Evaluating the Effects of Added Mass on a Reference Floating Marine Turbine

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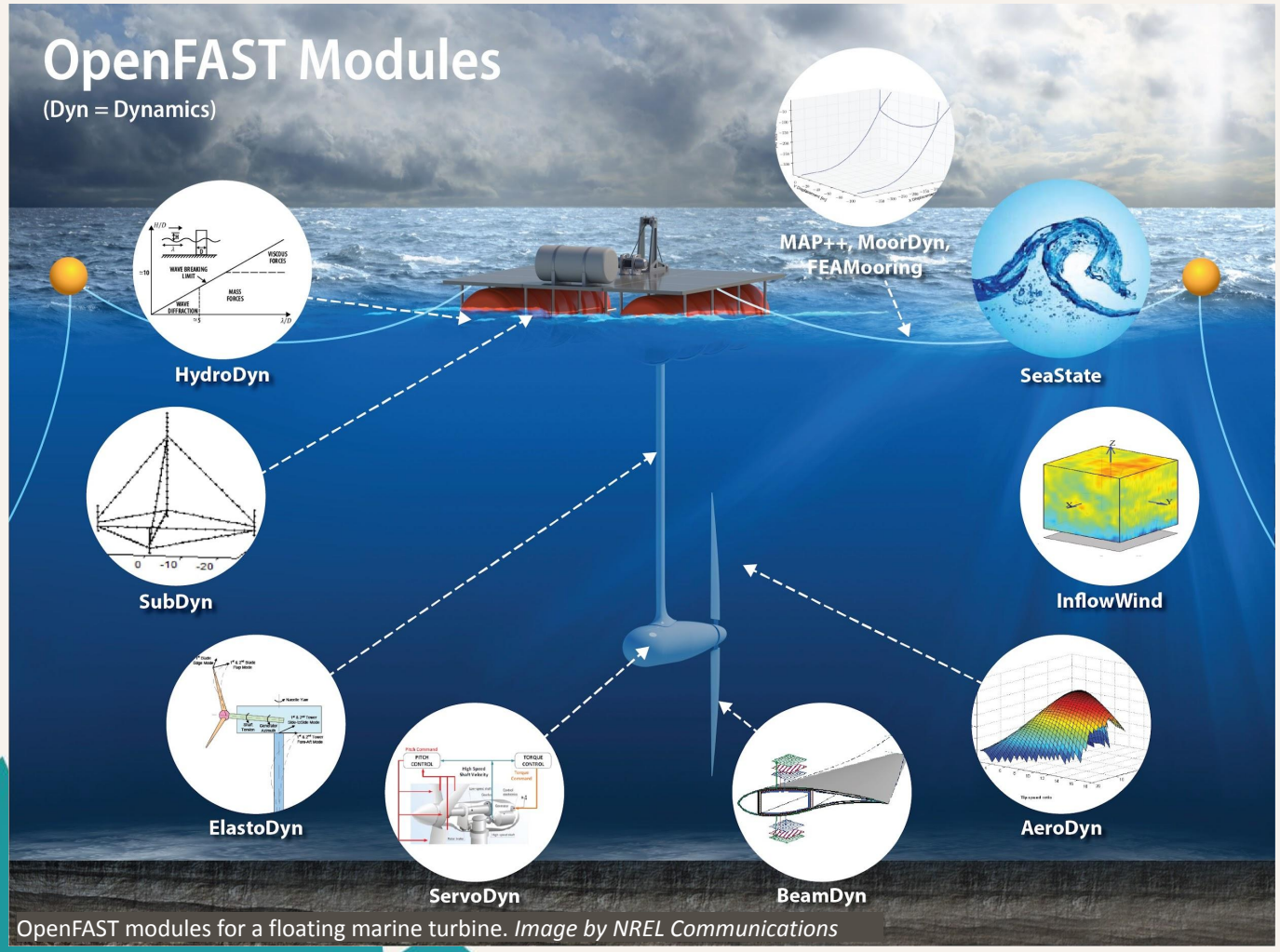
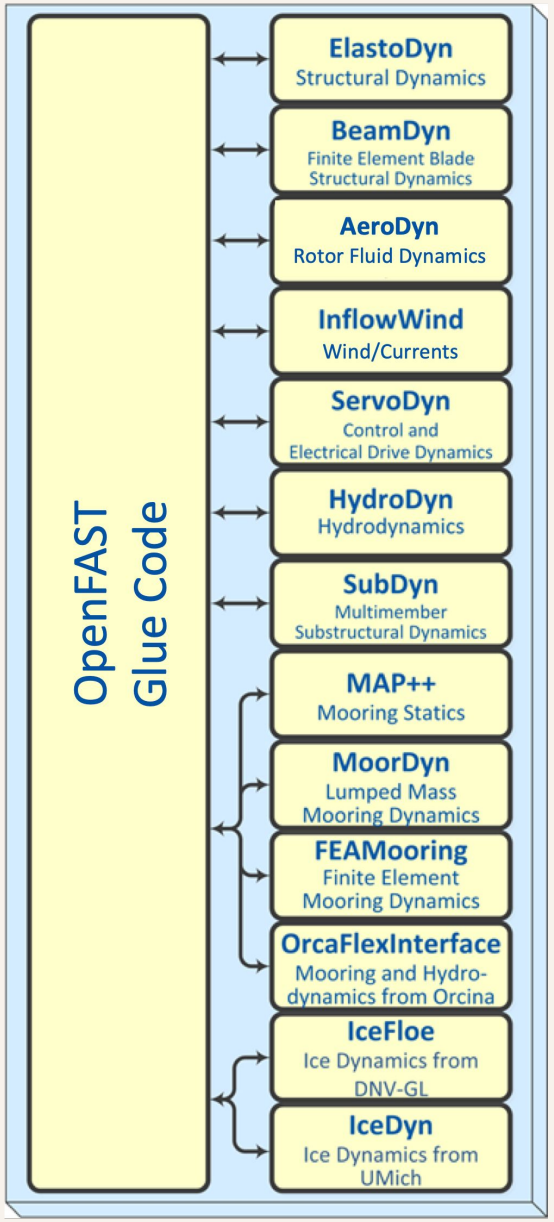
OpenFAST Summary



OpenFAST modules for a floating marine turbine. *Image by NREL Communications*



* SeaState
Waves/Currents
(pending release)

OpenFAST glue code and its modules.
Image by Jason Jonkman, NREL

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Added Mass

- Effective mass of a body increases as it moves through a fluid
- Neglected for wind turbines since added mass << structure mass
- Should be considered for marine turbines
- Implementation based on Morison's equation

$$F = \underbrace{\rho C_p V \dot{u}}_{\text{Froude-Krylov (fluid inertia)}} + \underbrace{\rho C_a V (\dot{u} - \dot{v})}_{\text{added mass}} + \underbrace{\frac{1}{2} \rho C_d A (u - v)|u - v|}_{\text{drag}}$$

Added Mass

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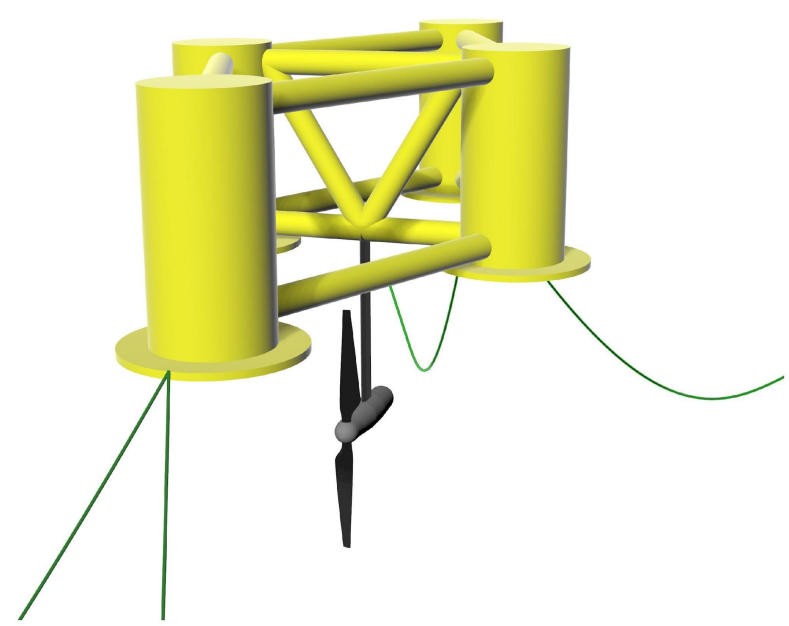
- $C_{a,n}$: normal to chord added mass coefficient
- $C_{a,t}$: tangential to chord added mass coefficient
- $C_{a,m}$: blade pitch added mass coefficient
- $C_{p,n}$: normal to chord dynamic pressure coefficient
- $C_{p,t}$: tangential to chord dynamic pressure coefficient

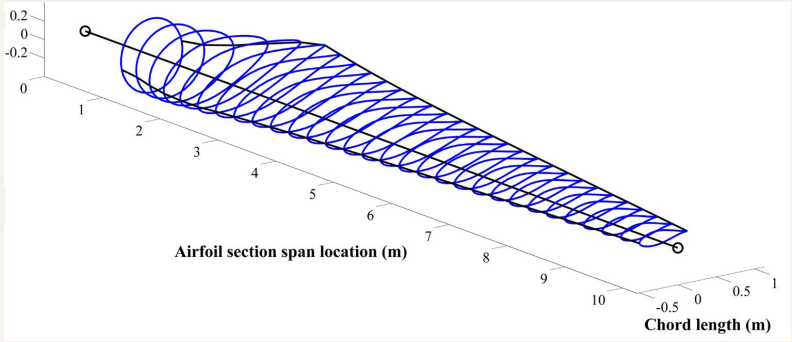
Demonstration Cases

- Simulations conducted using RM1 rotor[1]



Floating RM1 Quad. *Illustration by Will Wiley*

RM1 Rotor. *Illustration by Will Wiley*



RM1 Blade[2]

[1]V. Neary, M. Previsic, R. Jepsen, M. Lawson, Y. Yu, A. Copping, A. Fontaine, K. Hallett, D. Murray (2014). Methodology for Design and Economic Analysis of Marine Energy Conversion (MEC) Technologies. SAND2014-9040

[2]Bir, GS, Lawson, MJ, & Li, Y. "Structural Design of a Horizontal-Axis Tidal Current Turbine Composite Blade." Proceedings of the ASME 2011 30th International Conference on Ocean, Offshore and Arctic Engineering. Volume 5. Rotterdam, The Netherlands. June 19–24, 2011. pp. 797-808. ASME. https://doi.org/10.1115/OMAE2011-50063

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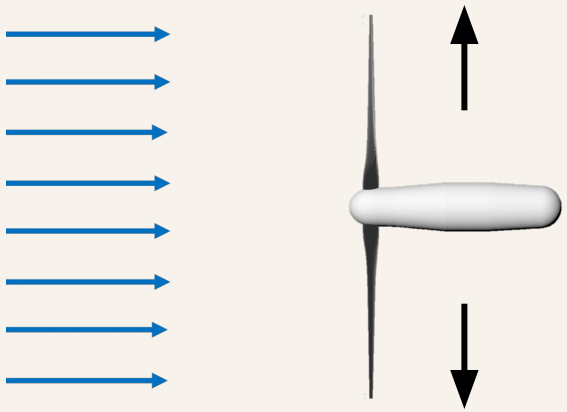
Demonstration Cases

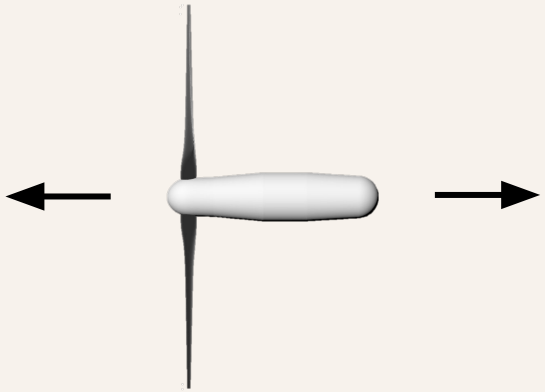
- No added mass: C_a coefficients = 0
- Inflow: C_a coefficients calculated at rated
- Calm: C_a coefficients calculated in still water

Heave



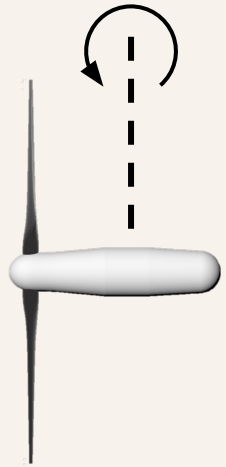
1 m amplitude
6 s period

Surge



1 m amplitude
6 s period

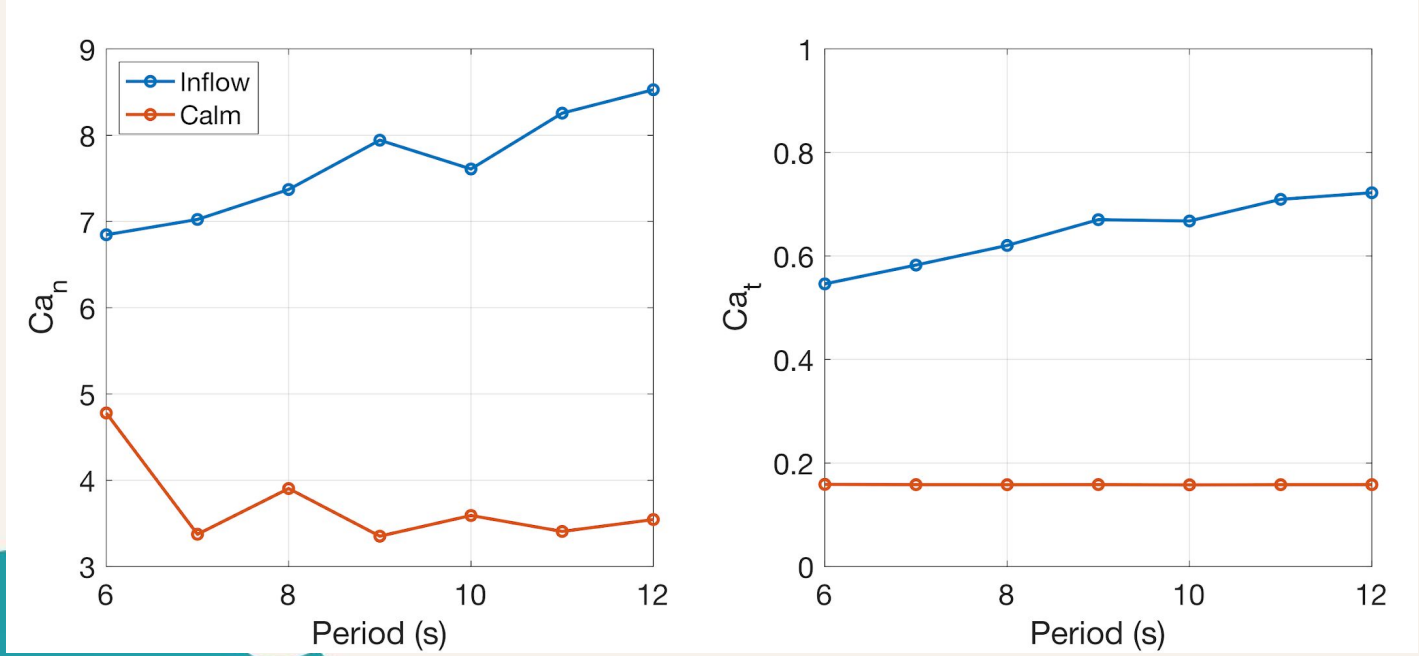
Pitch



5 deg amplitude
6 s period

Added Mass Coefficients

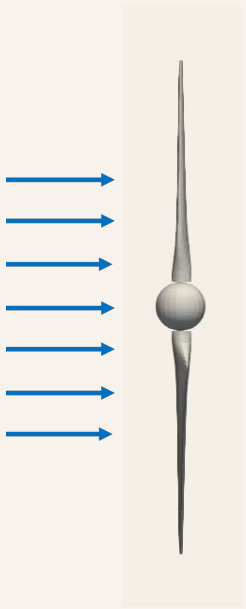
- Calculated from 2D CFD (see “Determination of Added Mass Coefficients for Floating Hydrokinetic Turbine Blades using Computational Fluid Dynamics” poster by Tran and Wiley)
  - “Inflow”: rated conditions (1.9 m/s steady and uniform inflow, 11.5 rpm)
  - “Calm”: still water conditions (no inflow, 11.5 rpm)

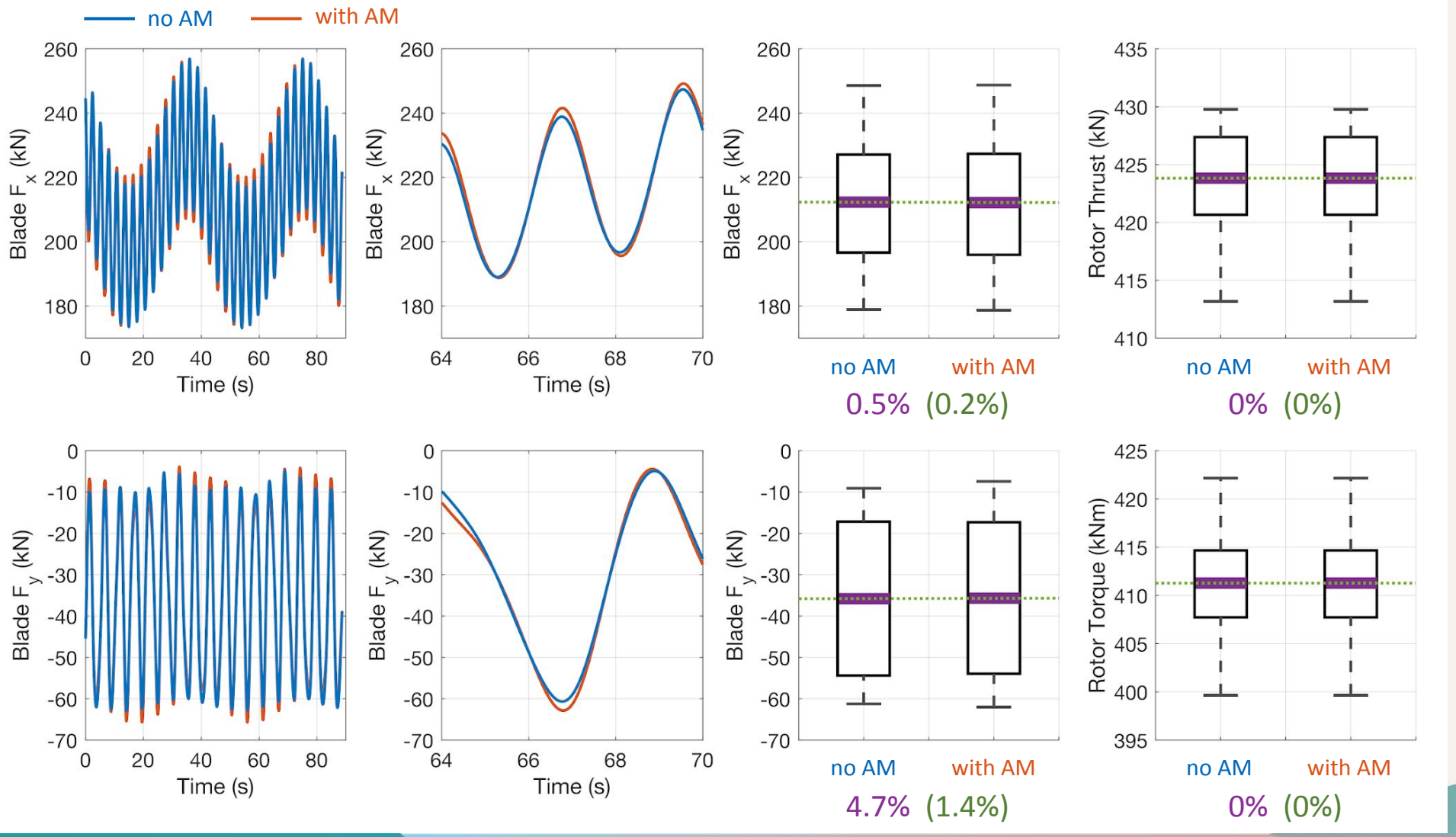


Heave: 6 s period, 1 m amplitude

Inflow $C_{a,n}$= 6.8, $C_{a,t}$= 0.55

Calm $C_{a,n}$= 4.8, $C_{a,t}$= 0.16





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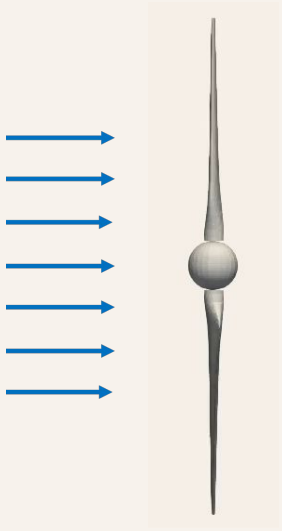

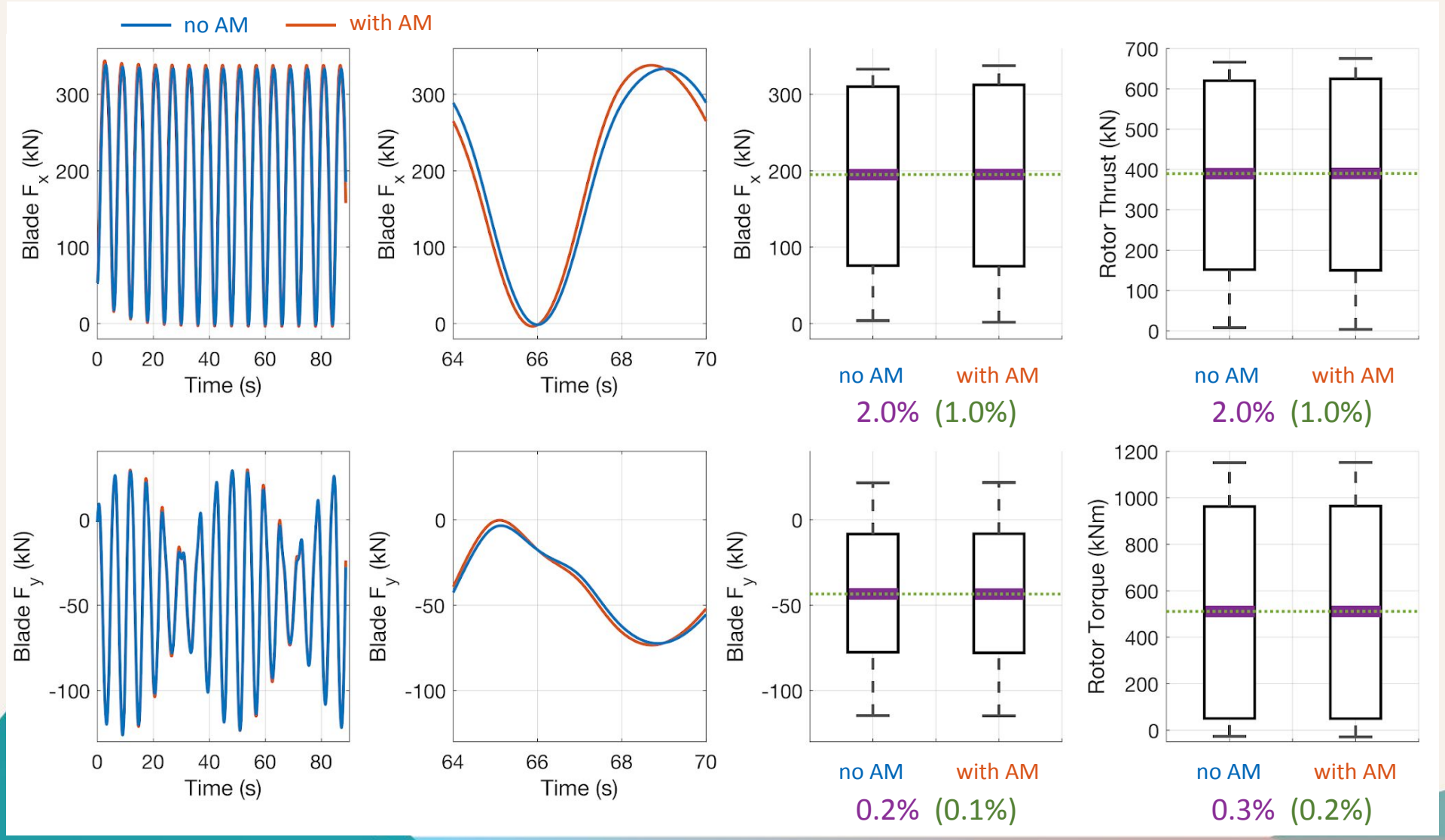

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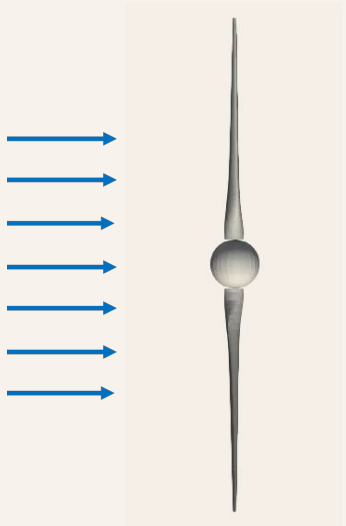
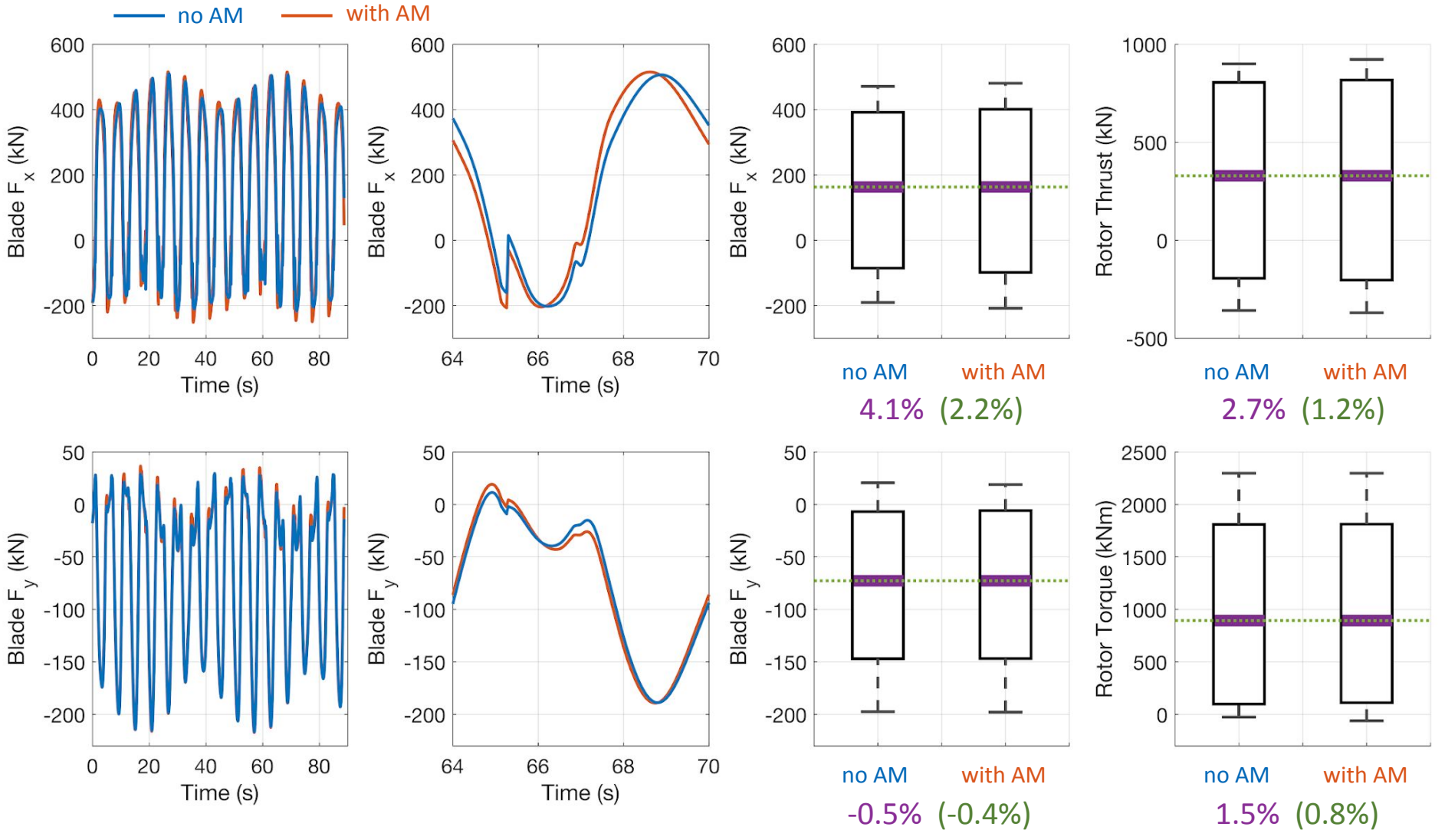
Pitch: 6 s period, 5 deg amplitude

Inflow $C_{a,n}$= 6.8, $C_{a,t}$= 0.55

Calm $C_{a,n}$= 4.8, $C_{a,t}$= 0.16





Conclusions

- OpenFAST can account for added mass on rotor blades
- Added mass coefficients are sensitive to inflow and body motions
- Added mass affects instantaneous blade and rotor loads
  - Blade, support structure, and generator sizing
  - Mean values unaffected
- Coefficients impact magnitude of added mass loads

Future Work

1. Incorporate tight coupling
2. Update example cases
3. Further quantify added mass effects
   - Wider range of amplitudes and frequencies
   - More realistic floating platform motions
   - Blade pitch, turbulent inflow, structural flexibility
   - Off-rated operating conditions

Acknowledgements

- U.S. Department of Energy Water Power Technologies Office
- U.S. Department of Energy Advanced Research Projects Agency – Energy
- Andy Platt (NREL)

NREL team encourages and supports community code contributions

- https://github.com/OpenFAST/openfast
- https://github.com/OpenFAST/r-test
- https://openfast.readthedocs.io/en/main