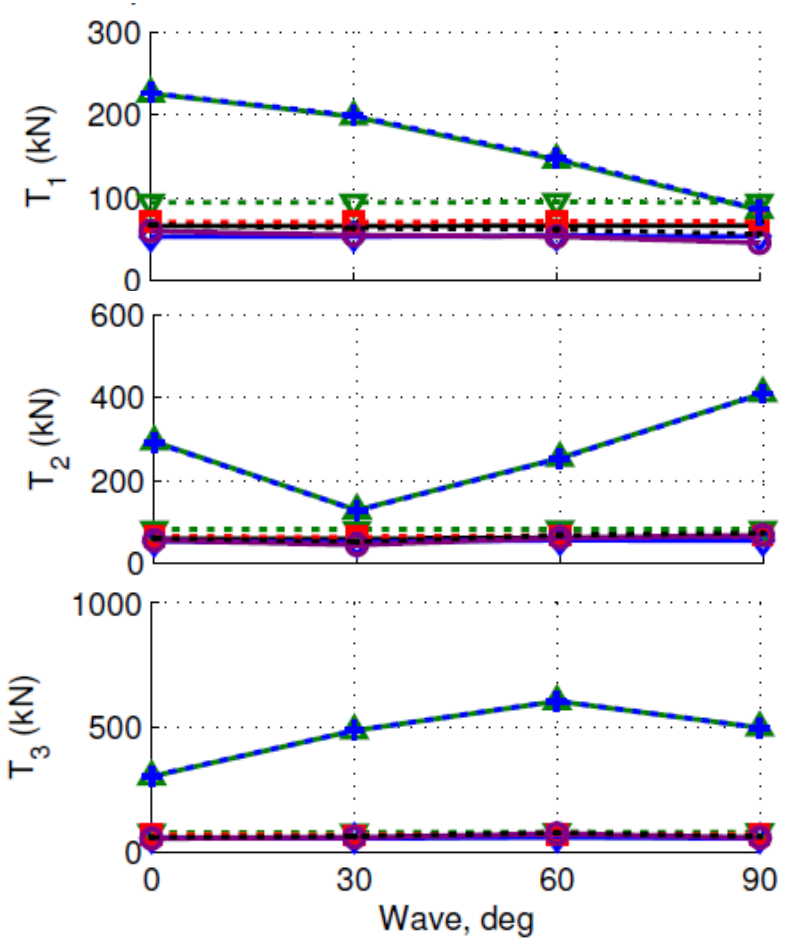
- Representative below-rated, at rated, above-rated, and storm conditions
- Normal and extreme turbulence considered
- Misalignment between wind and waves
- 1-hour simulations

Baseline performance: standard deviation of motions



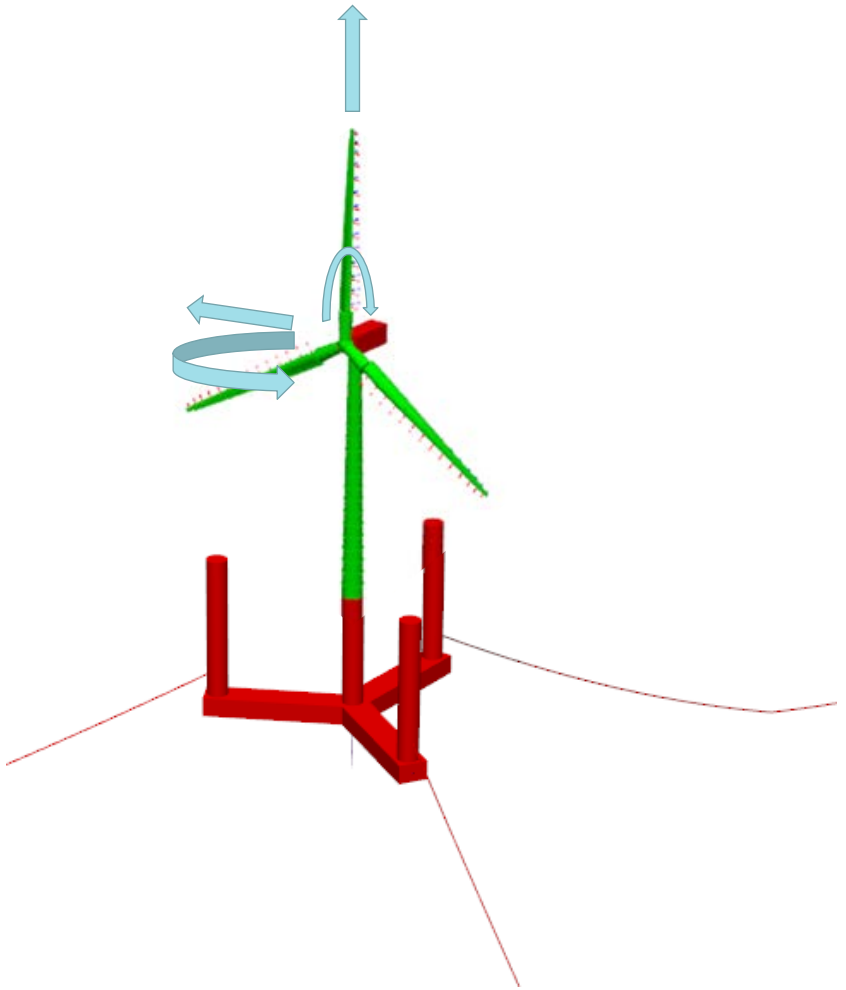
Baseline performance: standard deviation of tower base bending moments and mooring line tension





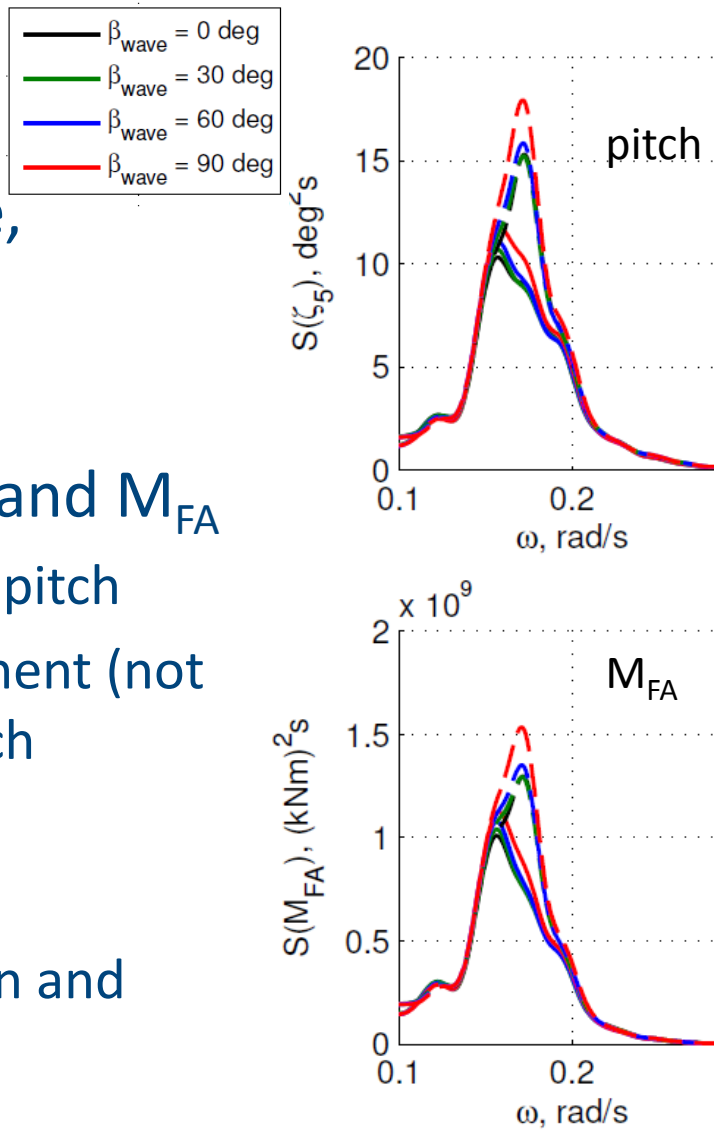
Sensitivity to limited actuation

- non-thrust aerodynamic loads:
  - pitch moment
  - yaw moment
  - sway force
  - heave force
- thrust directionality
- gyroscopic moments
- dynamic variation of generator torque



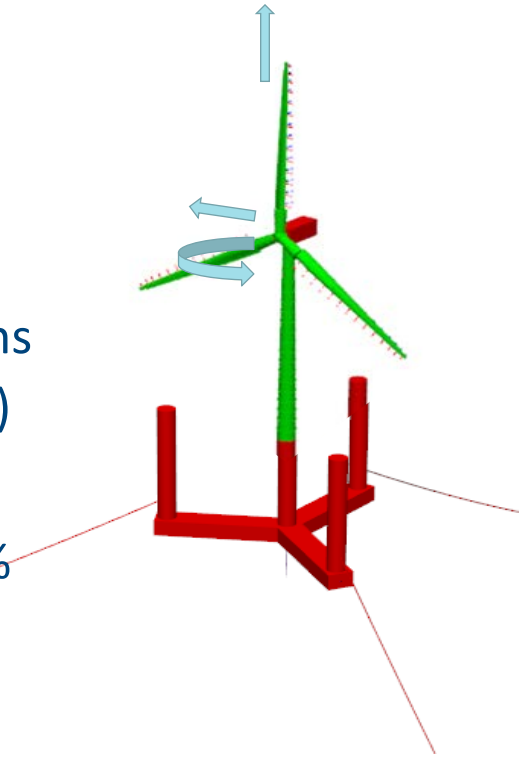
Results of removing rotor aerodynamic pitch moment

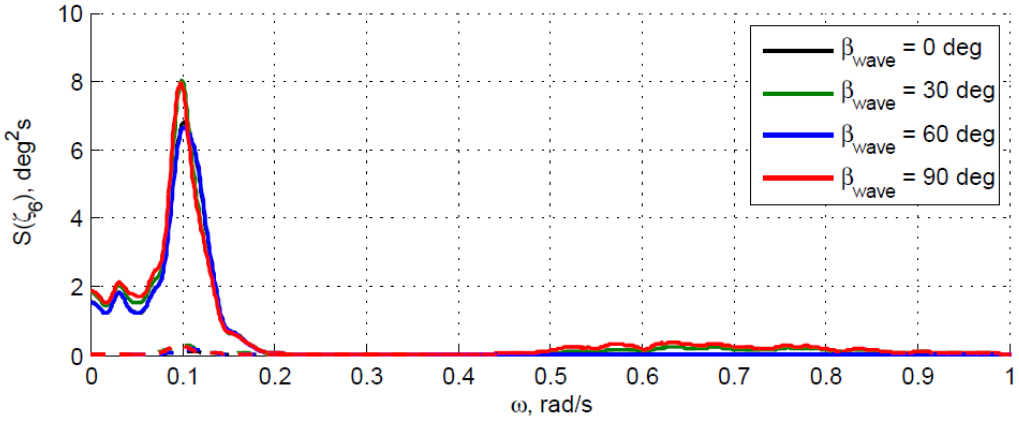
- 1-6% of total aero pitch
- Depends on tilt, wind shear, turbulence, platform motions
- Below rated: affects sway, roll, M_{FA}
- Above rated: affects pitch, line tension and M_{FA}
  - See figure: dashed lines are without aero pitch
  - MFA has a larger wave-frequency component (not shown), which is not affected by aero pitch
  - Effect on tower-bending frequency is also important
  - 10-14 % changes in std dev of line tension and pitch motion



Results of removing aerodynamic sway, heave, and yaw

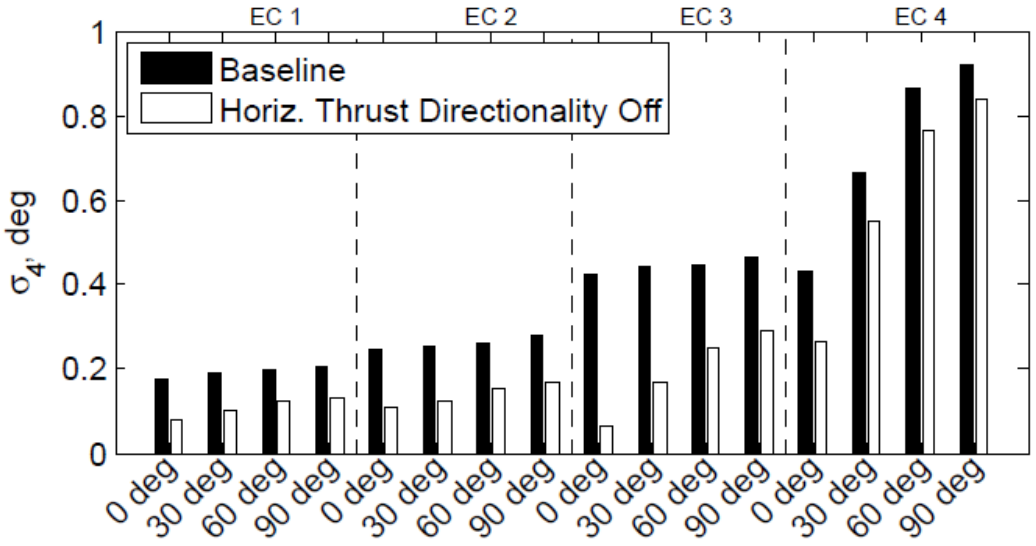
- Sway:
  - Sway motion, roll motion, and tower side-side bending moment
  - Large relative effect in aligned conditions (due to small absolute values)
- Heave
  - <3% effect on key responses in operational conditions
  - May be more important in parked (storm conditions)
- Yaw
  - Large effect on yaw motions at low frequencies (80% change in std. dev)



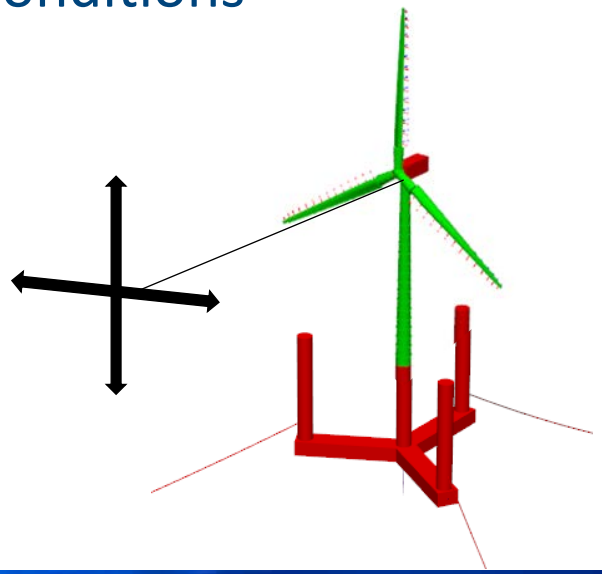


Results of removing thrust directionality

- Horizontal directionality
  - thrust actuator does not follow the motions of the hub in the horizontal plane
  - Affects sway, roll, M_{SS}
  - 50% effect on roll std. dev. in cases where roll ≈ pitch



- Vertical directionality
  - Thrust actuator does not follow the vertical hub motions
  - Less than 5% effect on key responses in operational conditions



Results of removing gyroscopic moments and dynamic generator torque

- Gyroscopic moments
  - Only relevant for the operational conditions
  - 5 % change in the std. dev. of the yaw motion
  - Effect seen near the yaw and pitch natural frequencies
- Dynamic generator torque
  - Control system prescribes constant torque above rated
  - Affects roll and M_{SS} in ECs 1 and 2 (4-9% effect on std. dev., but small absolute values)

Summary

- Methodology for investigating the sensitivity of ReaTHM testing of FWTs to limited actuation of aerodynamic forces
- For the given platform, with small motions, non-thrust/non-torque aerodynamic loads had relatively large effects on motions
- Informed trade-offs between complexity and fidelity can be made for experimental design

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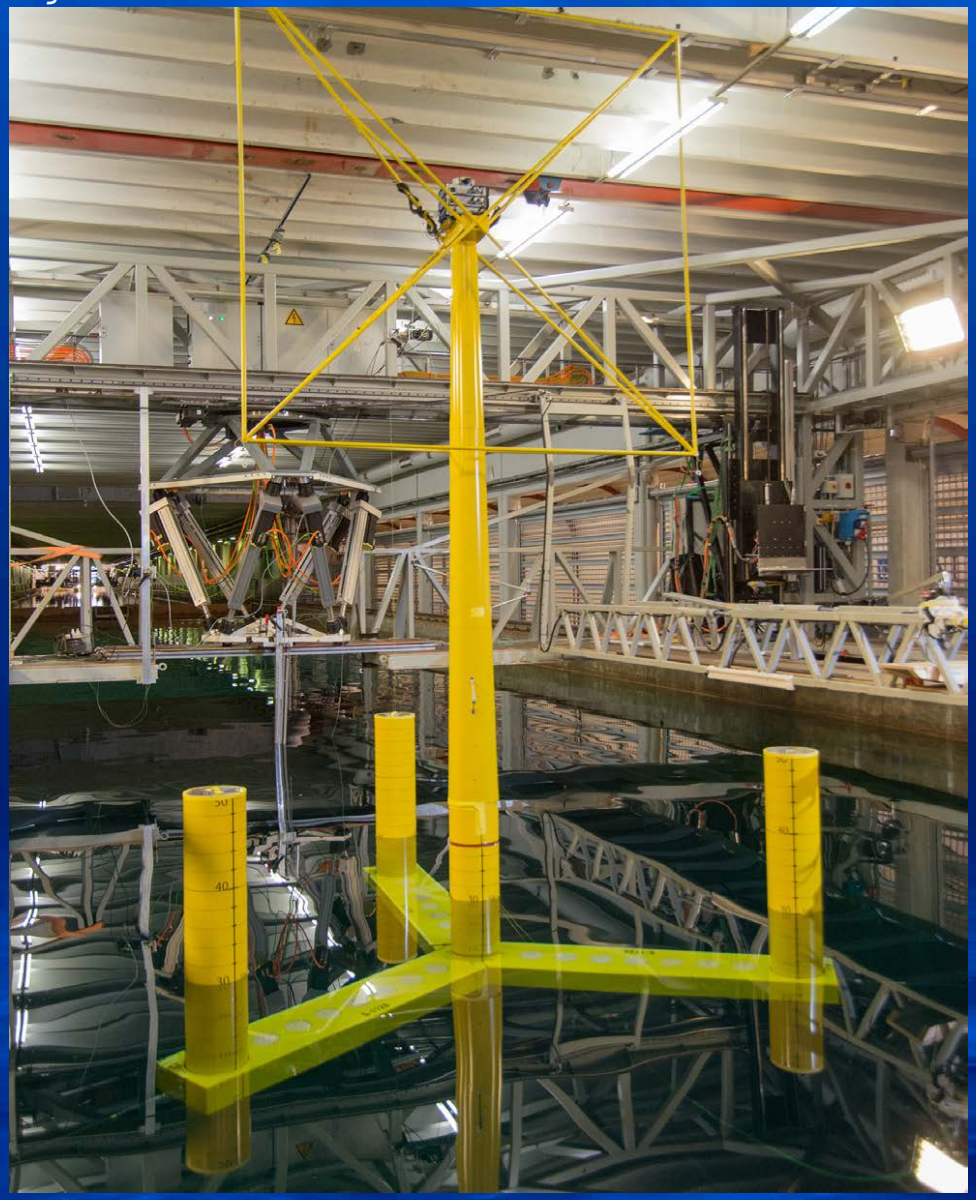

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