Validation of Model Predictions of the Influence from Hull-Based Tuned Mass Dampers on the Dynamics of a Floating Wind Semisubmersible Platform

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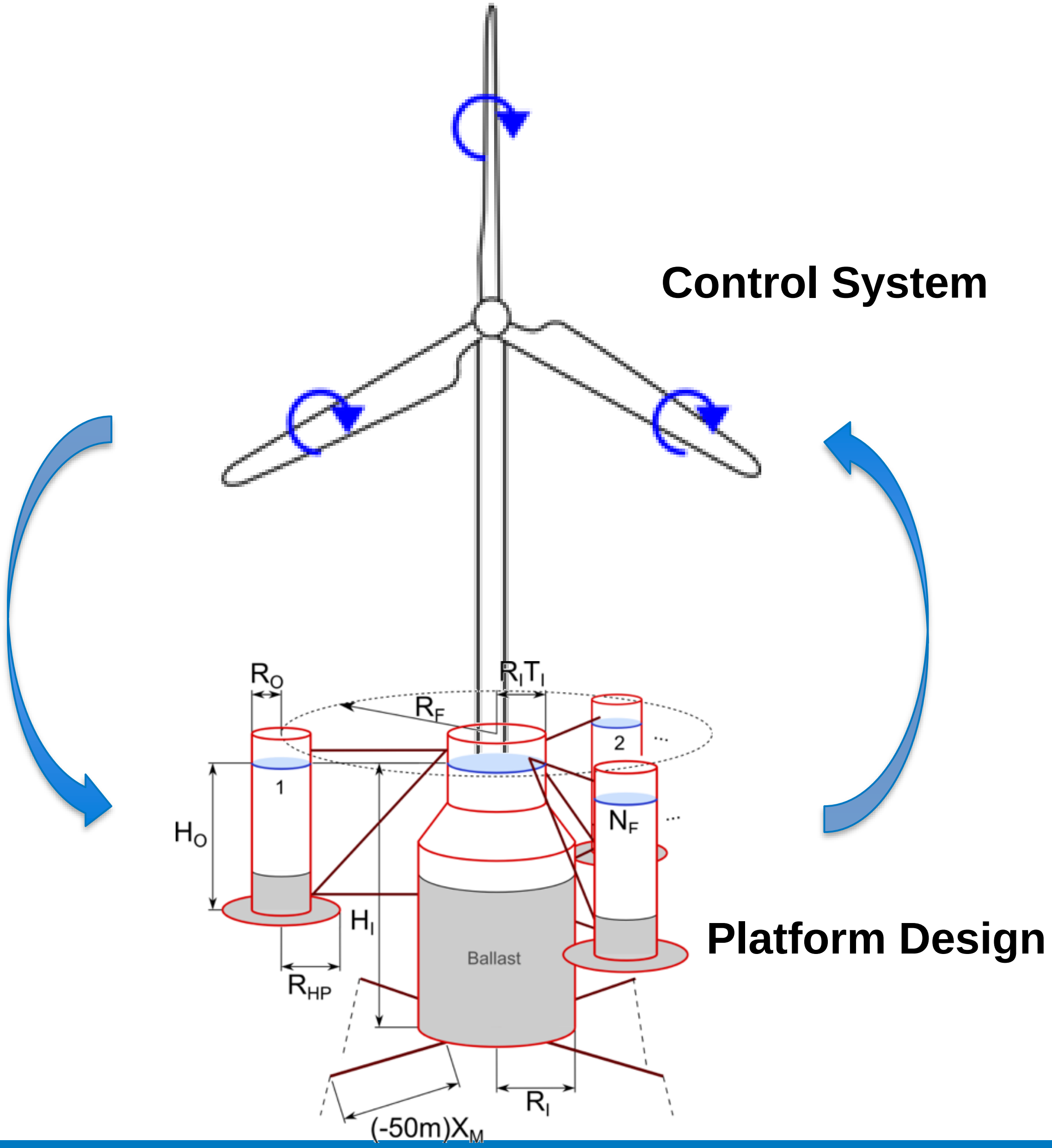
Control Co-Design (CCD)

More optimized floating wind designs can be achieved through a controls co-design (CCD) approach

- Controls as a fundamental part of the design process
- Controls can be used to reduce support structure requirements



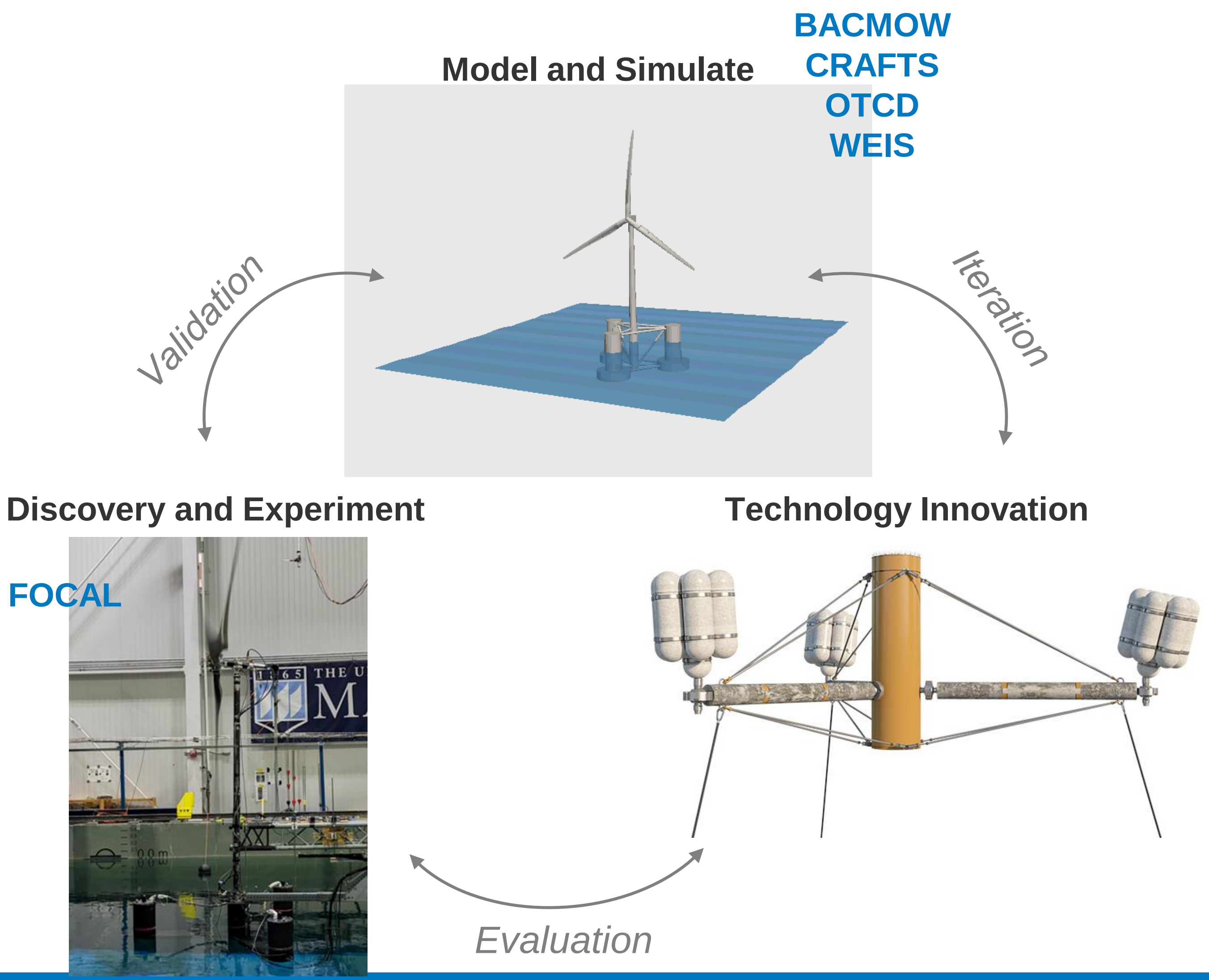
ATLANTIS Program

ARPA-E ATLANTIS

The **ATLANTIS** program by ARPA-e* brings CCD to offshore wind by addressing four critical areas

- **Computer Tools**
- **Experiments**
- New Designs
- Components

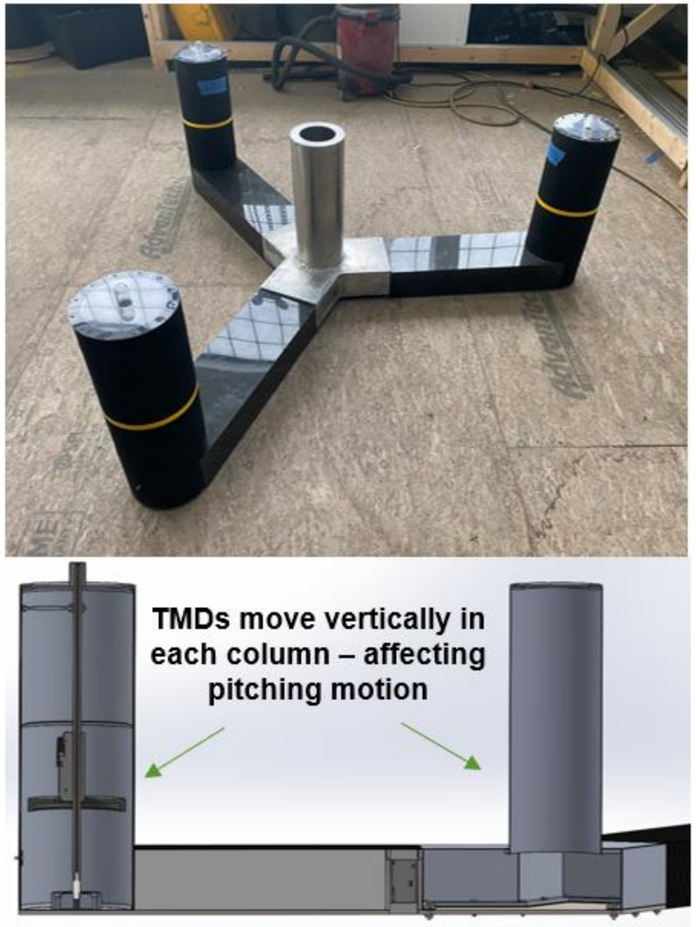
To effectively enable a CCD approach, coupled aero-servo-hydro-elastic software tools must be developed and then validated with experimental data



FOCAL Experimental Program

Four experimental campaigns to validate the tools used to optimize floating wind systems using a CCD approach.

Campaign 1: Advanced FOWT Controls



Campaign 2 and 3: Hull Controls and Flexibility

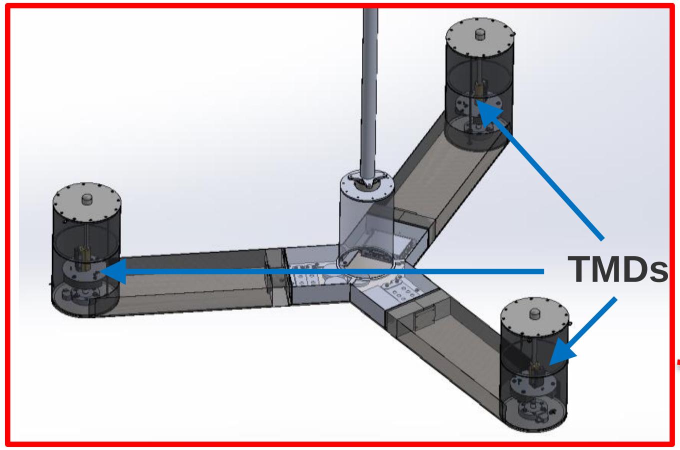
Campaign 4: Integrated System Control: Turbine+Hull

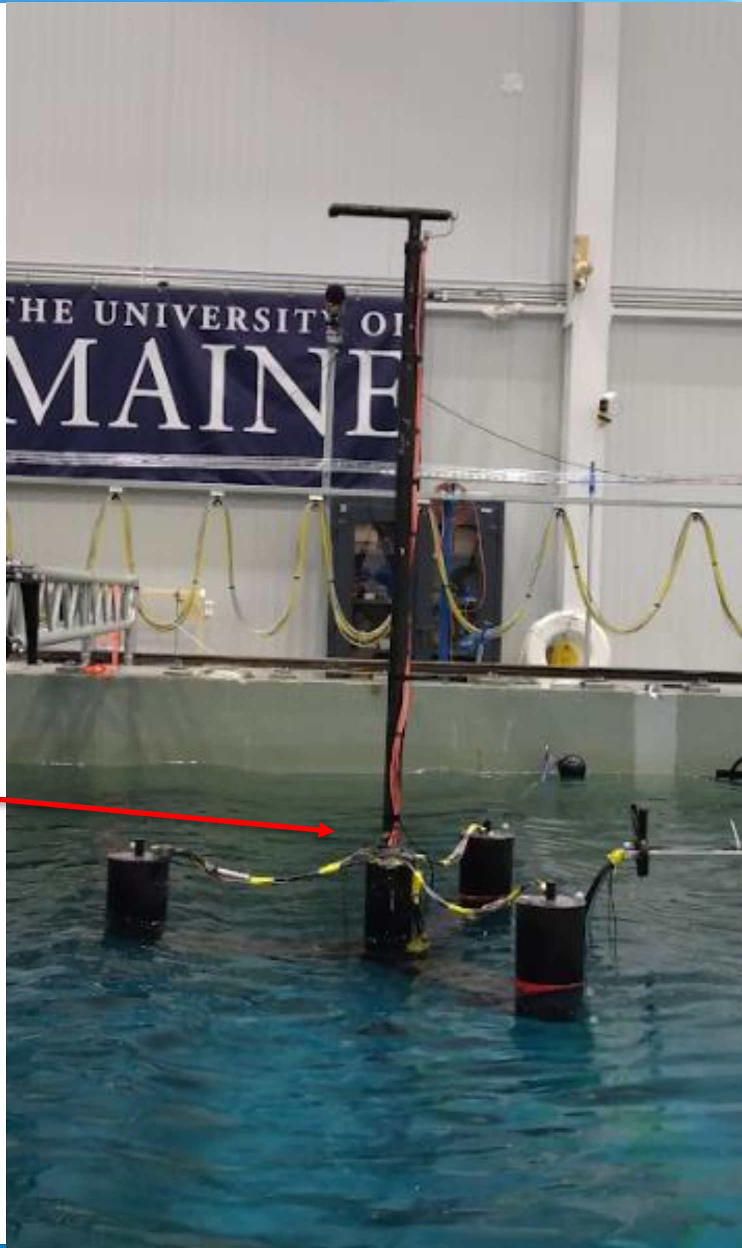
FOCAL Project - Campaign 2: ***Hull Control***

Objective: Generate a dataset to validate the performance and loads of a floating wind turbine with and without platform control.

- **Tuned-mass-damper (TMD) system** in the outer columns of the IEA 15MW VolturnUS-S semi-sub hull
- **Demonstrate decreased system motion and loads** for turbine, tower to allow for light-weighting of components
  - Advance industry standards - respond to wave excitation and not simply the mean offset due to wind thrust
  - Scale control approach to represent appropriate full-scale dynamics in scaled wind/wave facility.

Basin Model Hull Subframe





ATLANTIS Modeling Approaches for Validation

BACMOW

Tool: Bladed

Hydrodynamics:
- Linear hydrostatics
- 1st- and 2nd-order PF
- Linear damping matrix
- BACMOW1:
  - Quad. damp. matrix
- BACMOW2:
  - Morison drag

Structural Dynamics
- Platform = rigid body
- Tower = flex beam
- RNA = lumped mass
- Mooring = massless spring
- TMD = passive

CRAFTS

Tool: NEW

Hydrodynamics:
- Direct buoyancy calc based on geometry
- Strip theory w/ var coeff along length
- Linear damping matrix

Structural Dynamics
- Platform = rigid body
- Tower = flex beam
- RNA = lumped mass
- Mooring = massless spring
- TMD = passive

OTCD

Tool: NEW

Hydrodynamics:
- Direct buoyancy calc based on geometry
- Strip theory w/ var coeff along length
- Additional linear strip-theory drag force

Structural Dynamics
- Platform = rigid body
- Tower = flex beam
- RNA = lumped mass
- Mooring = massless spring
- TMD = passive

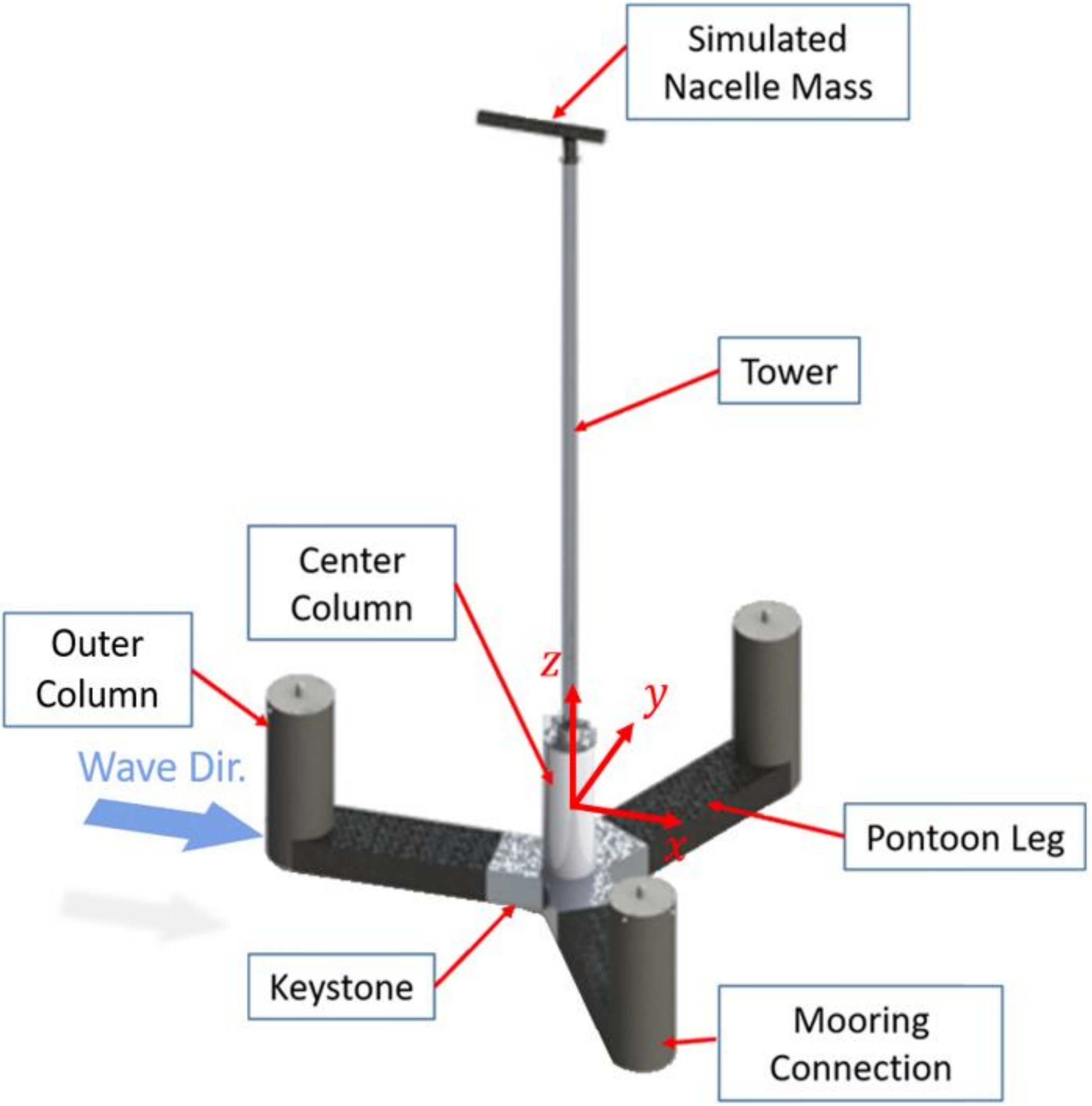
WEIS

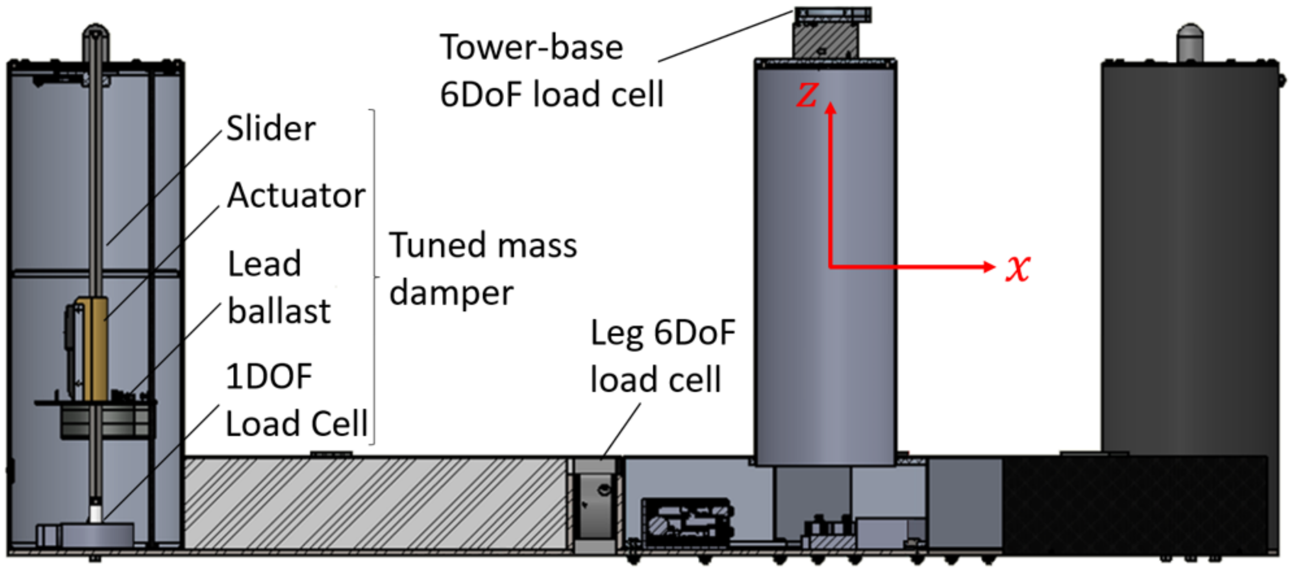
Tool: OpenFAST

Hydrodynamics:
- Linear hydrostatics
- 1st- and 2nd-order PF
- Linear damping matrix
- Quad. Damp. matrix

Structural Dynamics
- Platform = rigid body
- Tower = flex beam
- RNA = lumped mass
- Mooring = massless spring
- TMD = passive

1:70 model of the VolturnUS-S offshore wind semisubmersible





Load Cases

Table 1. Full-scale properties of the incident waves.

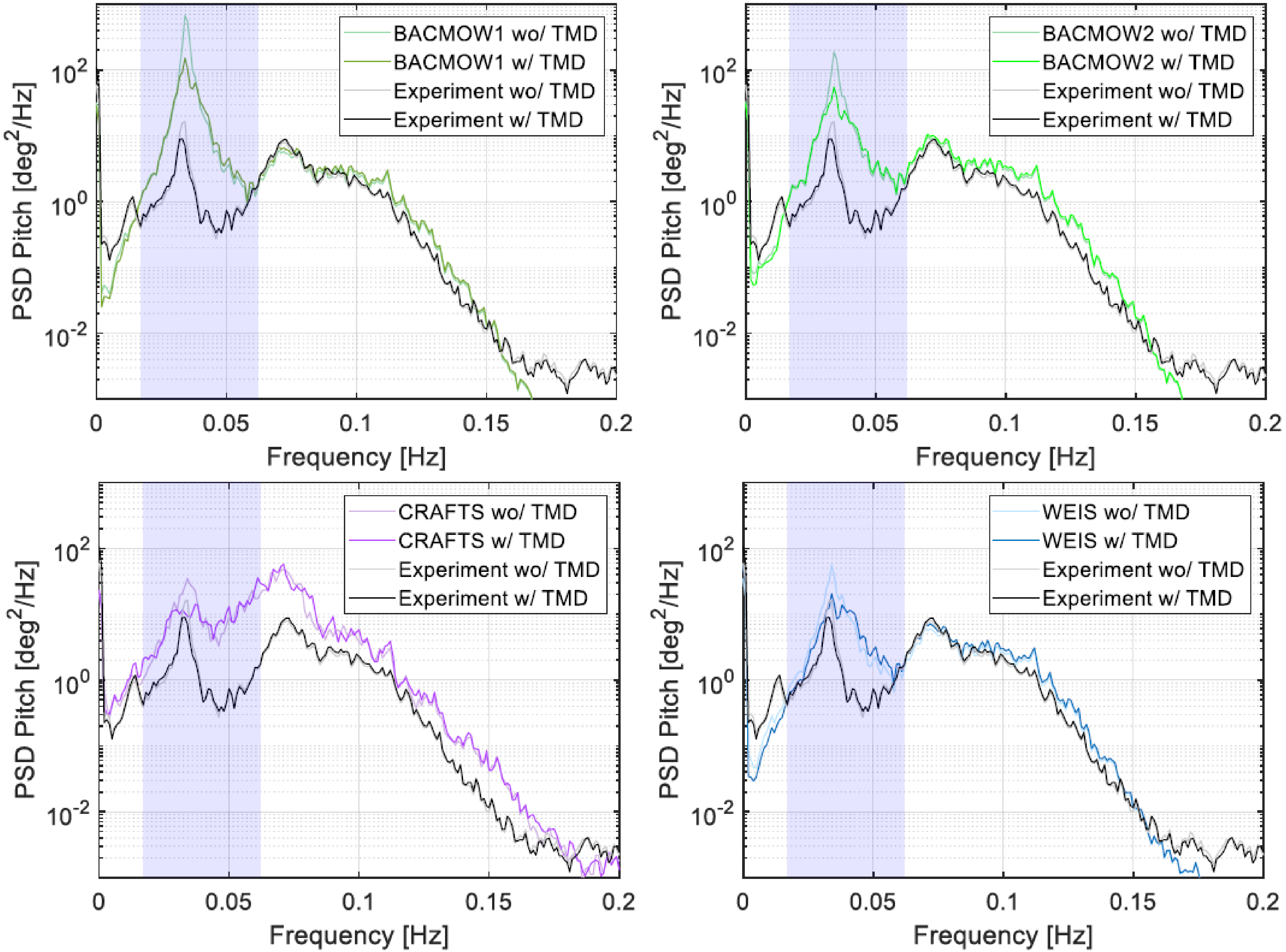
Wave Condition	Spectrum	Significant Wave Height [m]	Peak Period/ Period Range [s]	Peak Shape Factor [-]	Return Period [yr.]
I2	JONSWAP	6.3	11.46	2.75	1
I4	JONSWAP	10.89	14.20	2.75	50
PN1	Pink Noise	7.9	10.0–33.3	N/A	N/A

Table 2. List of load cases (LCs).

Wave Condition	TMDs locked	TMDs tuned to platform pitch resonance frequency	TMDs tuned to first fore-aft tower-bending frequency
I4	LC 3.2	LC 3.5	LC 3.8
PN1	LC 3.3	LC 3.6	LC 3.9
I2	LC 3.10	LC 3.11	LC 3.12

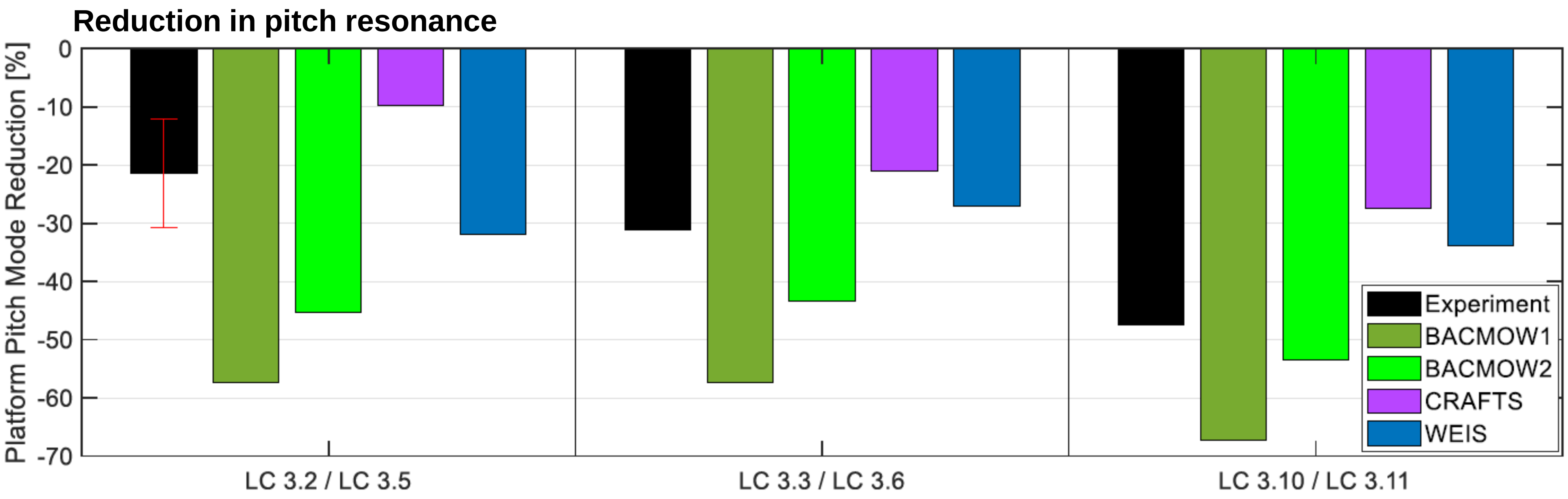
Impact of TMD on Pitch Motion

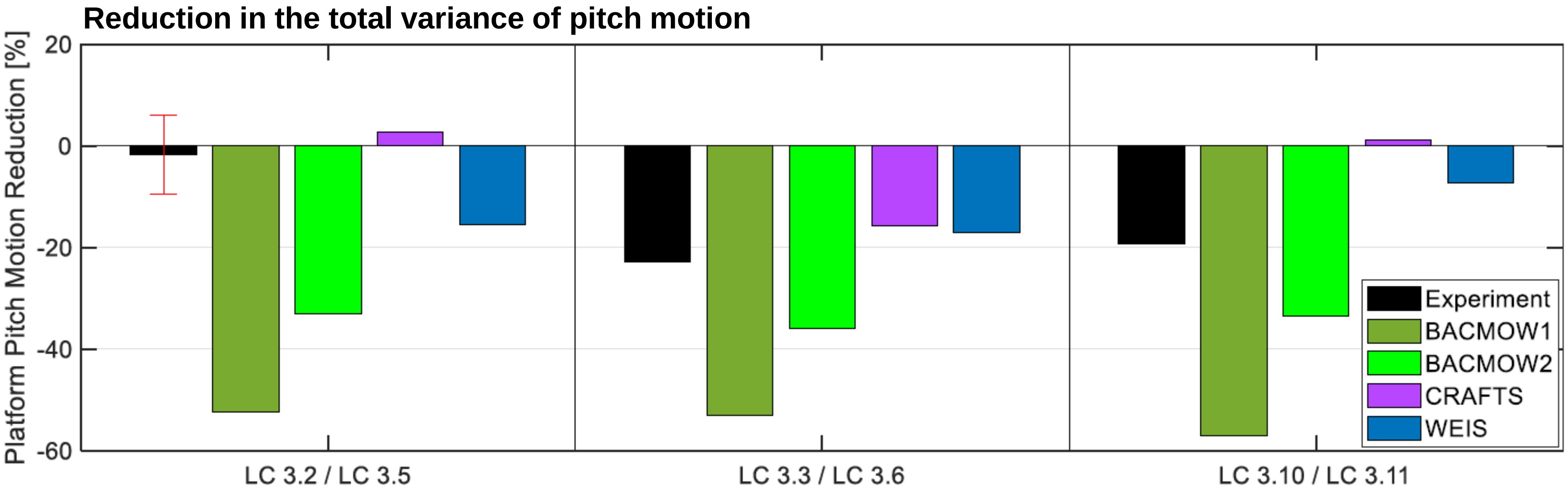
- TMDs tuned to pitch resonance frequency
- PSD shows reduction in peak of pitch resonance with compared to without TMDs
- All models overpredict low-frequency pitch motion
  - BACMOW using a poorly tuned pitch damping matrix
- CRAFTS also overpredicts the wave-frequency response



Pitch Motion - % Reduction when using TMDs tuned to pitch natural frequency

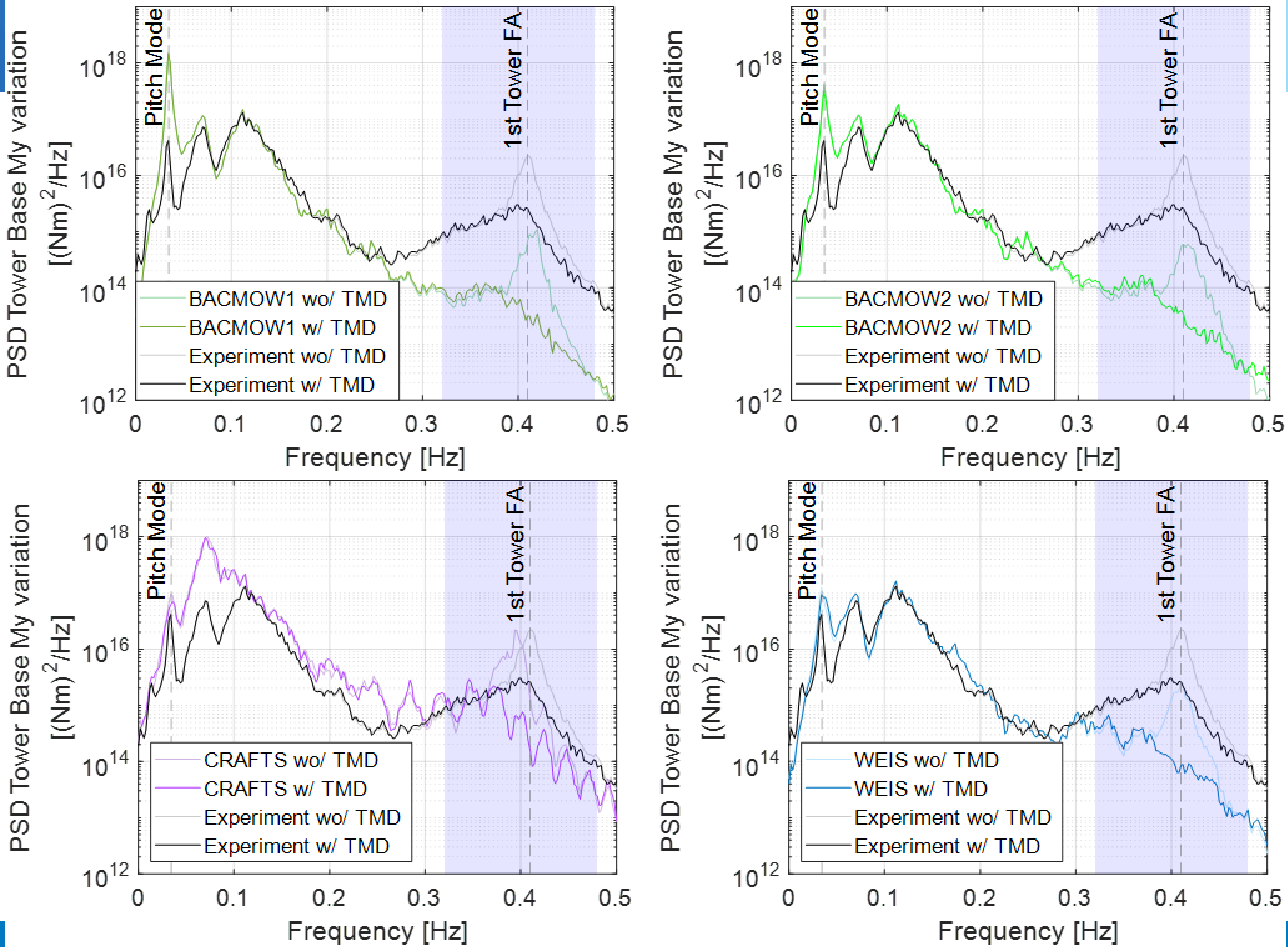
- Three irregular wave conditions (columns)
- Red bars indicate 90% confidence intervals covering random errors in the experiment
- Fatigue metric shown for:
  - Row 1: Pitch Res. Freq.
  - Row 2: Total Variance
- Reduction in pitch motion over-predicted by some tools – due to over-prediction of the low-frequency motion
  - BACMOW does not have sufficient pitch damping





Impact of TMD on Tower Loads

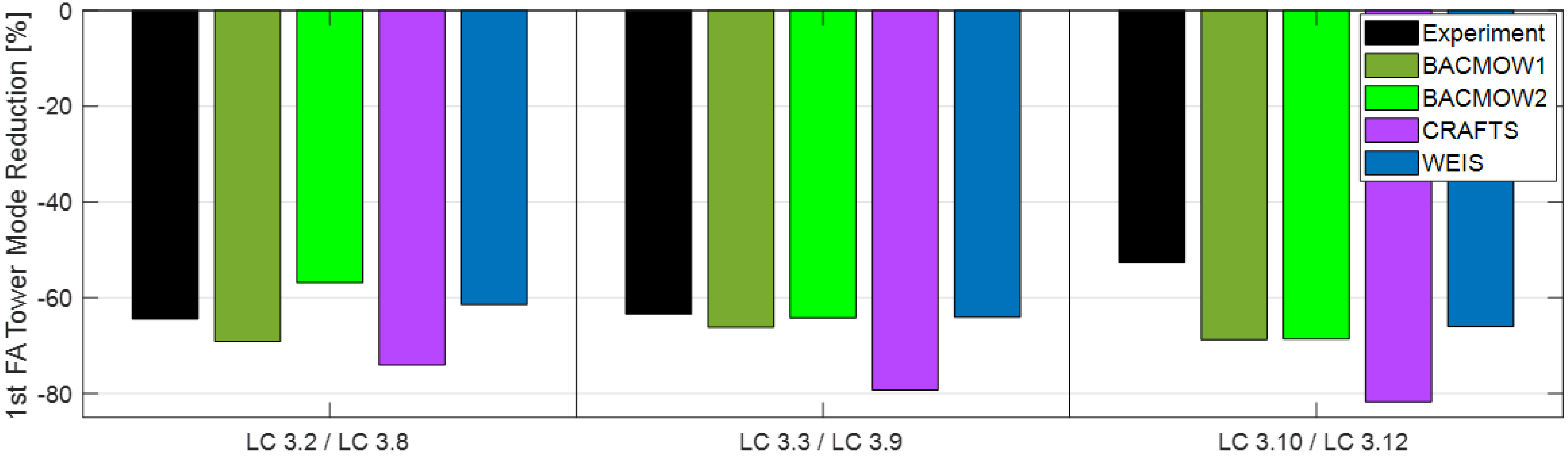
- TMDs tuned to tower-bending resonance frequency
- PSD of tower-base bending moment shows reduction near tower resonance when compared to without TMDs
- Tower resonance peak:
  - BACMOW/WEIS – (PF models) under-predict
  - CRAFTS – Captures the peak well but has a frequency shift



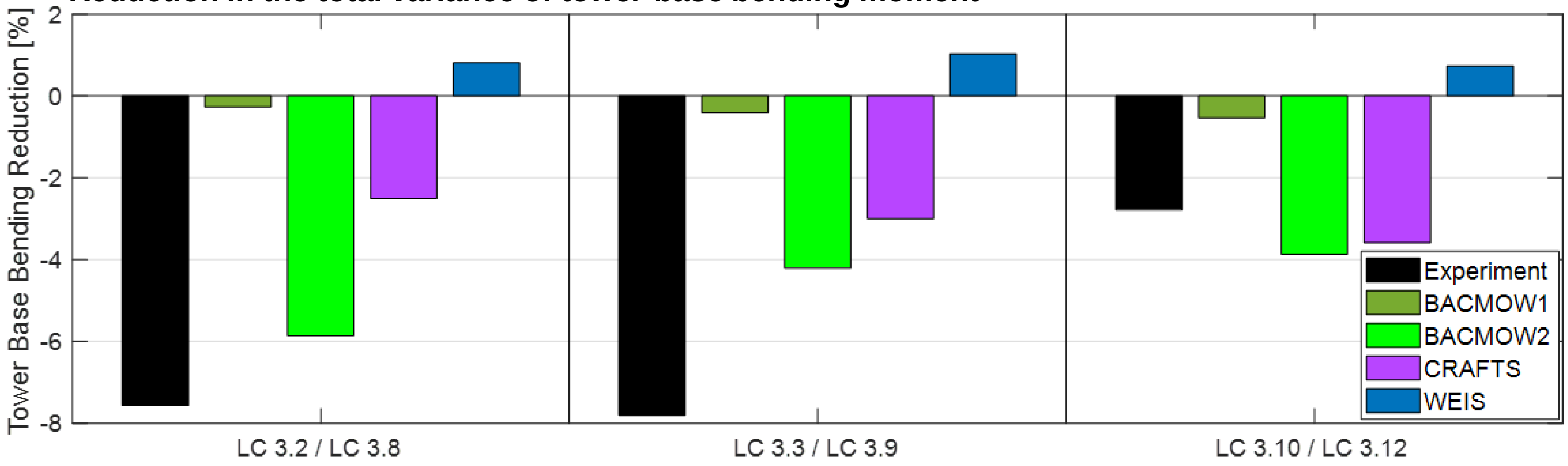
Tower Loads - % Reduction when using TMDs tuned to tower natural frequency

- Three irregular wave conditions (columns)
- Fatigue metric shown for:
  - Row 1: Tower Res. Freq.
  - Row 2: Total Variance
- Consistent relative reduction in tower-base loads from tower resonance
- Predicted reduction in the total variance of tower-base loads affected by the
  - underprediction of tower-resonance loads (BACMOW and WEIS) and
  - the overprediction of wave-frequency loads (CRAFTS)

Reduction in the tower-base bending moment from the first fore-aft tower-bending mode



Reduction in the total variance of tower-base bending moment



Conclusions

- When tuned to attenuate pitch or tower-bending resonance, the TMDs effectively reduce the pitch motion and/or the tower loads near the corresponding resonance frequency.
  - Reductions captured to some extent in the models.
- Limitations of the models:
  - CRAFTS hydrodynamic model is still needing some improvements without TMDs before it can be fairly judged for its ability to assess impact of TMDs
  - BACMOW's low-frequency damping needs better tuning
  - WEIS (and BACMOW) under-predict the tower natural frequency – this issue has been seen previously in PF-based models, with strip-theory models predicting a much larger response
- If tuned well, existing PF-based models such as OpenFAST and Bladed can predict the impact of the TMDs in the frequency region they are targeted for, but differences seen in the impact for broader frequency spectrum.

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Questions?

Thank you!