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Gradient-based Design Optimization of Fully-flexible Tension-leg Platform Wind Turbines

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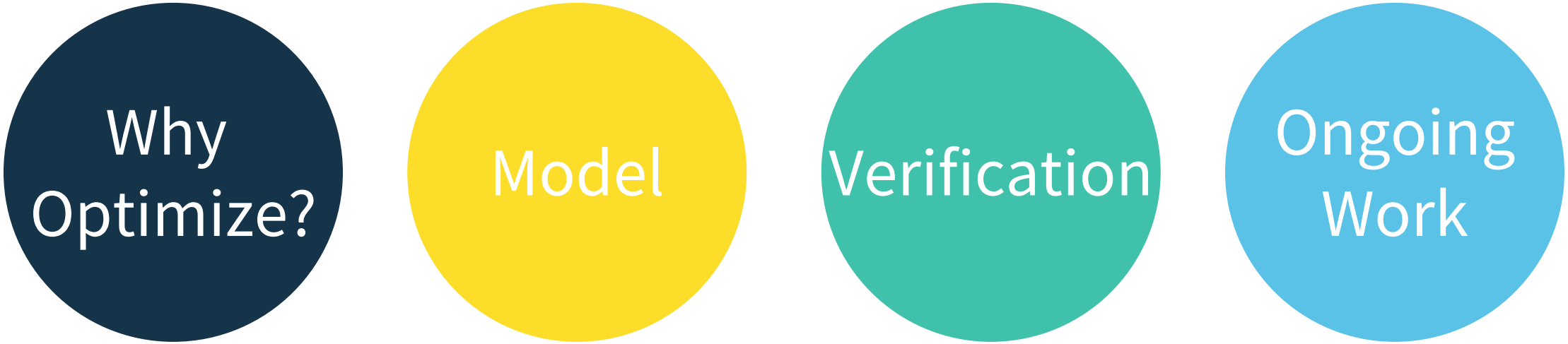
Presentation Overview



Why optimize TLPWTs?

Why Optimize?

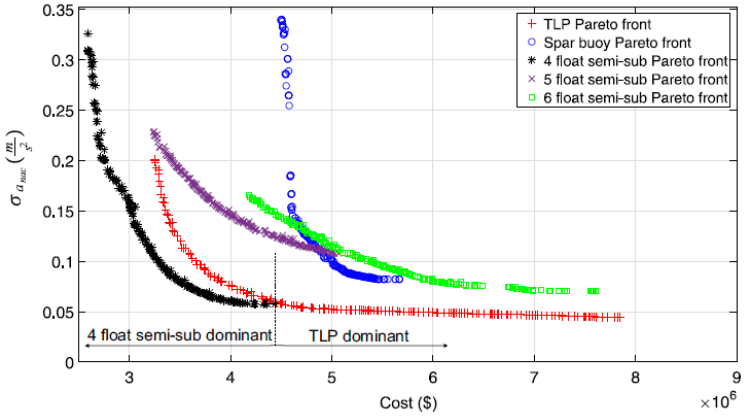
- Promising concept for restricted seabed regions
- Underexplored areas of design space
  - How do designs diverge from O/G TLPs?
- Technically interesting problem
  - Multiple submerged members
  - Significant non-rigid modes

GE/Glosten 12MW Pelastar TLPWT Design

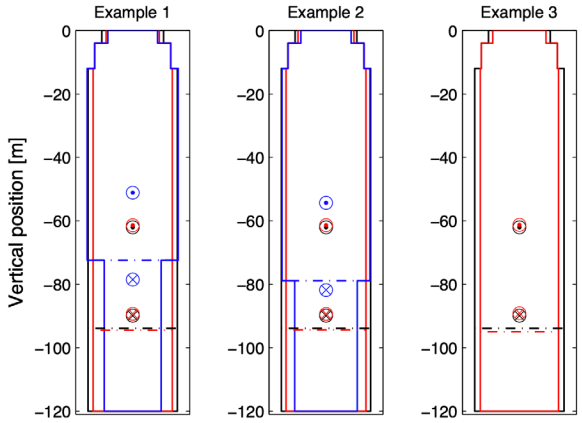
Previous FWT Optimization

Why Optimize?

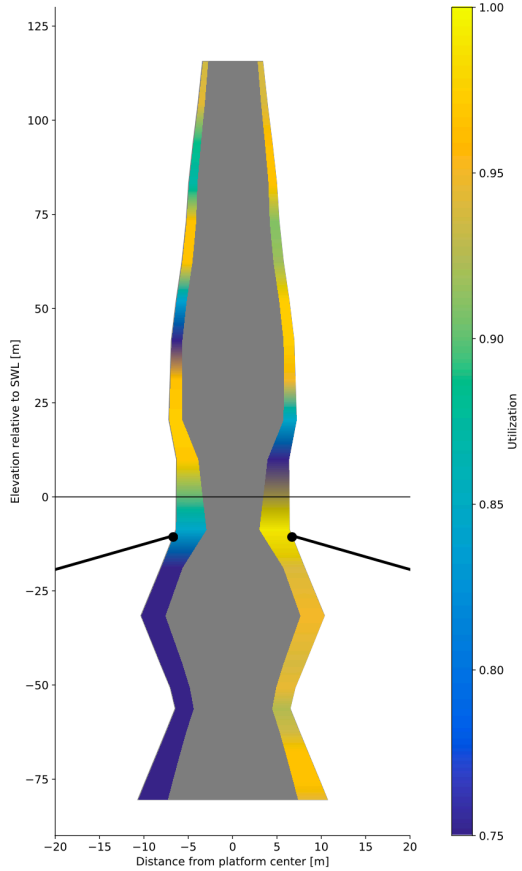
- Several applications of genetic algorithms
  - Robust methods applied to several concepts
  - Typically optimizing for cost/nacelle motions
- Gradient-free methods limit scope of studies
  - Typically limited to ~10 design variables
  - Fylling and Berthelsen showed use of gradient-based methods (GBM) for simple spar
    - Finite-difference gradients limited accuracy
- Hegseth used GBM to optimize with 80 variables
  - Combined spar/tower bending responses
  - Vectorized design variables, scantling design
  - 30 environmental conditions considered



Karimi et al., 2017



Fylling and Berthelsen, 2011



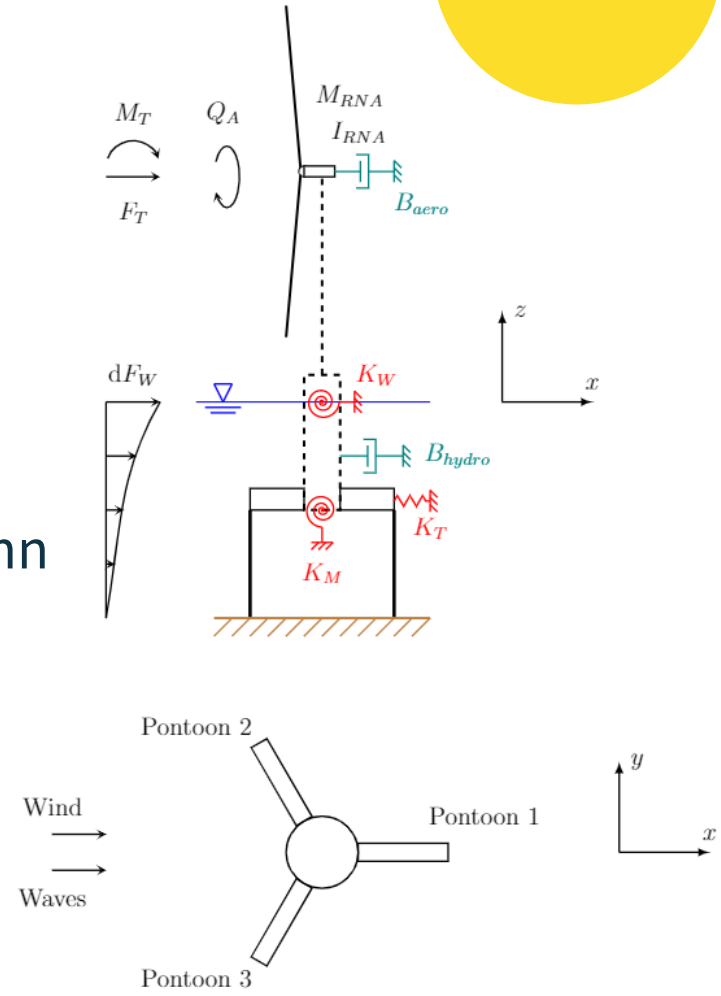
Hegseth et al., 2020

Model Development - TLPOpt

Model

- Linearized aero-hydro-servo-elastic model
  - Equation of motion constructed in state-space
  - Vectorized inputs describe column/tower

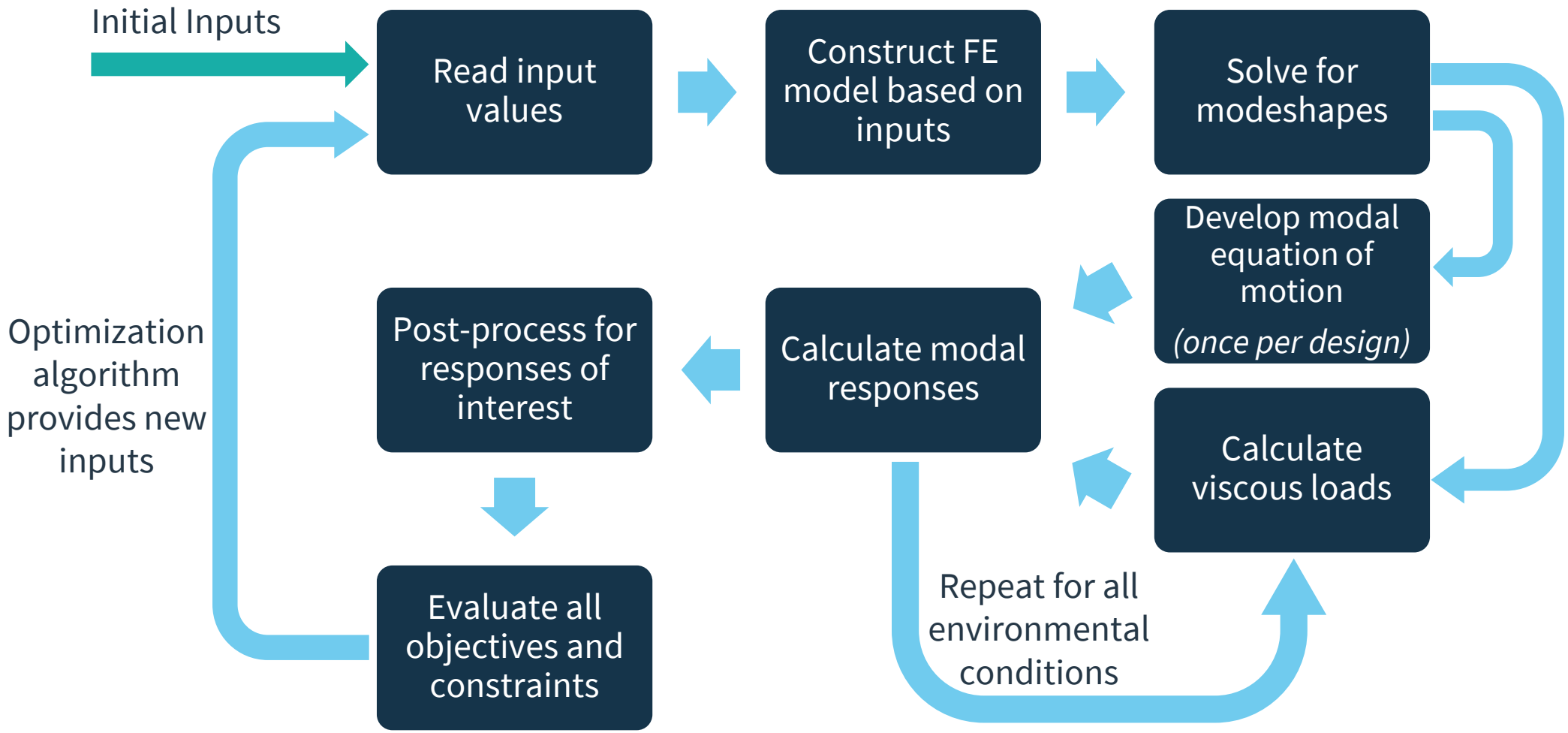
- **Hydrodynamics:** MOJS for pontoons, MacCamy-Fuchs for column
- **Structure:** Euler beams, generalized coordinates
- **Moorings:** Linear springs, neutral buoyancy
- **Aero:** Quasi-steady BEM theory
- **Controls:** Variable-speed, variable blade-pitch



Linear model of TLPWT

Model Development - TLPOpt

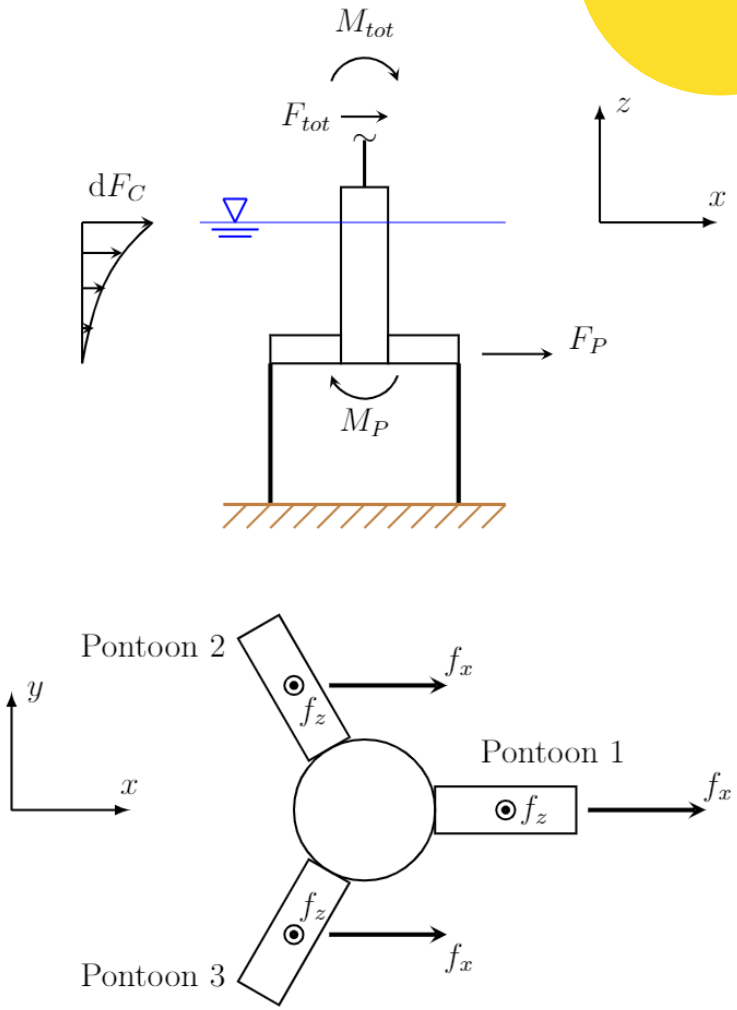
Model



Hydrodynamic Modeling

Model

- Wave loads from combination of:
  - MacCamy-Fuchs for central, surface-piercing column
  - MOJS for horizontal, submerged pontoons
  - Can be applied to generic modeshapes
- Much faster than potential flow, similar results
  - Analytical gradients can be defined for each theory
  - Flexibility for several cross-sections/layouts
- Constant added mass calculation using strip theory

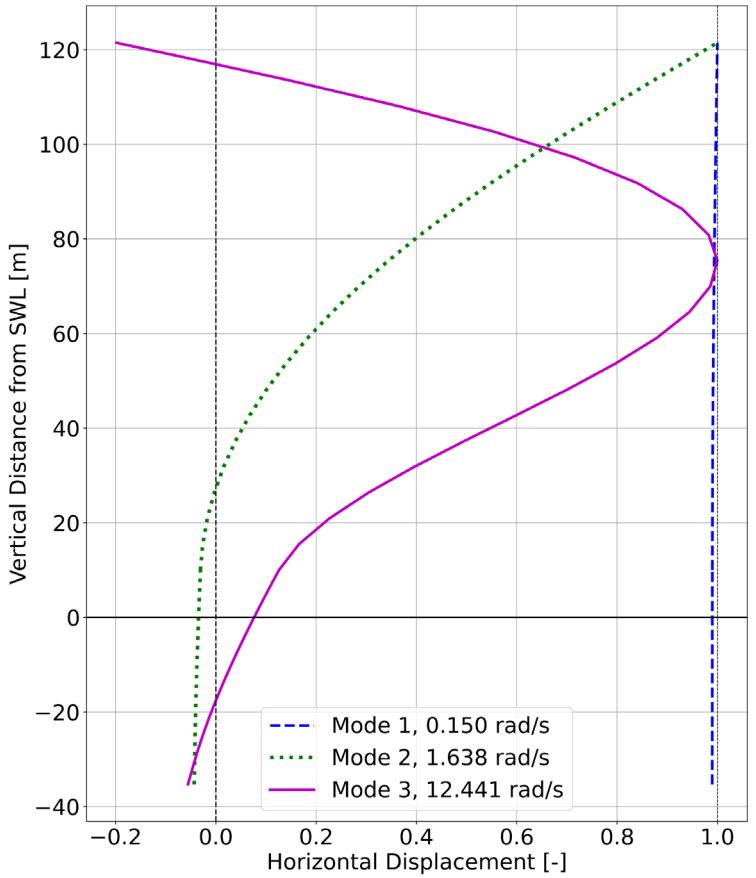


Hydrodynamic forcing of TLPWT

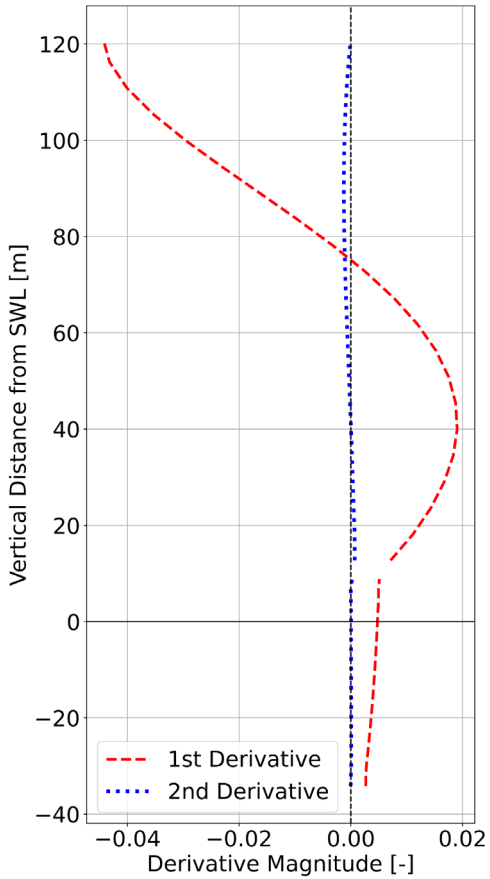
Fully Flexible Model

Model

- Rigid-body motions can not capture full response
  - FWTs experience significant bending
- Consider the first three modes in X-Z plane
  - Expandable beyond three modes
  - Applicable for other floating structures
- Finite element model used to find modes
  - Only computed once per design
- Spatial derivatives of modeshapes calculated
  - Used to develop modal equation of motion



First 3 modes of 10MW TLPWT Design



Modeshape 3 derivatives

Verification Techniques

Verification

WAMIT

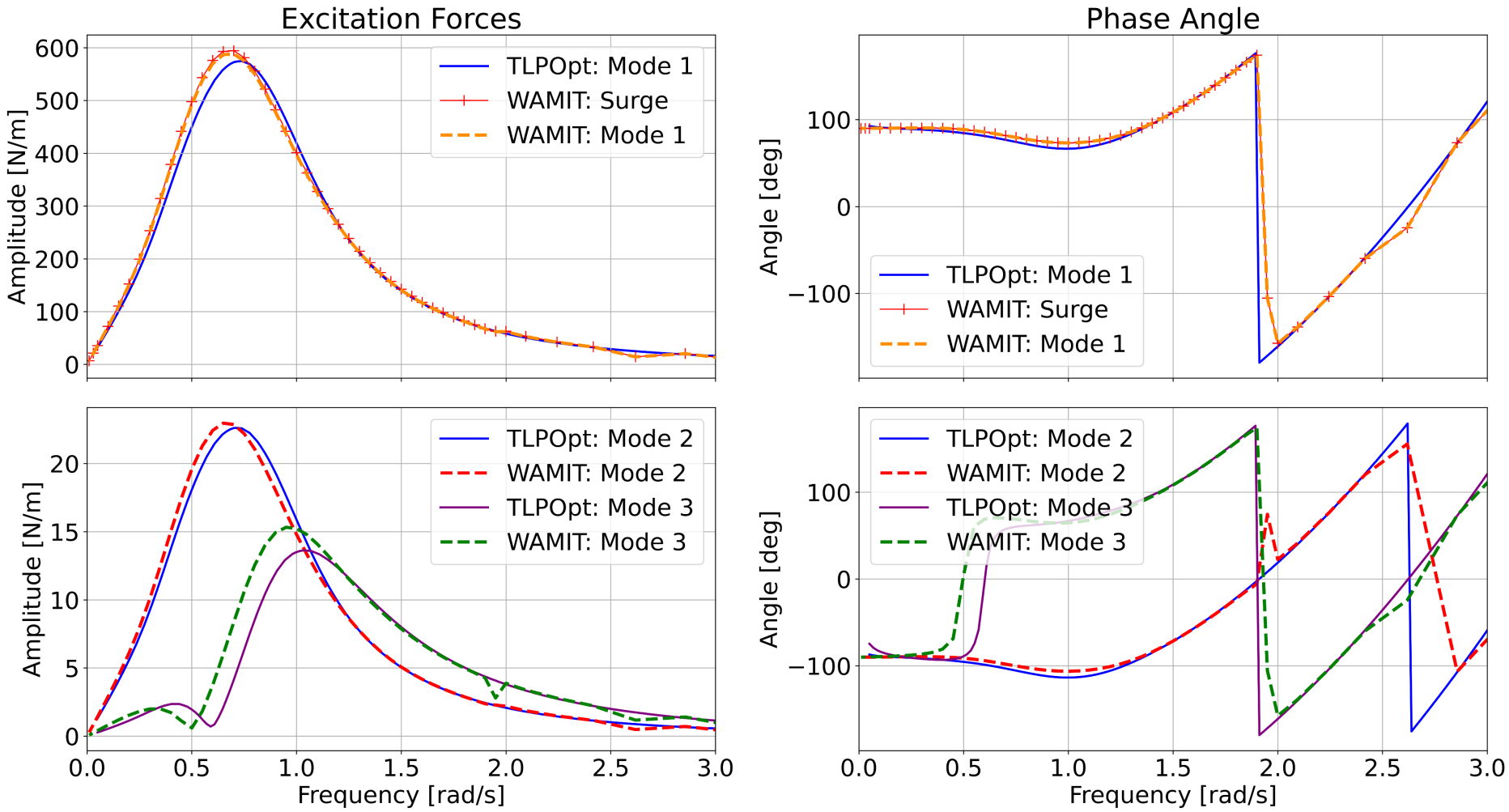
- Modeshapes from TLPOpt FE Model
- Rigid .gdf file and custom newmodes.f
- WAMIT potential flow solution with generalized modes
- Frequency-domain forcing, added mass, responses

SIMA

- Sizing Details from TLPOpt Inputs
- Construct FE model (RIFLEX and SIMO bodies)
- Time-domain Simulations
- Post-process to Frequency-domain

Verification of Modal Forcing

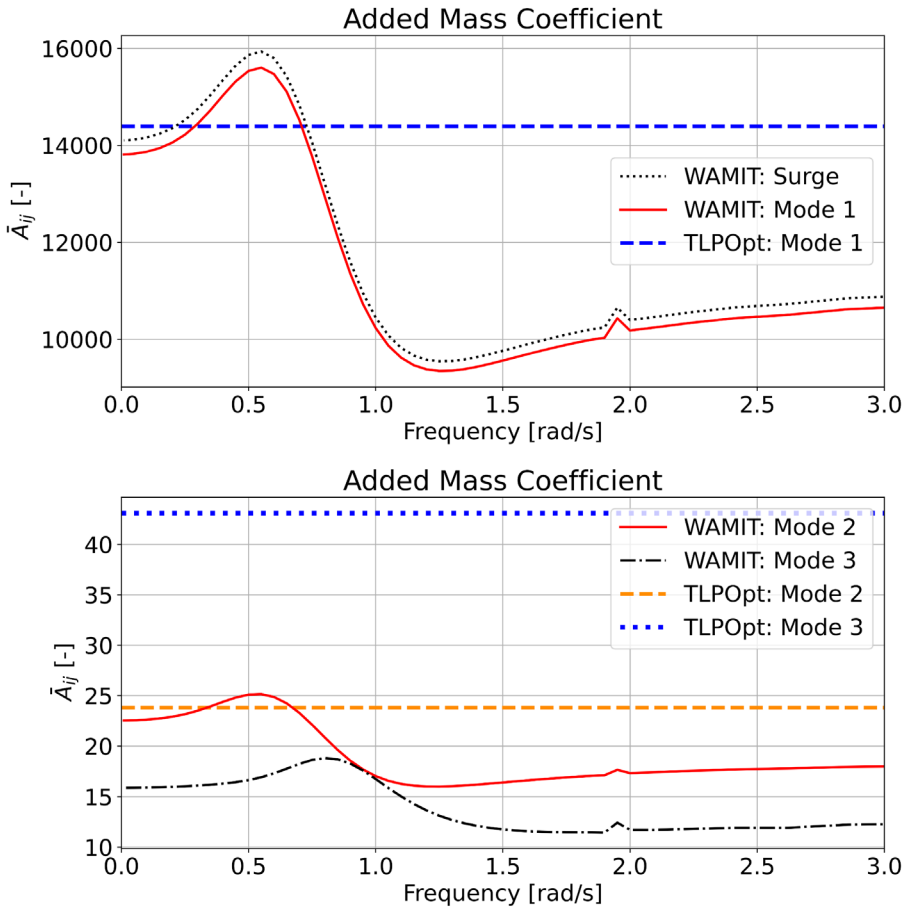
Verification



Verification of Added Mass

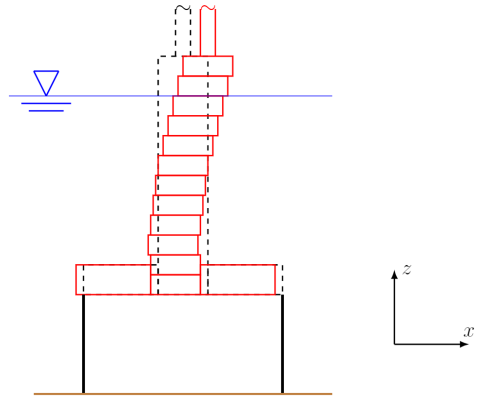
Verification

- Solving the 3D radiation problem is not feasible in the optimization loop
- Good agreement in Mode 1 and Mode 2
- Mode 3 shows poor agreement
  - Highest curvature mode shape
  - Lack of rotation in WAMIT generalized modes

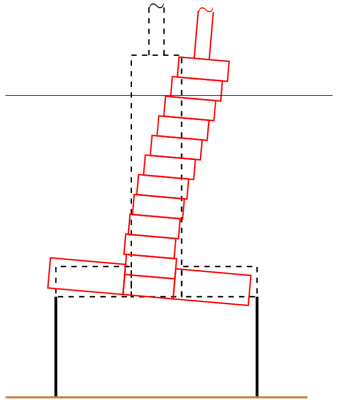


Modal Representation

WAMIT



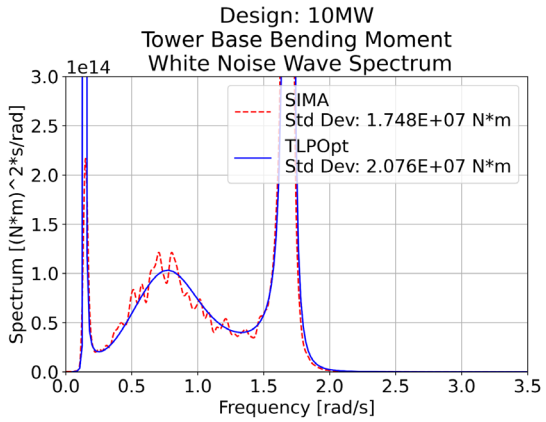
TLPOpt

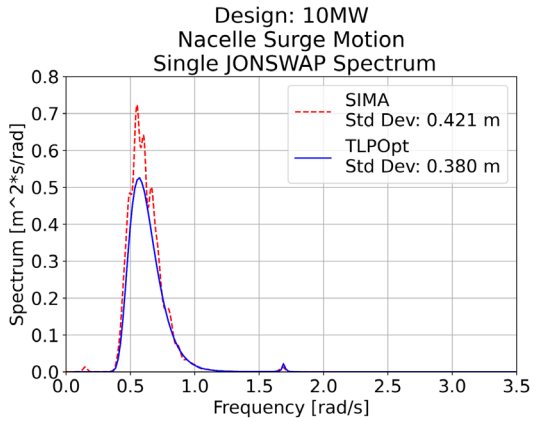


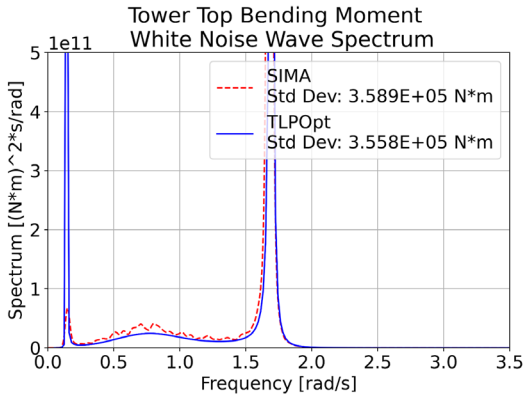
Verification of Spectral Results

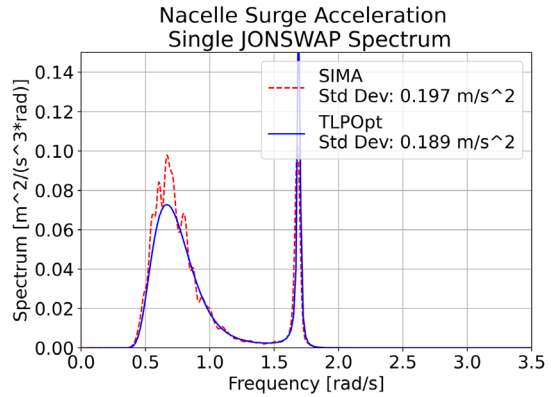
Verification

- Spectral results allow comparison
  - Using ‘derived’ metrics of response:
    - Bending moments, nacelle motion/acceleration, tendon tension
- Standard deviations are used in stochastic calculations of fatigue and extremes
- Initial results show promising agreement
  - May need more than three modes in analysis
  - Possible issues in forcing calculation





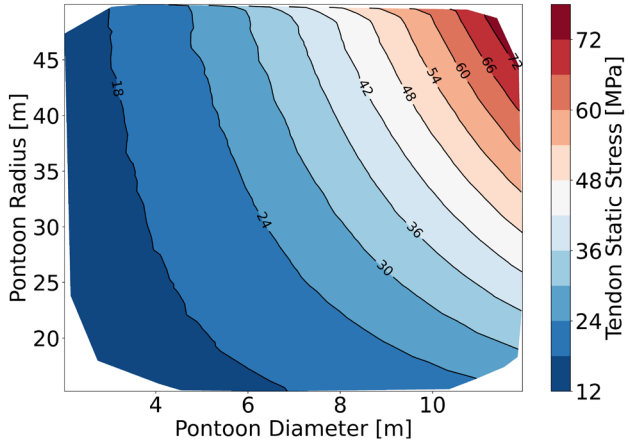


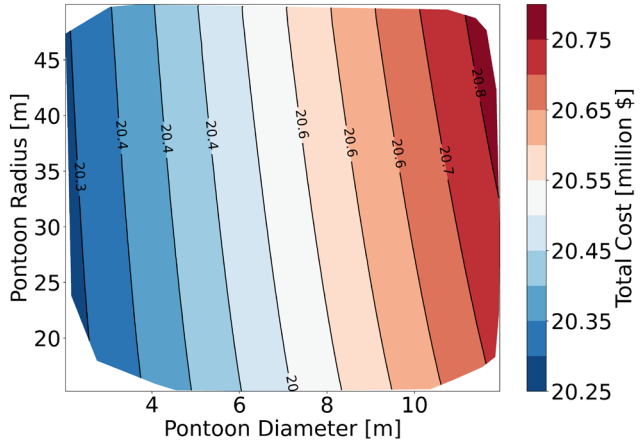


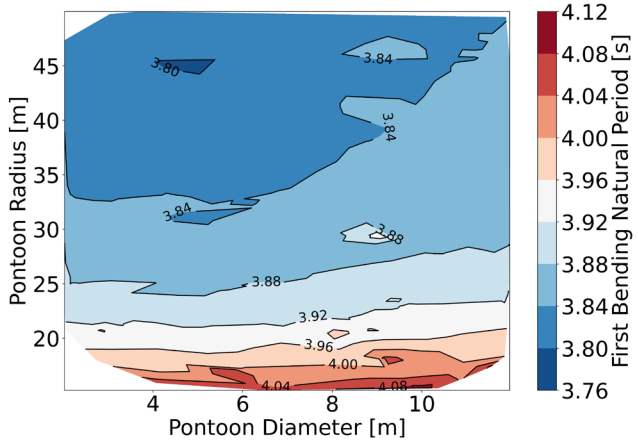
Design Space Exploration

Ongoing Work

- Model can also be used to explore design space
  - Observe high-level trends, guide initial designs
  - Can be used like a gradient-free model by restricting design variables
- Analysis remains valid over a range of TLP designs
- Three example contour plots shown
  - Results follow physical intuition
  - All combinations of two inputs and one output are possible
- Full optimization will follow





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