# A preliminary comparison on the dynamics of a VAWT on three different support structures

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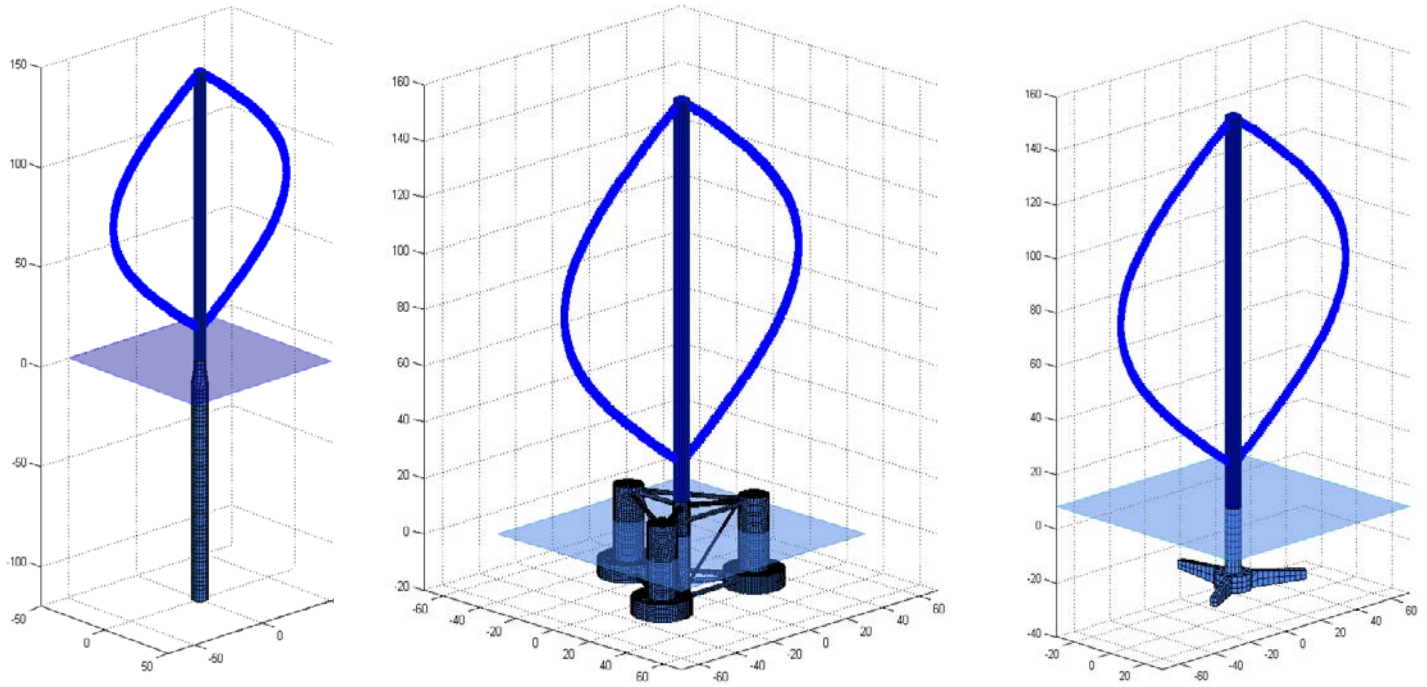
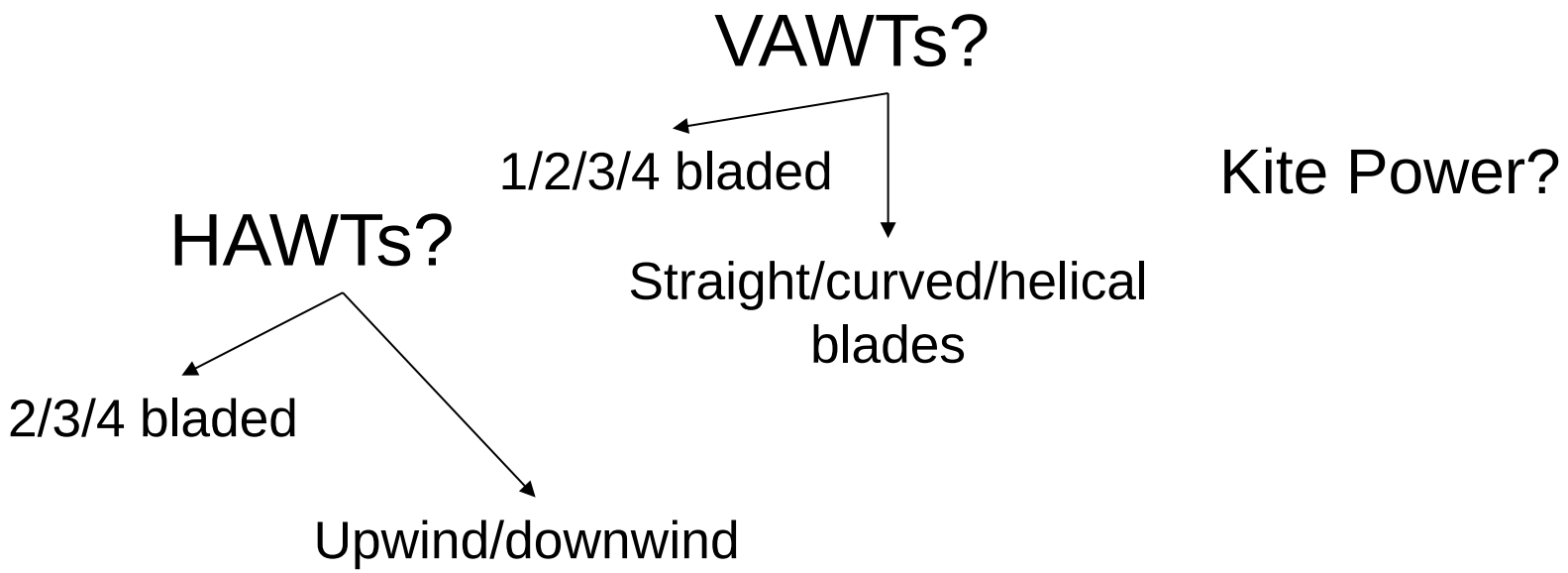


# Outline

- Context
- Floating Wind Turbines studied
- Degrees of Freedom
- Loading Conditions
- Results
- Conclusions

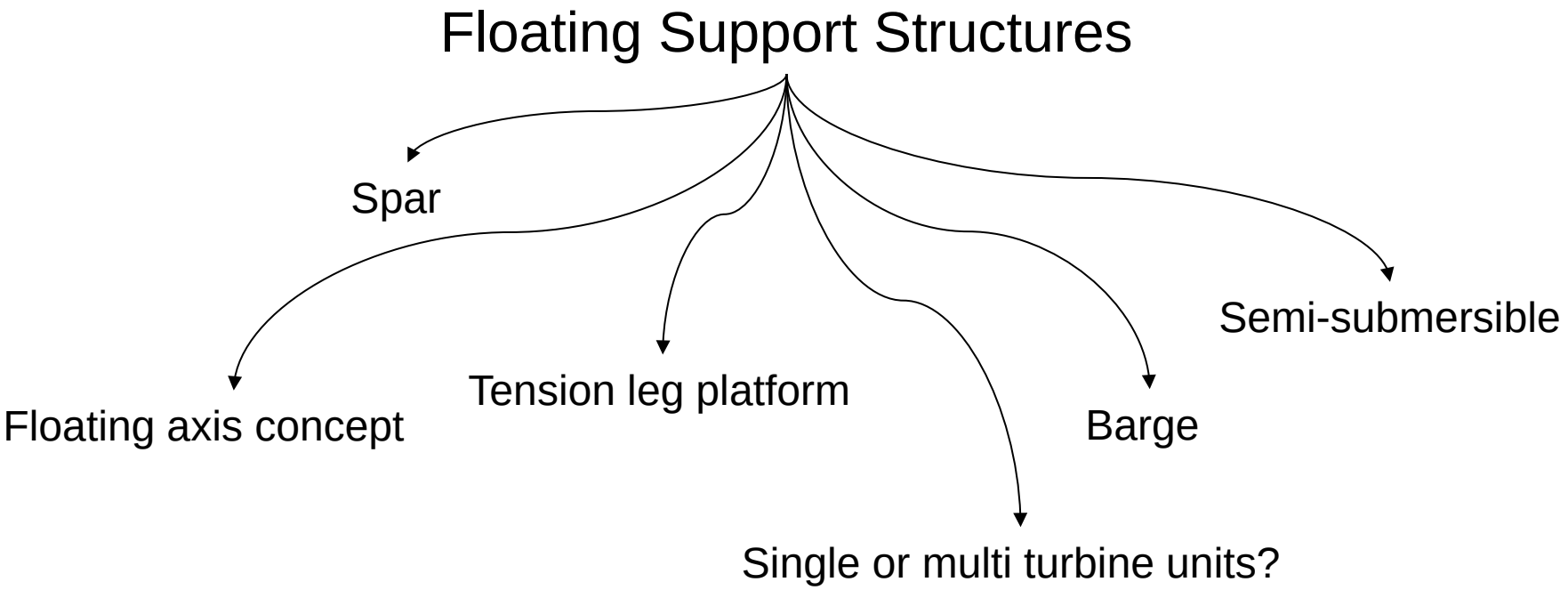
# Context

- Identifying optimal floating wind configurations



# Context

- Identifying optimal floating wind configurations



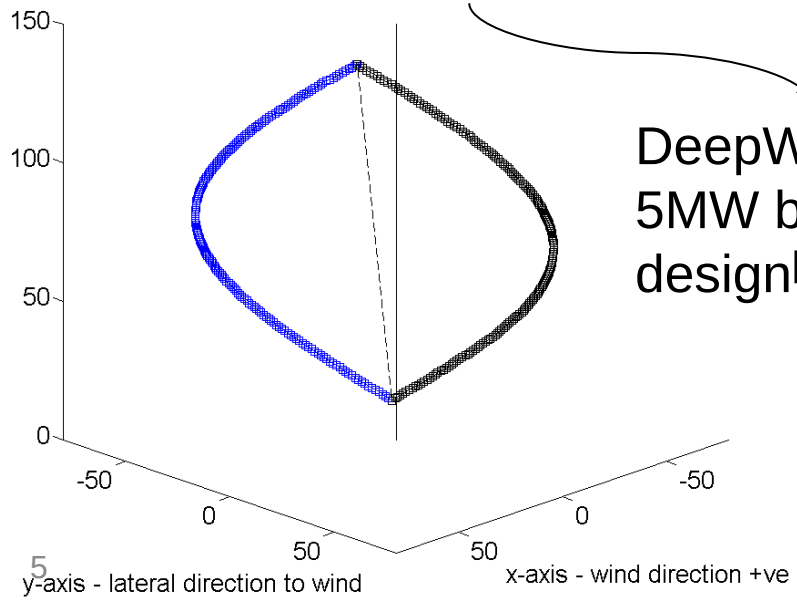
# Context

- Scope of this work

VAWT

2-bladed curved Darrieus rotor

DeepWind 5MW baseline design[1]




Three support structures

- OC3 Spar[2]
- OC4 Semi-submersible[3]
- UMaine/DeepCwind Tension leg platform[4]

# Floating Wind Turbines

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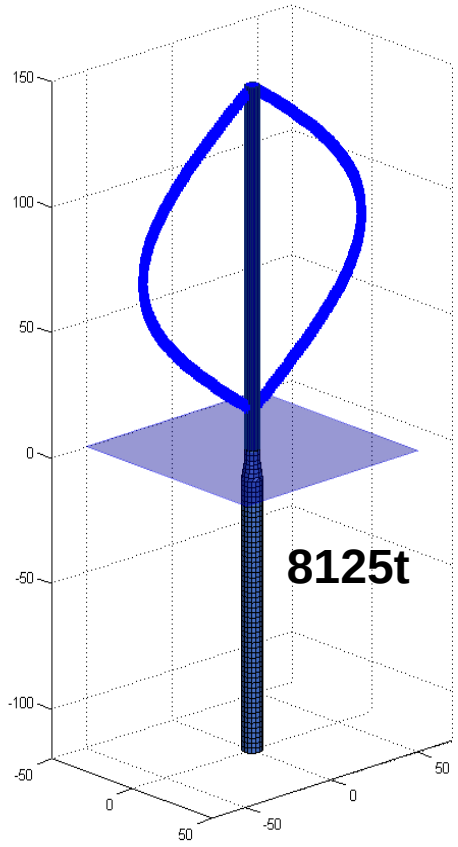
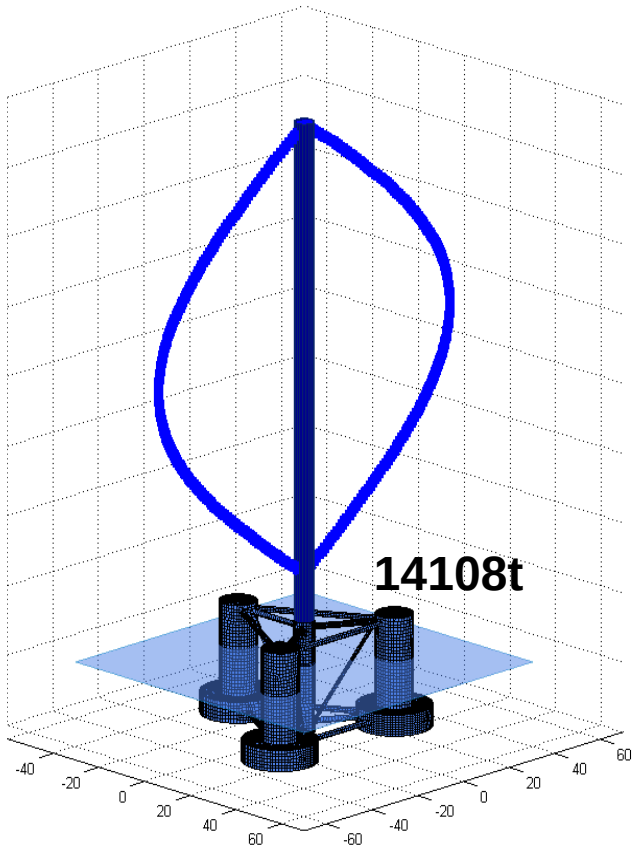
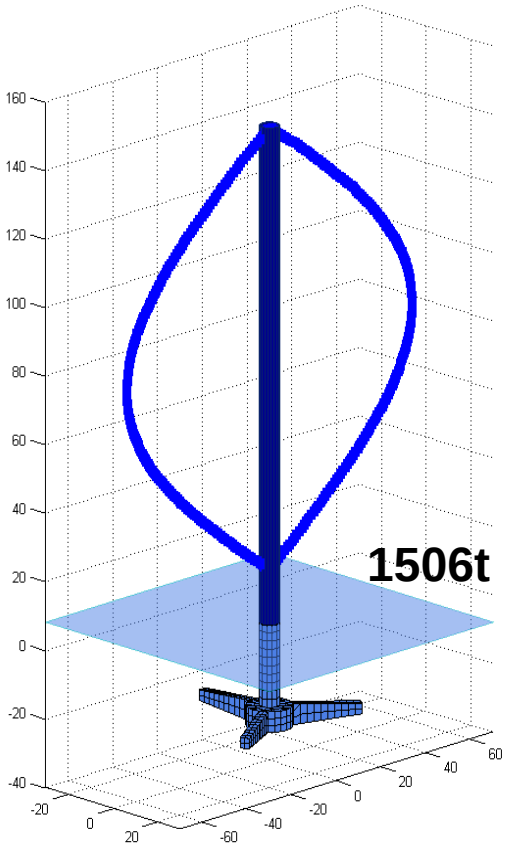
Spar




Semi-submersible

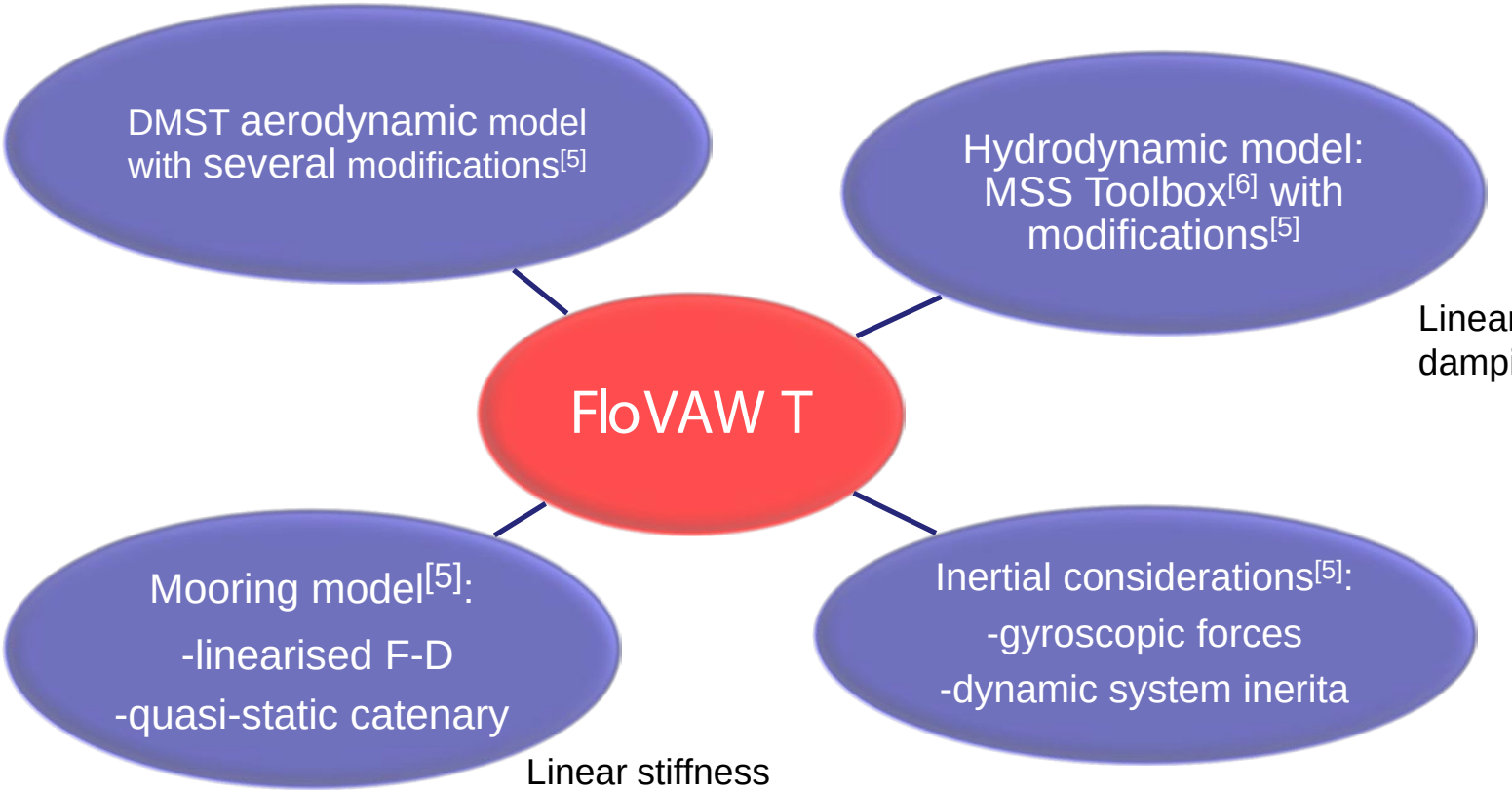



TLP



# Numerical Tool

- FloVAWT in development at Cranfield University

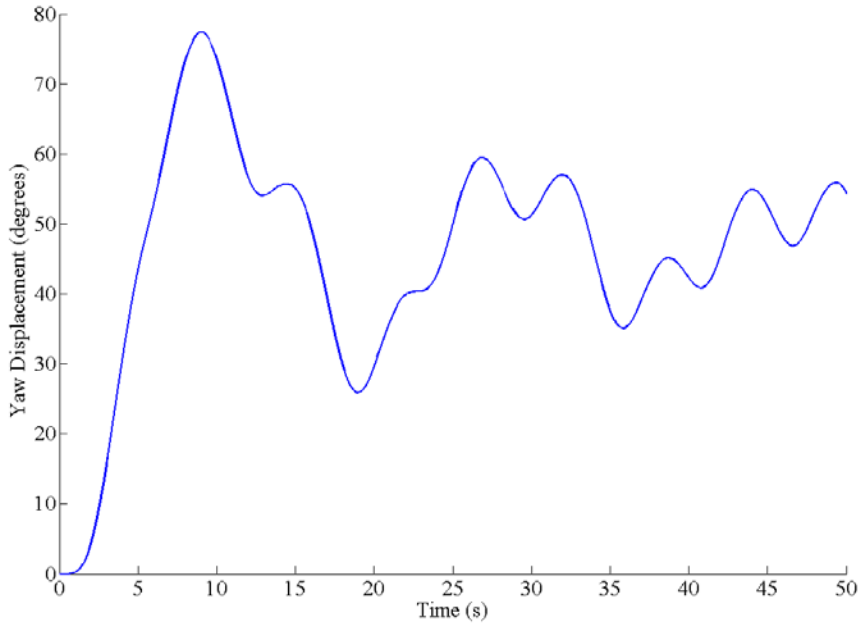


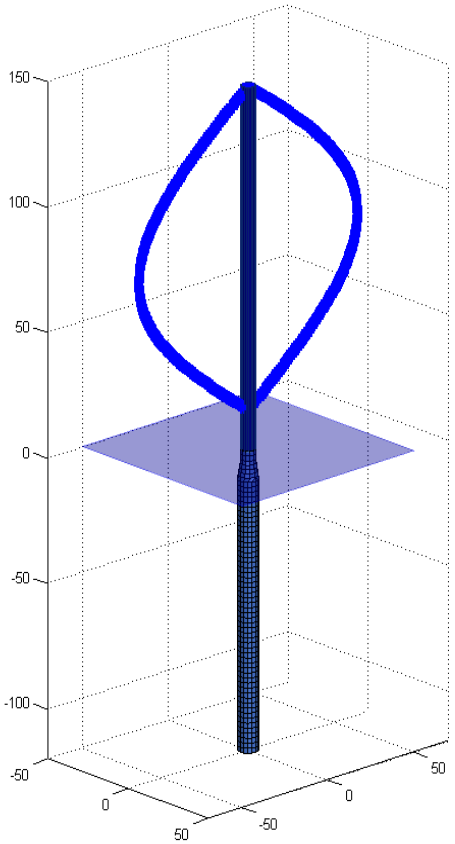
# Degrees of Freedom Issues

- Aerodynamic forces excitation of platform
- HAWT: relatively steady thrust + torque in roll
- VAWT: oscillatory surge, sway, roll, pitch, yaw loads

# Degrees of Freedom Issues

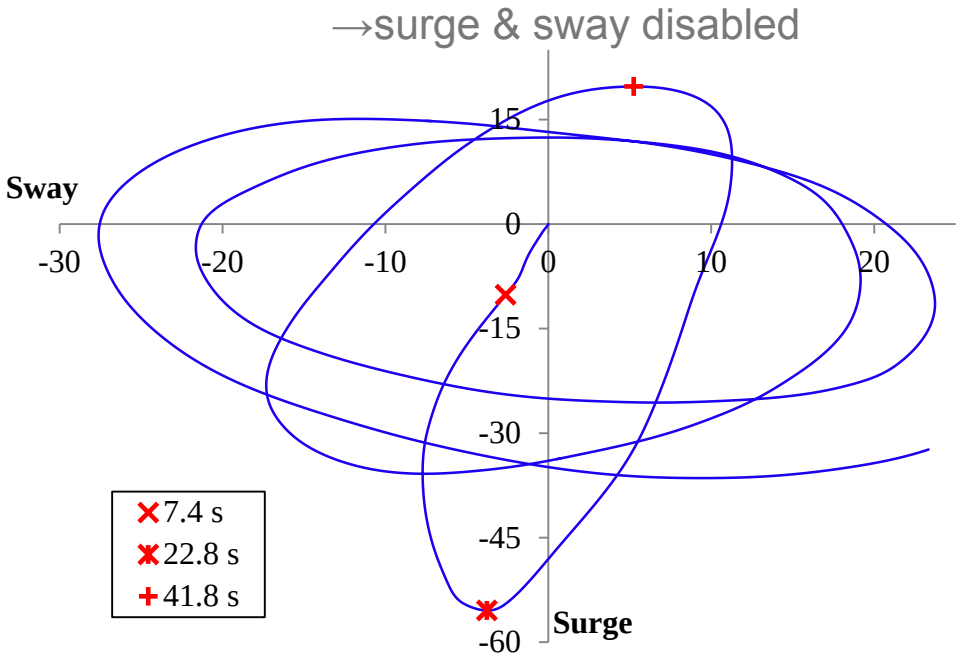
- Spar
  - Mooring system yaw stiffness
    - Not sufficient→ Yaw DOF disabled

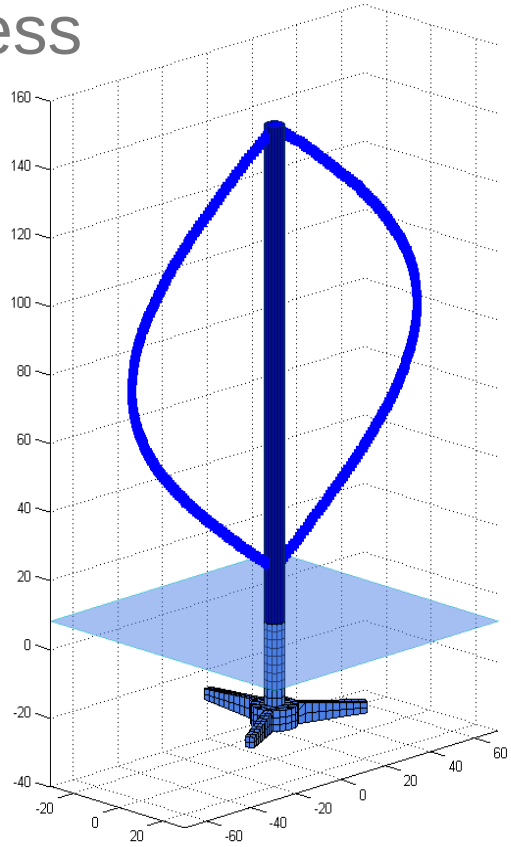


# Degrees of Freedom Issues

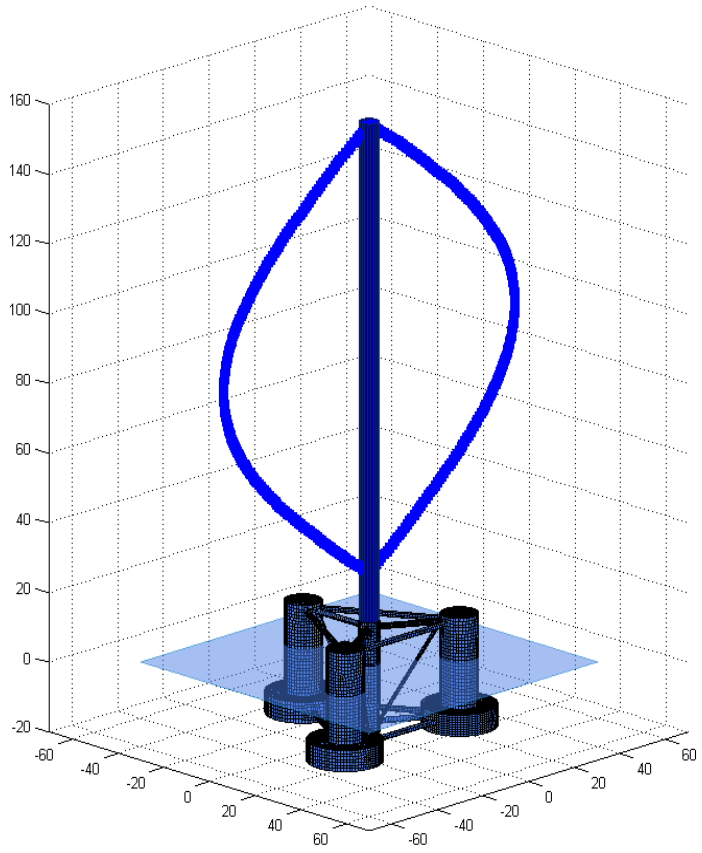
- TLP
  - Mooring system surge/sway stiffness
    - Unstable behaviour



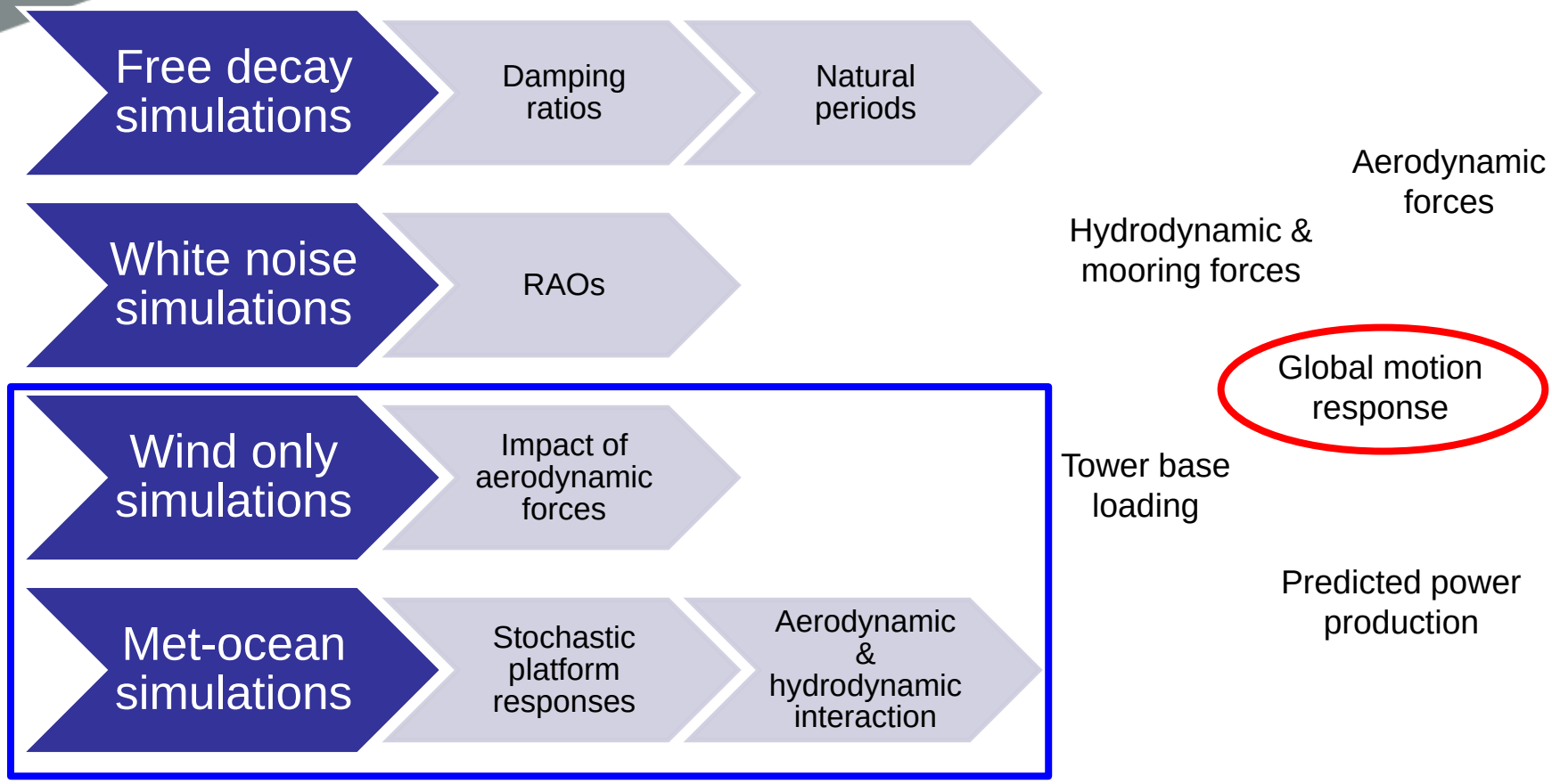



# Degrees of Freedom Issues

- Semi-submersible
  - No problems!



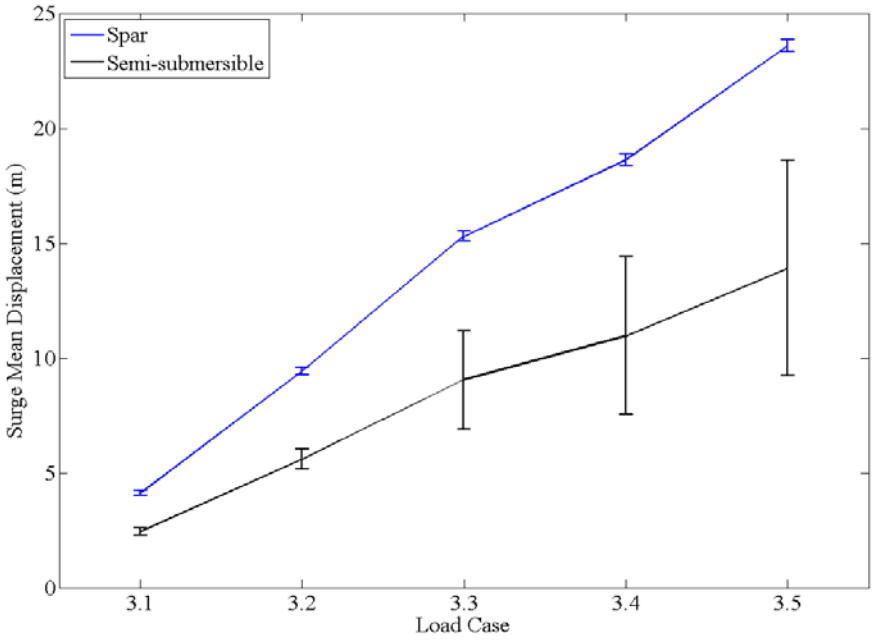
# Load Cases

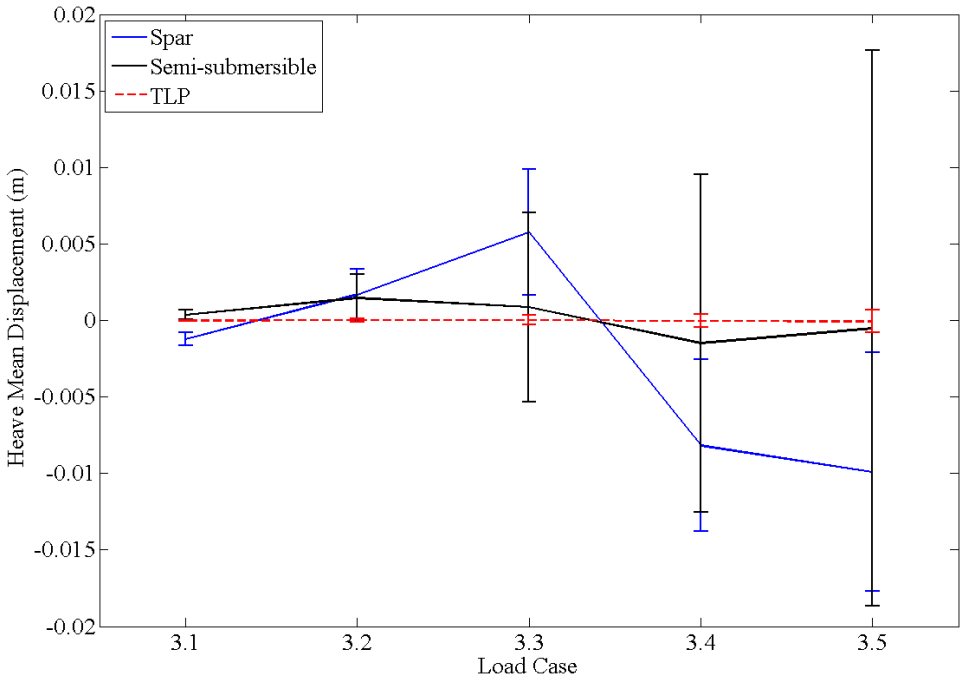

Free decay simulations
Damping ratios
Natural periods
White noise simulations
RAOs
Wind only simulations
Impact of aerodynamic forces
Met-ocean simulations
Stochastic platform responses
Aerodynamic & hydrodynamic interaction
Aerodynamic forces
Hydrodynamic & mooring forces
Global motion response
Tower base loading
Predicted power production

# Load Cases 3 & 4

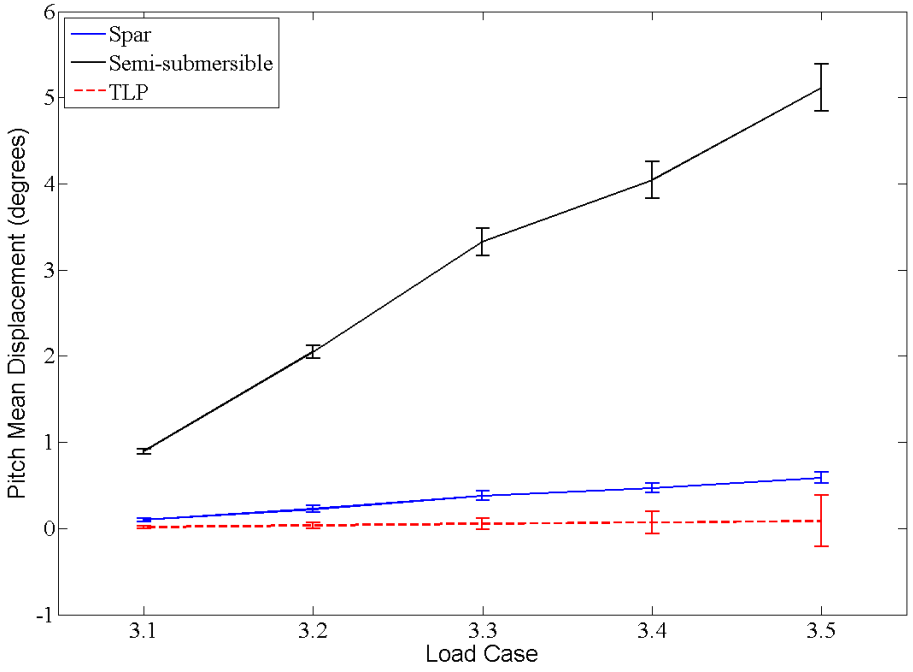
| Load Case | Wind Speed (m/s) | Hs (m)/Tp (s), LC4 |
|---|---|---|
| x.1 | 5 (BR) | 2.1/9.74 |
| x.2 | 9 (BR) | 2.88/9.98 |
| x.3 | 14 (R) | 3.62/10.29 |
| x.4 | 18 (AR) | 5.32/11.06 |
| x.5 | 25 (AR) | 6.02/11.38 |

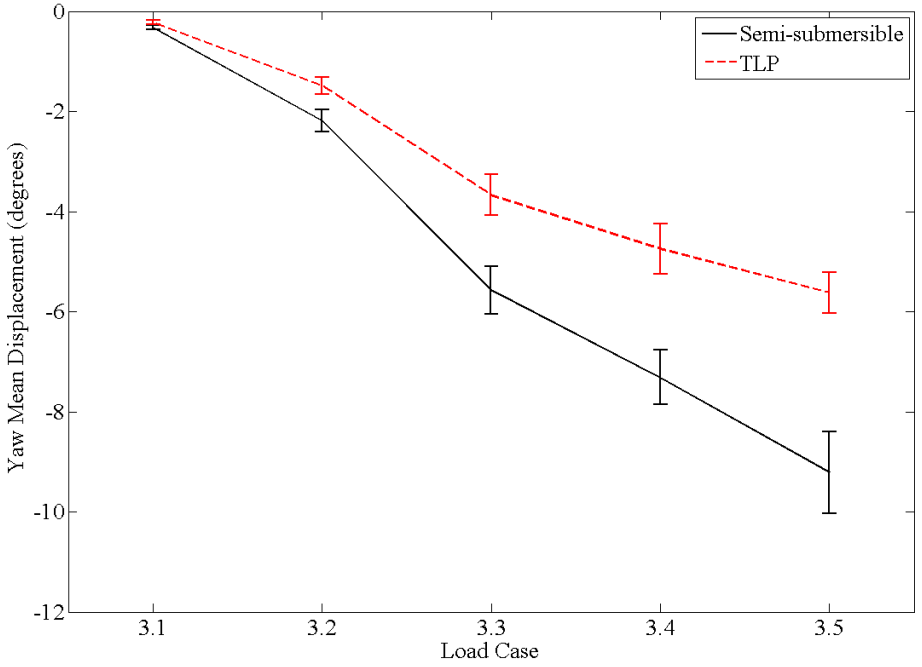
# Results
## Wind Only



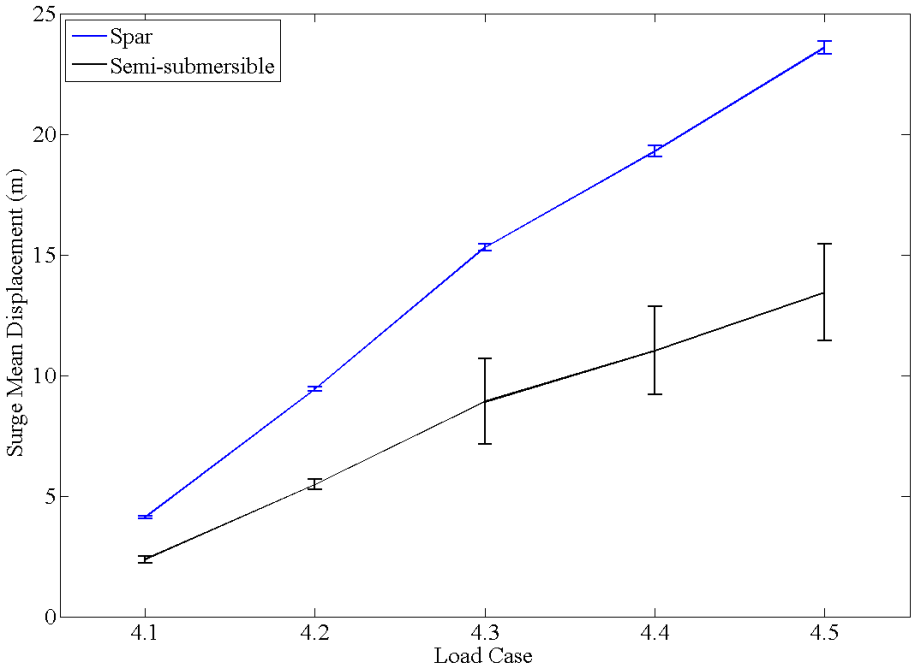



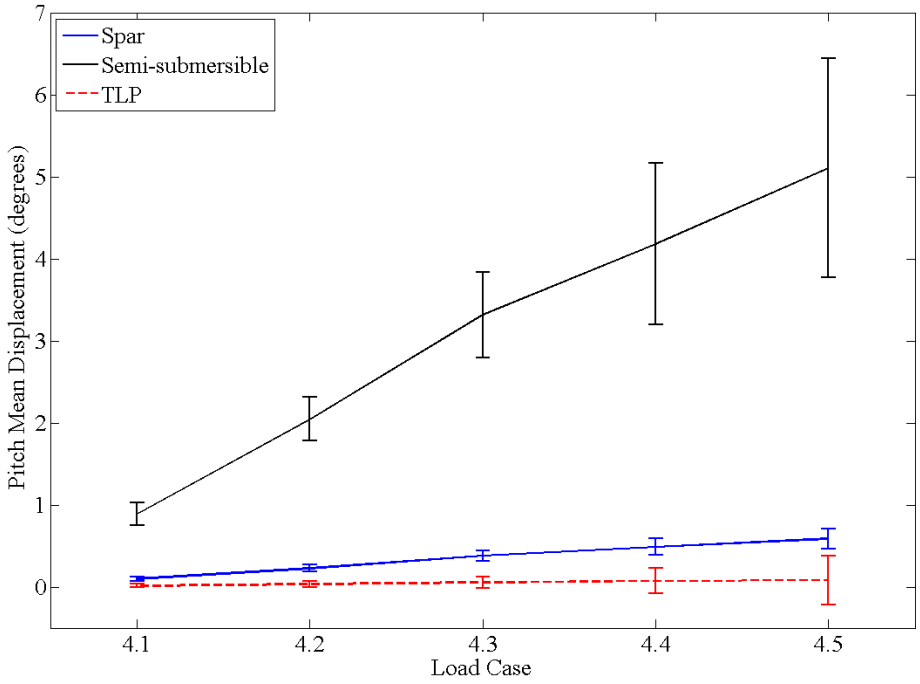
# Results Wind Only



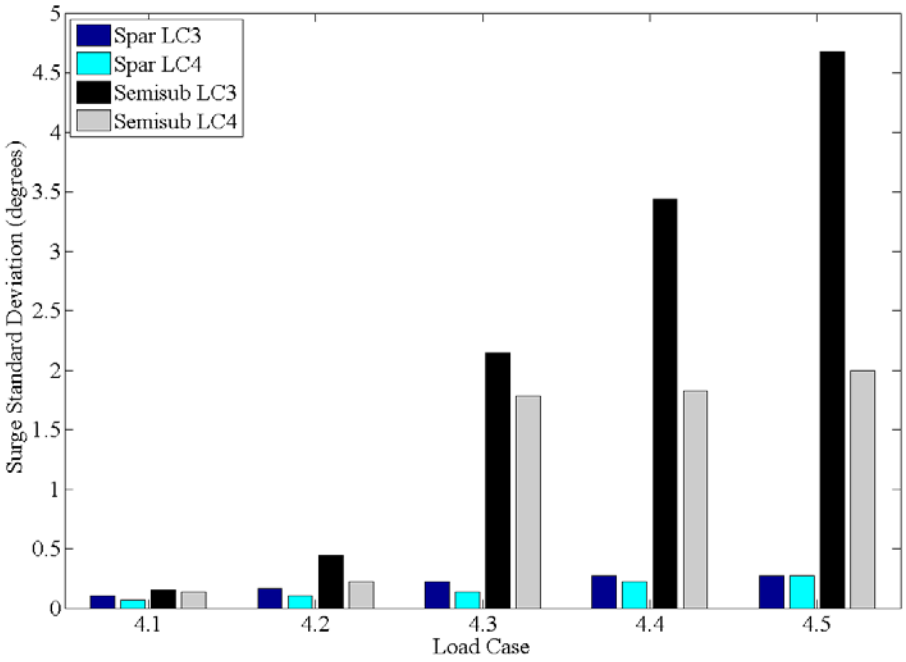
# Results
# Met-ocean



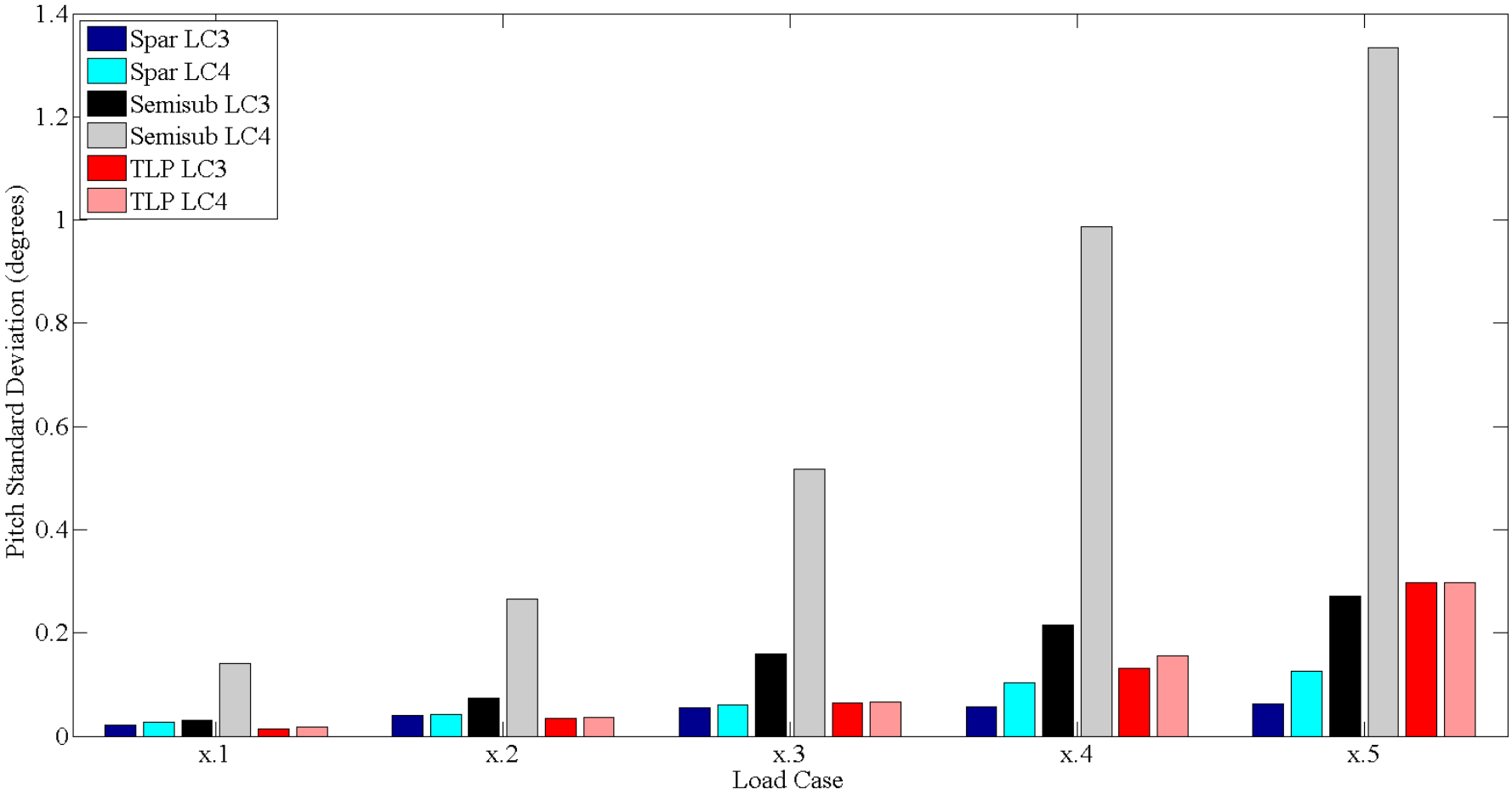
# Results

## Wind Only vs. Met-ocean



# Results

## Wind Only vs. Met-ocean



# Conclusions

- Three floating VAWT configurations
- Differences in mooring systems required HAWT vs. VAWT
- Wind-only & met-ocean responses

**FUTURE WORK**

- Frequency response analyses
- More expansive load cases
- Use DeepWind optimised design

Thank you for attention

Questions?

# References


[1] Vita, L. (2011), *Offshore floating vertical axis wind turbines with rotating platform (Ph.D. thesis), Technical University of Denmark, Roskilde, Denmark.*

[2] Jonkman, J. and Musial, W. (2010), *Offshore Code Comparison (OC3) for IEA Task 23 Offshore Wind Technology and Deployment, NREL/TP-5000-48191, NREL, Colorado*

[3] Robertson, A., Jonkman, J., Musial, W., Vorpahl, F. and Popko, W. (2013), "Offshore Code Comparison Collaboration, Continuation: Phase II Results of a Floating Semisubmersible Wind System", *EWEA Offshore 2013, 19-21 November, 2013, Frankfurt, Germany.*

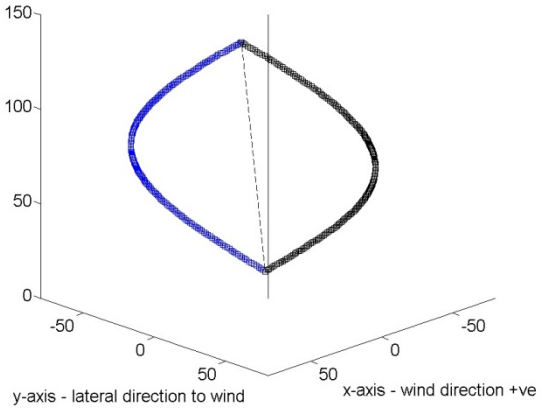
[4] Stewart, G. M., Lackner, M., Robertson, A., Jonkman, J. and Goupee, A. J. (2012), "Calibration and Validation of a FAST Floating Wind Turbine Model of the DeepCwind Scaled Tension-Leg Platform", *22nd International Offshore and Polar Engineering Conference, 17-22 June, 2012, Rhodes, Greece, ISOPE*

[5] Collu, M., Borg, M., Shires, A., Rizzo, N. F. and Lupi, E. (2014), "Further progresses on the development of a coupled model of dynamics for floating offshore VAWTs", *ASME 33rd International Conference on Ocean, Offshore and Arctic Engineering, 8-13 June 2014, San Francisco, USA.*

[6] Fossen, T. I. and Perez, T. *, MSS. Marine Systems Simulator (2010), available at: http://www.marinecontrol.org*

# VAWT Definition

| | |
|---|---|
| Rotor height, root-to-root (m) | 129.56 |
| Rotor radius (m) | 63.74 |
| Chord (m) | 7.45 |
| Airfoil section | NACA0018 |
| Total mass, including tower and generator (kg) | 844226 |
| Centre of gravity, from tower base (m) | 67.4 |
| Rated power (MW) | 5.0 |
| Rated wind speed at 79.78m above MSL (m/s) | 14 |
| Rated rotational speed (rpm) | 5.26 |



# FOWT Definitions

| | Spar | Semi-sub | TLP |
|---|---|---|---|
| Draft, from keel (m) | 120 | 20 | 30 |
| Mass (tonnes) | 8125.2 | 14108 | 1505.8 |
| Centre of Gravity (CG), from keel (m) | 45.37 | 11.07 | 64.1 |
| Radius of gyration about CG , roll (m) | 30.11 | 30.59 | 66.88 |
| Radius of gyration about CG, pitch (m) | 29.01 | 29.97 | 64.13 |
| Radius of gyration about CG, yaw (m) | 8.83 | 29.91 | 19.85 |

# Load Cases

| | | Initial conditions | | | Simulation Length (s) | | | Time step (s) |
|---|---|---|---|---|---|---|---|---|
| | | Spar | Semi-sub | TLP | Spar | Semi-sub | TLP | |
| LC1.1 | Surge | +12m | +12m | N/A | 1200 | 1200 | N/A | 0.1 |
| LC1.2 | Heave | +6m | +6m | +0.35m | 150 | 150 | 50 | 0.1 |
| LC1.3 | Pitch | +5deg | +8deg | +0.5deg | 300 | 300 | 50 | 0.1 |
| LC1.4 | Yaw | N/A | +8deg | +15deg | N/A | 900 | 200 | 0.1 |

| | No.of wave components | Length (s) | Time step (s) |
|---|---|---|---|
| LC2.1 | 800 | 3600 | 0.1 |

# Load Cases

| | Wind Condition | $U_{ref}$ (m/s) | Simulation Length (s) | Time step (s) |
|---|---|---|---|---|
| LC3.1 | Cut-in | 5 | 1800 | 0.1 |
| LC3.2 | Below-rated | 9 | 1800 | 0.1 |
| LC3.3 | Rated | 14 | 1800 | 0.1 |
| LC3.4 | Above-rated | 18 | 1800 | 0.1 |
| LC3.5 | Cut-off | 25 | 1800 | 0.1 |

# Load Cases

| | $U_{ref}$ (m/s) | $H_s$ (m) | $T_p$ (s) | Simulation Length (s) | Time step (s) |
|---|---|---|---|---|---|
| LC4.1 | 5 | 2.1 | 9.74 | 3600 | 0.1 |
| LC4.2 | 9 | 2.88 | 9.98 | 3600 | 0.1 |
| LC4.3 | 14 | 3.62 | 10.29 | 3600 | 0.1 |
| LC4.4 | 18 | 5.32 | 11.06 | 3600 | 0.1 |
| LC4.5 | 25 | 6.02 | 11.38 | 3600 | 0.1 |

# Natural Periods/ Damping Ratios

| | Natural period (s) | | | | Damping ratio | | | |
|---|---|---|---|---|---|---|---|---|
| | Surge | Heave | Pitch | Yaw | Surge | Heave | Pitch | Yaw |
| Spar | 137.7 | 31.7 | 41.0 | N/A | 0.050 | 0.060 | 0.057 | N/A |
| Semi-submersible | 112.6 | 17.5 | 29.0 | 80.2 | 0.066 | 0.097 | 0.050 | 0.037 |
| TLP | N/A | 1.07 | 2.85 | 15.9 | N/A | 0.021 | 0.046 | 0.025 |

# Predicted RAOs