



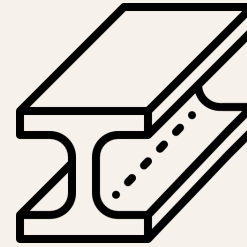
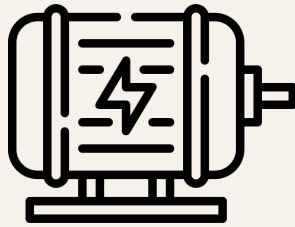
MDOcean: an Open-Source Software for Efficient Simulation and Optimization of WECs

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Symbiotic Engineering and Analysis Laboratory, Cornell University



Wave Energy Converters are Multidisciplinary



Geometry

Hydrodynamics

Dynamics & Control

Structures

Economics

Problem 1: high computation time to optimize many interacting subsystems

Solution 1: semi-analytical models, clever optimization formulation

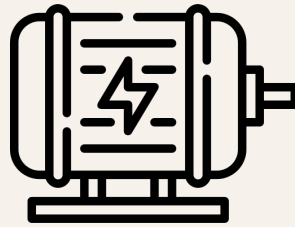
Wave Energy Converters are Multidisciplinary



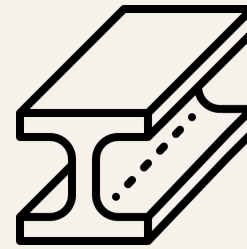
Geometry



Hydrodynamics



Dynamics & Control



Structures



Economics

Problem 2: high uncertainty in cost model

Solution 2: multi-objective optimization and sensitivity analysis

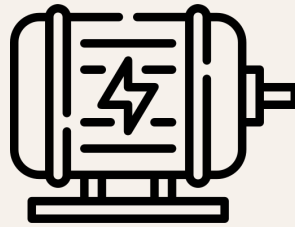
Wave Energy Converters are Multidisciplinary



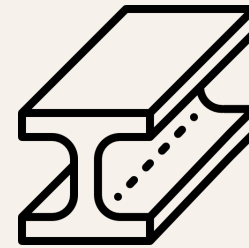
Geometry



Hydrodynamics



Dynamics & Control



Structures



Economics

Problem 3: lack of replicability and comparison between models and designs

Solution 3: open source software with benchmarks, end-to-end tests, and CI

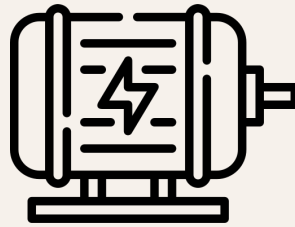
Wave Energy Converters are Multidisciplinary



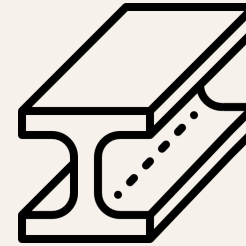
Geometry



Hydrodynamics



Dynamics & Control



Structures



Economics

Matched Eigenfunction Expansion Method leverages cylindrical symmetry

Semi-analytical: complex derivation, fast execution

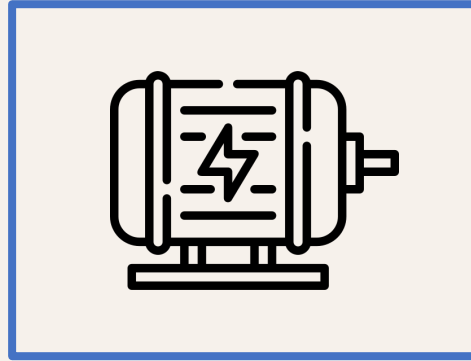
Wave Energy Converters are Multidisciplinary



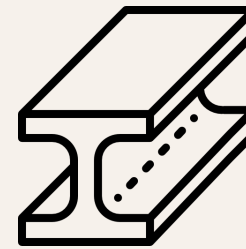
Geometry



Hydrodynamics



Dynamics & Control



Structures

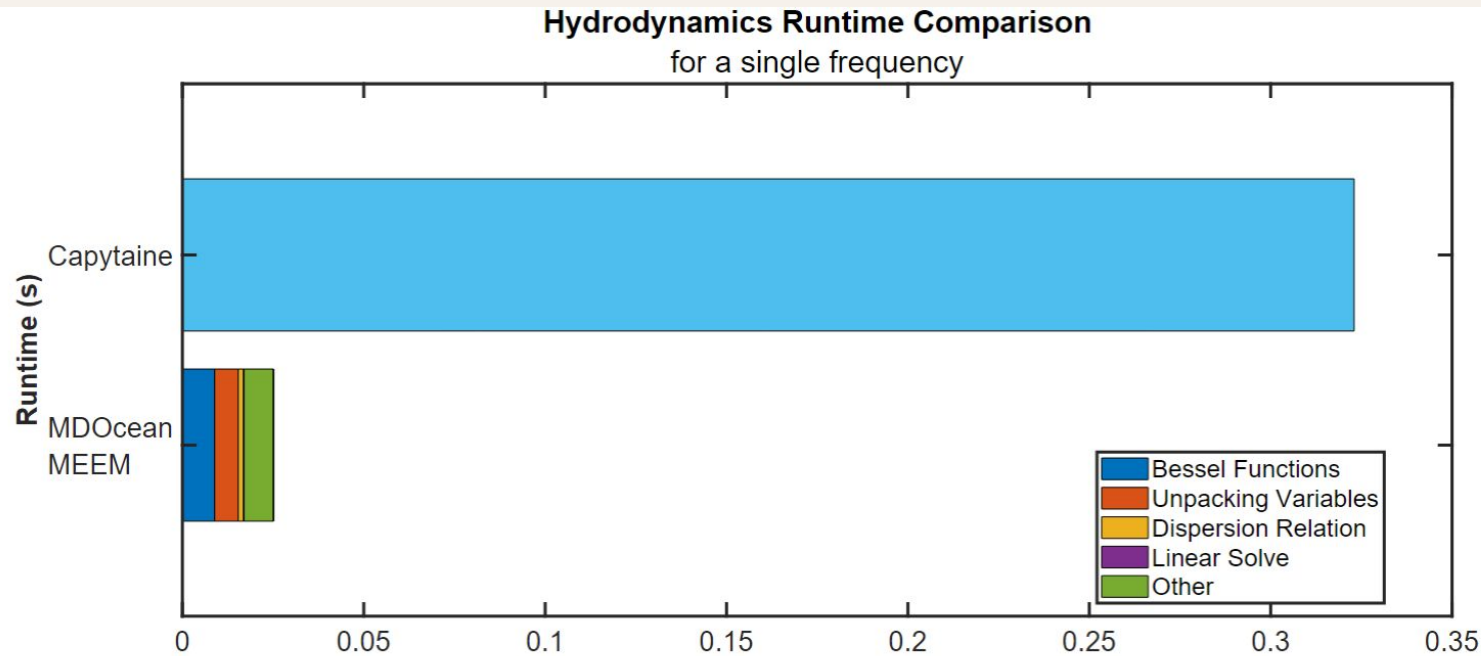


Economics

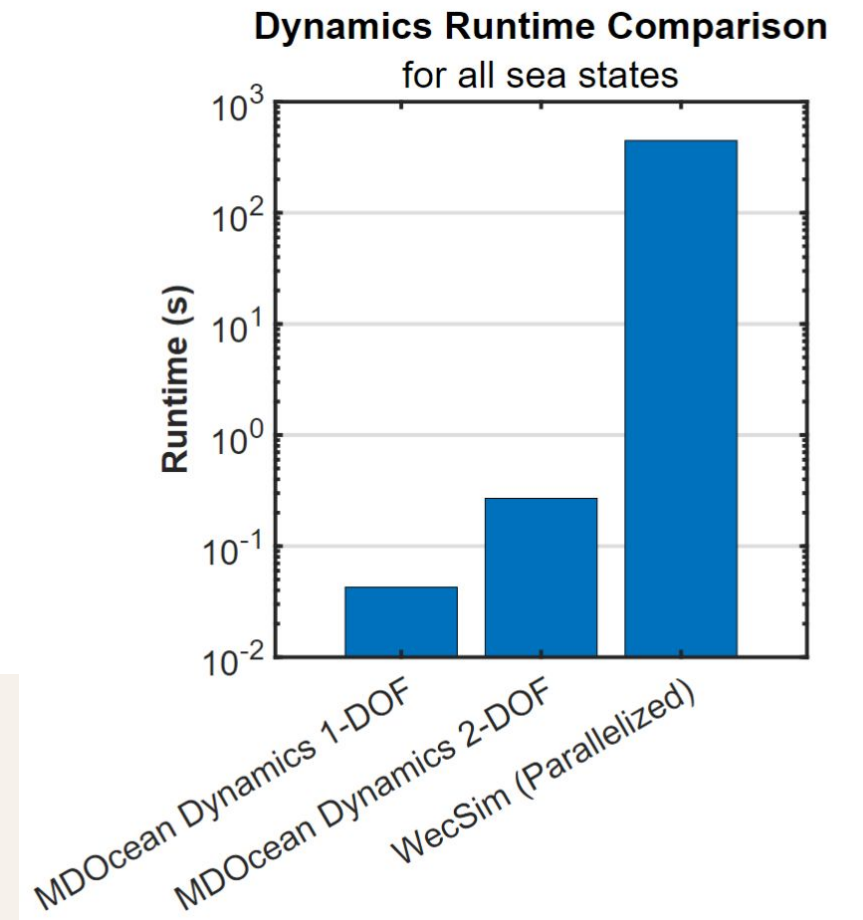
Quasi-linearize drag and saturation nonlinearities with **describing functions**

Solve in **frequency domain** while accounting for time domain peaks

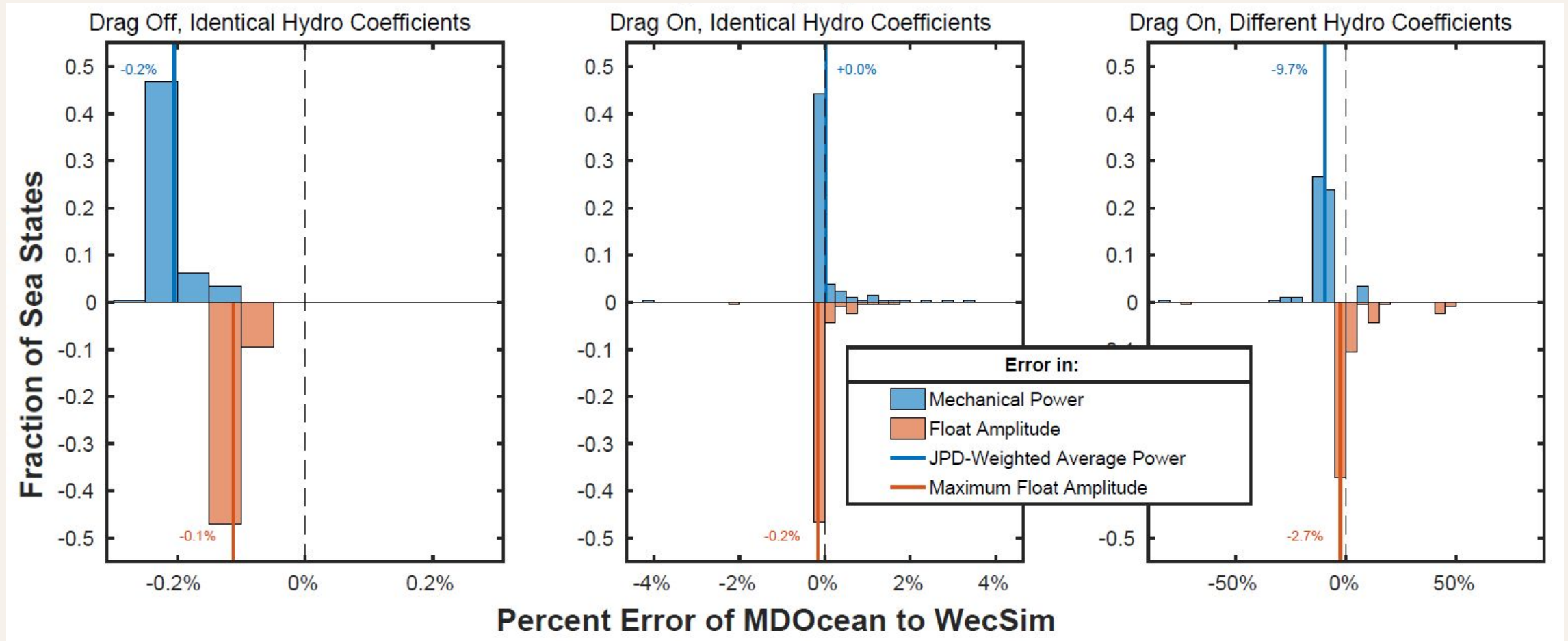
Both Models Achieve Significant Speedup



10x faster hydro, 1000x faster dynamics



Both Models are Accurate within 10%



Clever Optimization Formulation

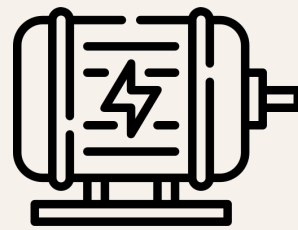
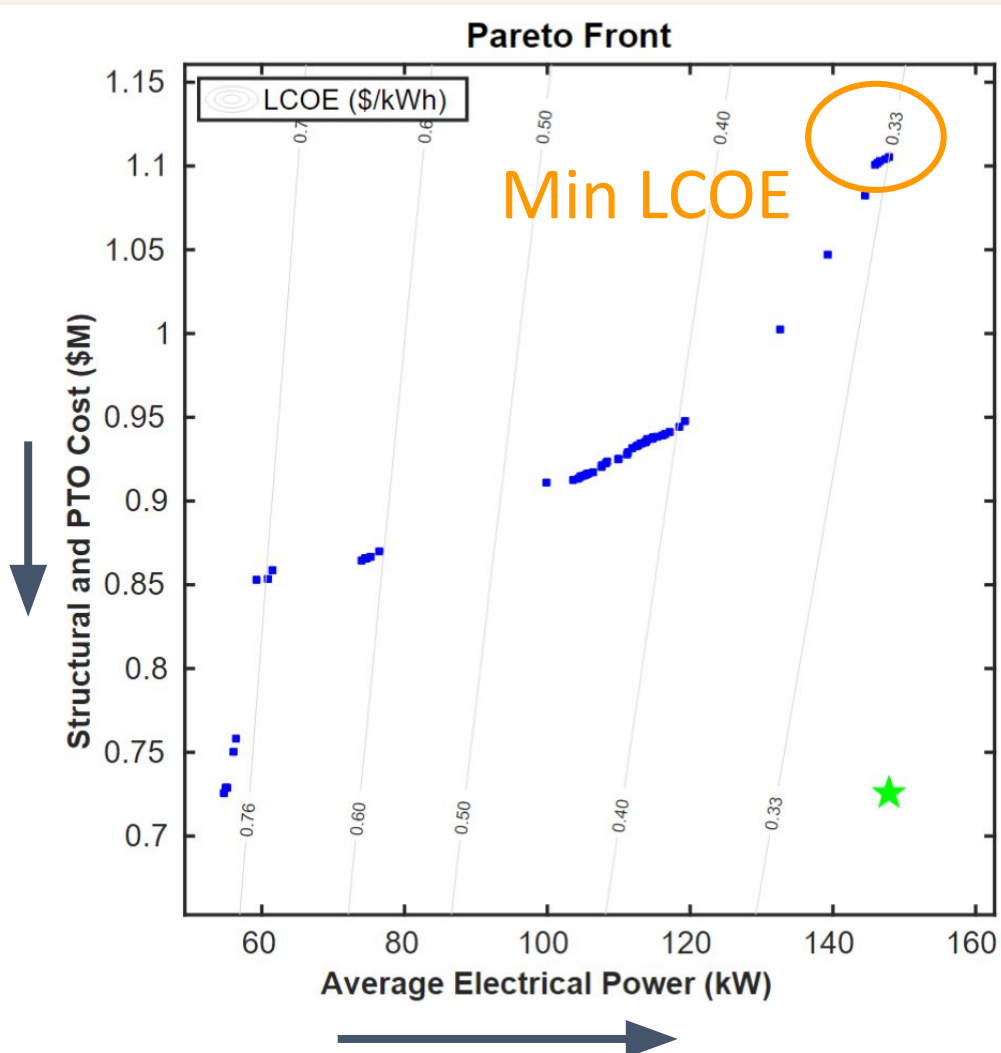
Prioritize requirements by model validity

Enforce high-priority requirements with **bounds or linear constraints**

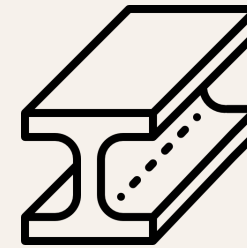
Automatic design variable scaling to keep hessian well-conditioned

Epsilon-constraint seeds to leverage gradients in multi-objective

Pareto Analysis to Address Economic Uncertainty



Dynamics & Control



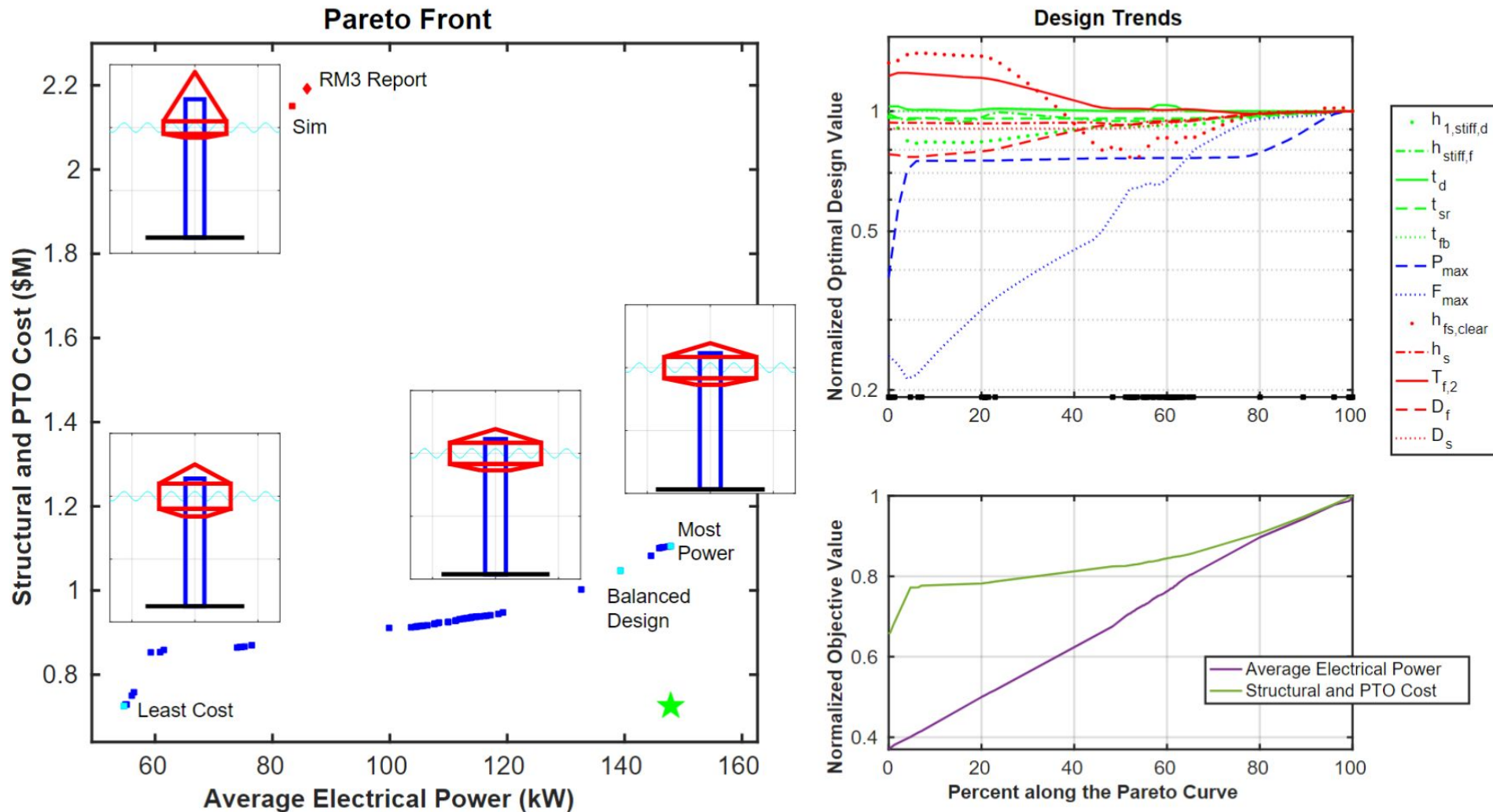
Structures



Economics

- Pareto front of structures + PTO cost vs average power (with LCOE contours)
- Visualize effect of changing constant cost and fixed charge rate

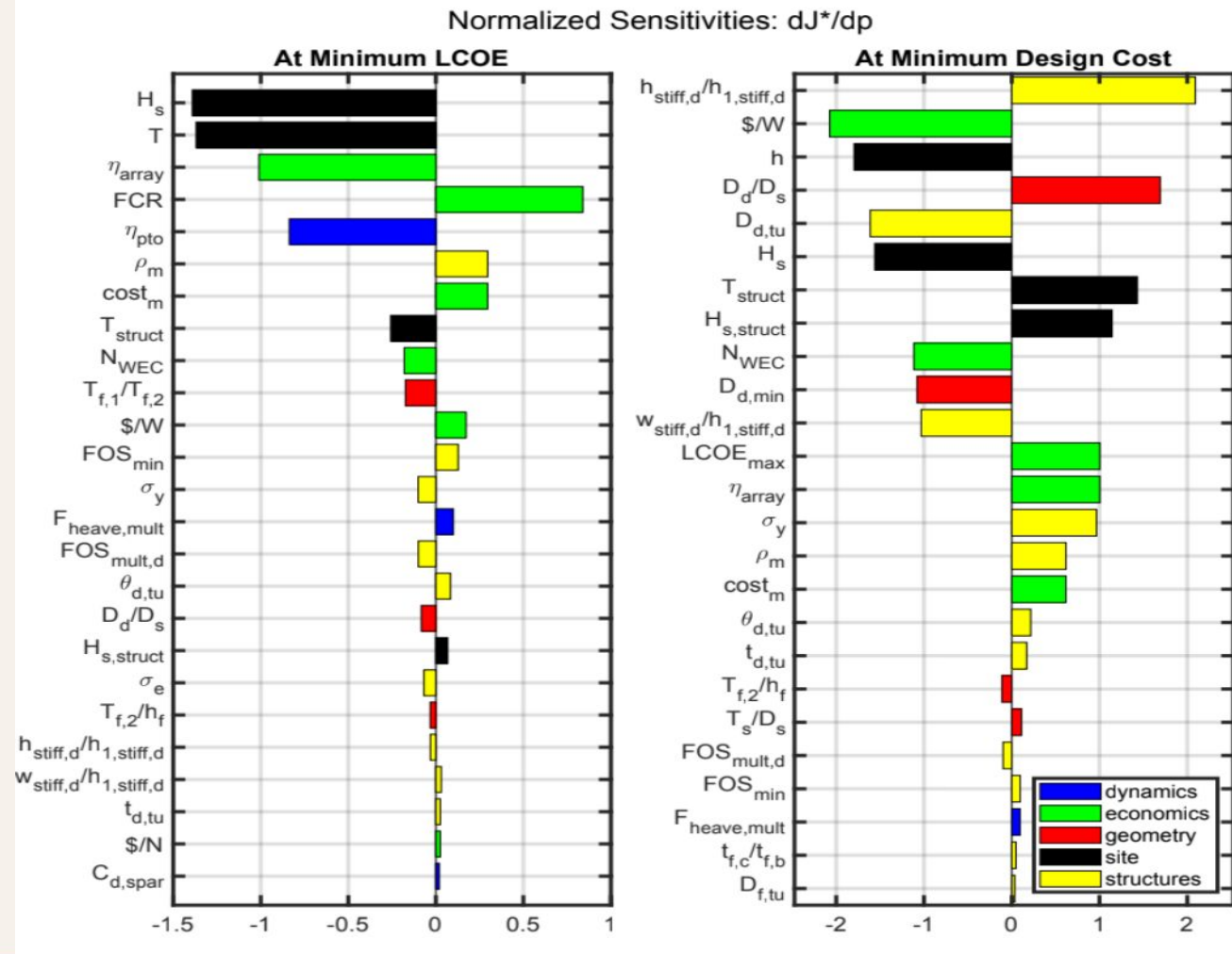
Pareto Analysis to Address Economic Uncertainty



Min LCOE design:

- 57% lower LCOE
- 37% lower structural / powertrain cost
- 89% higher power

Sensitivity Analysis to Address Economic Uncertainty

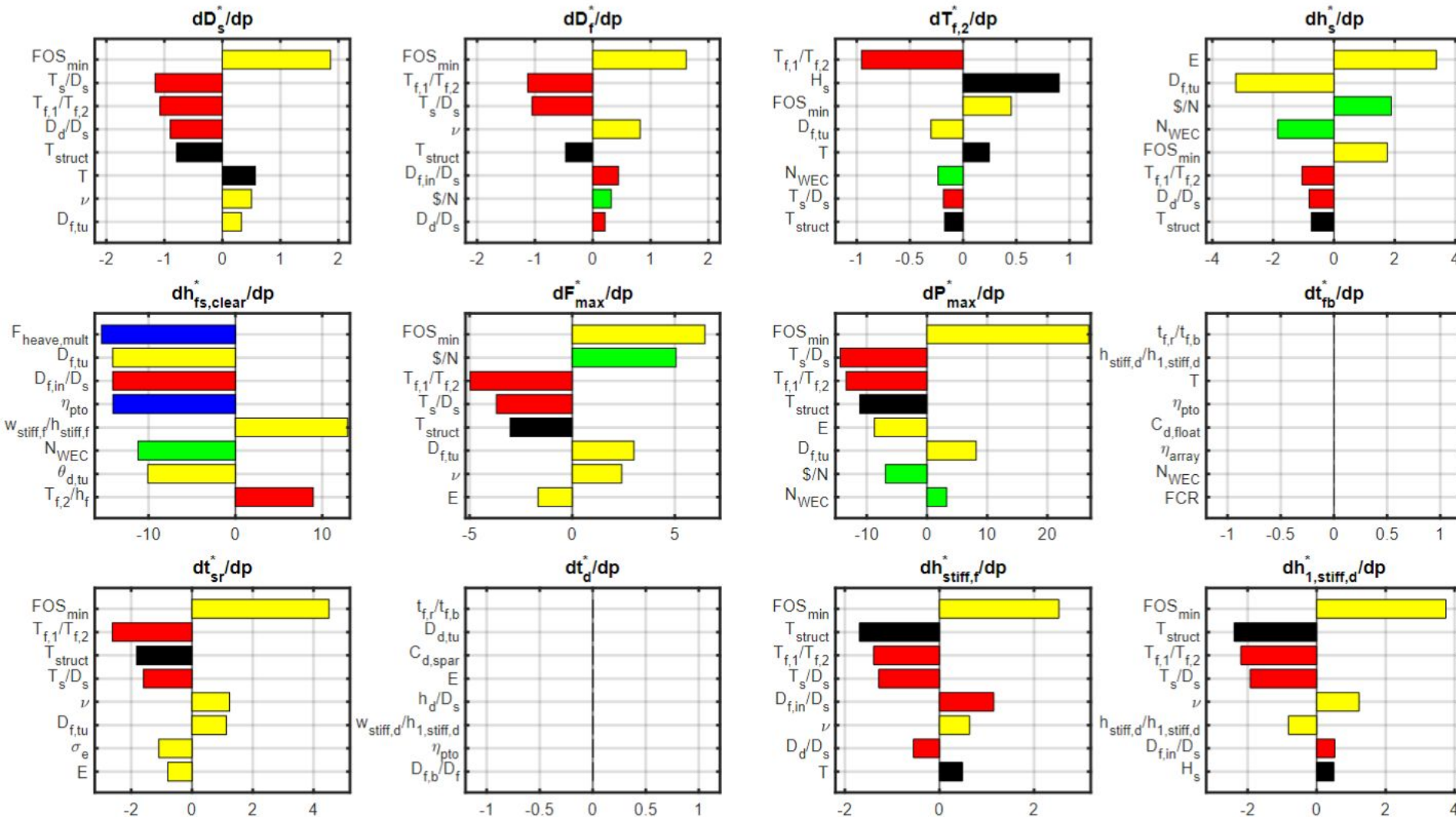


H_s and T_{struct} (site wave conditions) are in top 10 for both objectives

Most sensitive parameter is structural in both cases

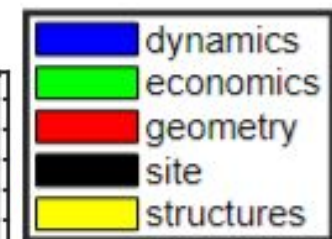
Sensitivity Analysis to Address Economic Uncertainty

Normalized Sensitivities at Minimum LCOE



7/12 are most sensitive to FOS_{min}

$h_{fs,clear}$, F_{max} , and P_{max} are highly sensitive



End to End Tests for Benchmark Comparison

✓ validateNominalReport

Test Parameters: field_report=LCOE, rel_tol_report=0.25_2

The test passed.

Duration: 0.6740 seconds

Event:

Verification passed.

Test Diagnostic:

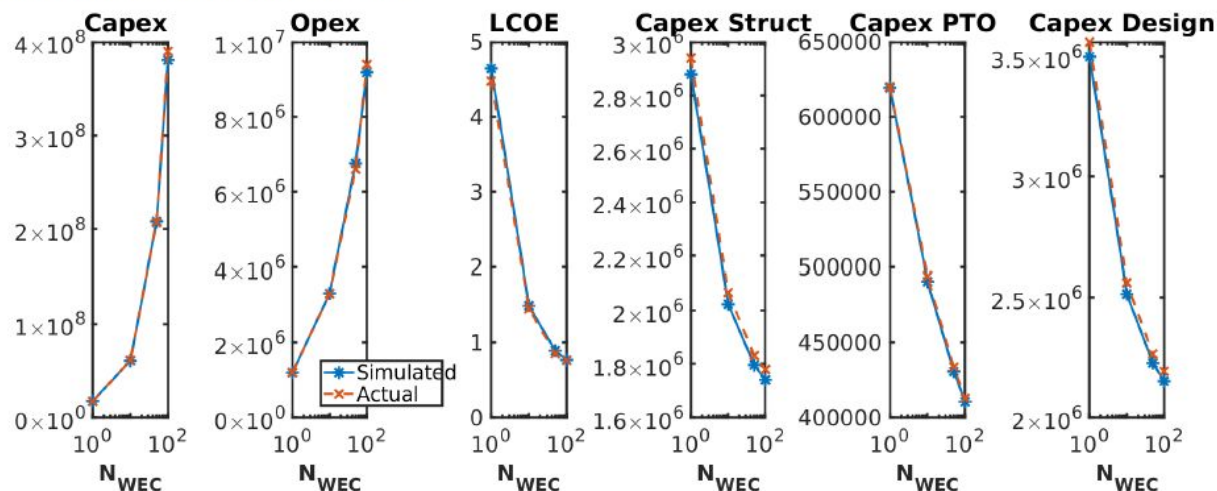
Figure saved to:

--> /home/becca/Documents/git/actions-runner/_work/MDOcean/MDOcean/test-results/2025-04-25_12.46.53/dfcb388c-bc25-4cc0-9161-a2f449c17929/econ_val

idation_report1afc1974-3169-4d25-be89-4c5f34f8b680.fig

--> /home/becca/Documents/git/actions-runner/_work/MDOcean/MDOcean/test-results/2025-04-25_12.46.53/dfcb388c-bc25-4cc0-9161-a2f449c17929/econ_val

idation_report1afc1974-3169-4d25-be89-4c5f34f8b680.png



Framework Diagnostic:

verifyEqual passed.

--> The error was within relative tolerance.

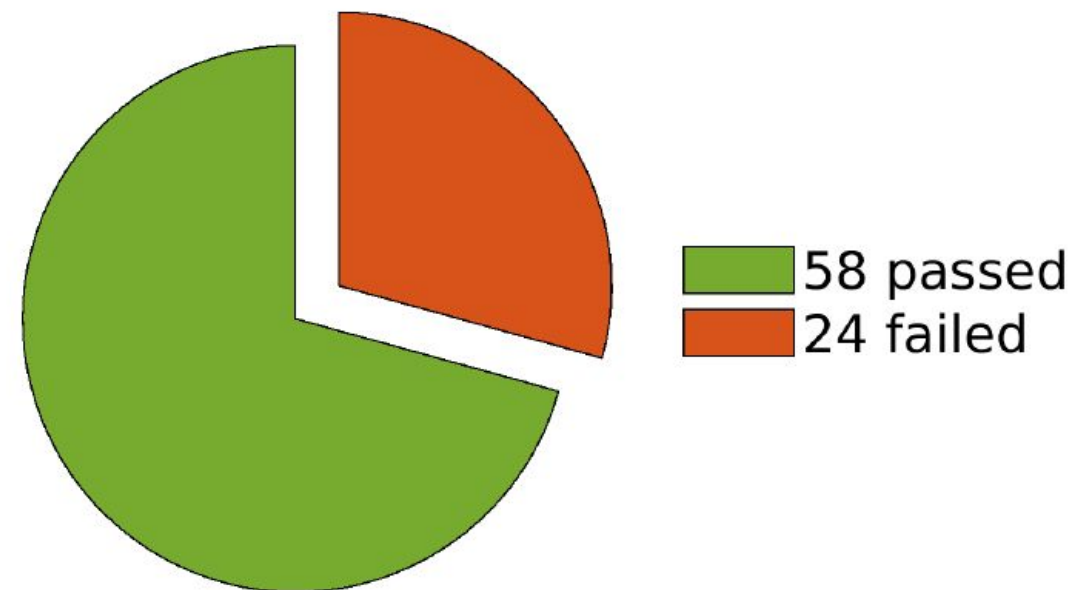
Actual Value:

4.647303820626163 1.492688733308334 0.890516519108912 0.767758969576778







Expected Value:

4.480000000000000 1.450000000000000 0.850000000000000 0.760000000000000

Comparison against **WEC-Sim** and **reference model report** facilitates validation and direct comparison of optimized designs



Continuous Integration to Catch Problems Early

← → ↻ github.com/symbiotic-engineering/MDOcean/actions/workflows/tests.yml      

Actions

New workflow

All workflows

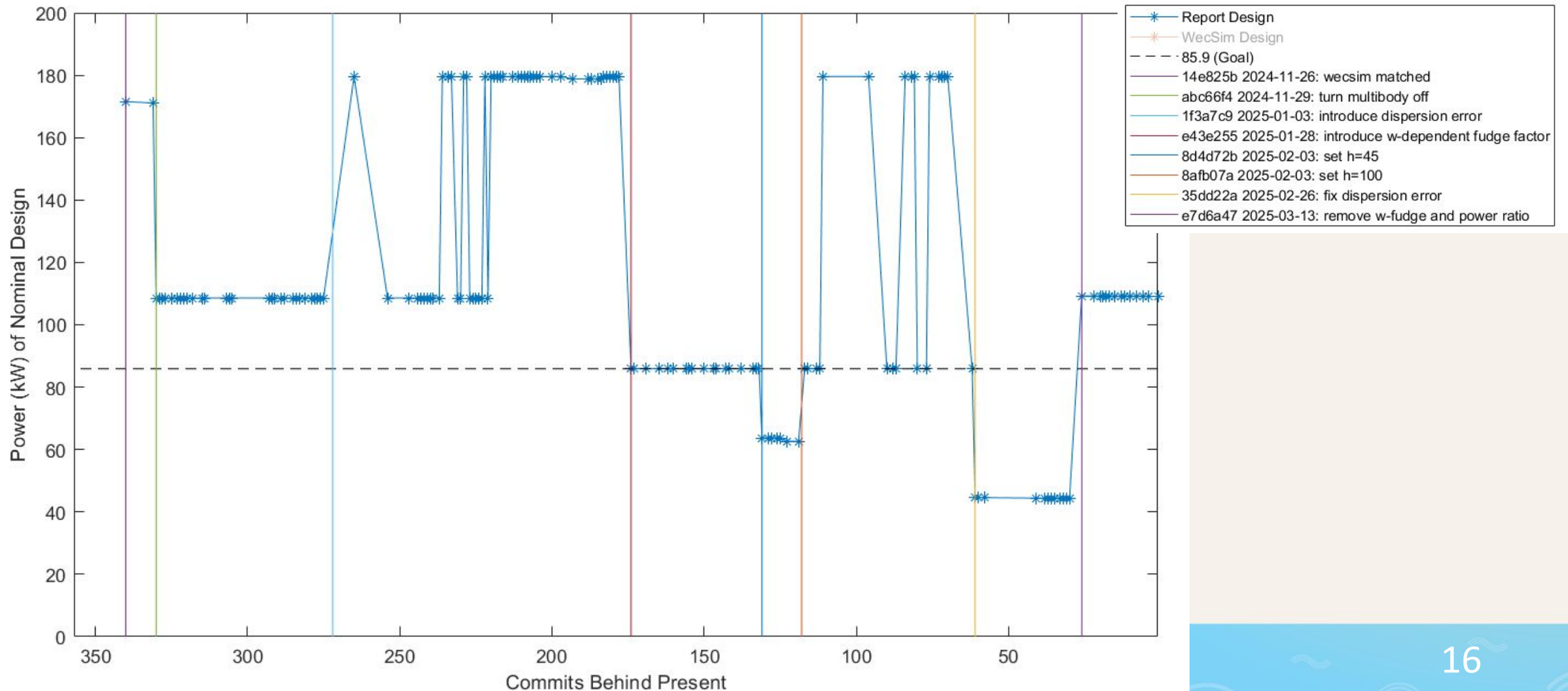
CI

Management

- Caches
- Attestations
- Runners
- Usage metrics
- Performance metrics


























✓ Add runtime figures and update numbering CI #583: Commit 4ae5522 pushed by rebeccamccabe	figures-by-script	3 hours ago 1h 27m 1s	...
✗ remove wecsim bemio from path to force using mdocean version CI #582: Commit 63299c5 pushed by rebeccamccabe	force-saturation-fix	5 hours ago 3h 23m 30s	...
✓ Update param sensitiv to include all output plots CI #581: Commit 54d3ef0 pushed by rebeccamccabe	figures-by-script	5 hours ago 1h 42m 53s	...
✗ merge force saturation into lagrange CI #580: Commit 4d1c4b1 pushed by MadisonDietrich	lagrange-redo-merge	6 hours ago 2h 22m 30s	...
✗ Merge branch 'force-saturation-fix' into lagrange-multiplier-fix CI #579: Commit 6a7170a pushed by MadisonDietrich	lagrange-multiplier-fix	8 hours ago 2h 53m 22s	...
✗ add constraints as row instead of column, so editing of matlab sourc... CI #578: Commit 235deb1 pushed by rebeccamccabe	force-saturation-fix	9 hours ago 1h 42m 6s	...

Continuous Integration to Catch Problems Early



Automatic Figure/Table Generation

is PC > Downloads > test-report (81) > test-results > 2025-04-25_12.47.33

Name	Date modified	Type	Size
 Figure_6	4/26/2025 10:19 PM	Adobe Acrobat D...	12 KB
 Figure_7	4/26/2025 10:19 PM	Adobe Acrobat D...	42 KB
 Figure_8	4/26/2025 10:19 PM	Adobe Acrobat D...	27 KB
 Figure_9	4/26/2025 10:19 PM	Adobe Acrobat D...	28 KB
 Figure_12	4/26/2025 10:19 PM	Adobe Acrobat D...	9 KB
 Figure_15	4/26/2025 10:19 PM	Adobe Acrobat D...	9 KB
 Figure_16	4/26/2025 10:19 PM	Adobe Acrobat D...	74 KB
 Figure_17	4/26/2025 10:19 PM	Adobe Acrobat D...	113 KB
 Figure_18	4/26/2025 10:19 PM	Adobe Acrobat D...	222 KB
 Figure_22	4/26/2025 10:19 PM	Adobe Acrobat D...	12 KB
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 table_20	4/26/2025 10:19 PM	TeX Document	3 KB
 table_21	4/26/2025 10:19 PM	TeX Document	9 KB

```
table2latex(tab5,[save_folder 'table_19.tex'])
```

Calkit: one-click reproducibility with environment replication and caching

Sphinx Documentation

← → ↺

🔍 symbiotic-engineering.github.io/MDOcean/generated/optimization.multiobjective.html

☆

MDOcean

Navigation

API

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- [simulation.modules](#)
- [simulation.modules.dynamics](#)
- [simulation.modules.econ](#)
- [simulation.modules.MEE](#)
- [simulation.modules.structures](#)
- [simulation.run](#)

optimization.multiobjective

`optimization.multiobjective.paretoFront(p)`
Filters a set of points P according to Pareto dominance, i.e., points that are dominated (both weakly and strongly) are filtered.

Inputs: - P : N-by-D matrix, where N is the number of points and D is the number of elements (objectives) of each point.

Outputs: - P : Pareto-filtered P - idxs : indices of the non-dominated solutions

Example: p = [1 1 1; 2 0 1; 2 -1 1; 1, 1, 0]; [f, idxs] = :func:`_paretoFront`(p)

f = [1 1 1; 2 0 1] idxs = [1; 2]

`optimization.multiobjective.pareto_curve_heuristics()`
`optimization.multiobjective.pareto_search(filename_uuid)`

Encourage use by
other researchers
and WEC
developers

Summary: Careful Decisions Everywhere Add Up

- 1: Semi-analytical models and clever formulation decrease computation time
- 2: Multi-objective optimization and sensitivity analysis mitigate cost uncertainty
- 3: Open source software with benchmarks, tests, and CI facilitates consistency

Thank You



McCabe, Dietrich, & Haji, 2025. “Semi-Analytical Modeling of Wave Energy Converters.” In prep for submission to Applied Ocean Research.

McCabe, Dietrich, & Haji, 2025. “Leveraging Multidisciplinary Design Optimization to Advance WEC Viability.” In prep for submission to Renewable Energy.

This material is based upon work supported by the National Science Foundation Graduate Research Fellowship under Grant No. DGE–2139899. Any opinion, findings, and conclusions or recommendations expressed in this material are those of the authors(s) and do not necessarily reflect the views of the National Science Foundation.

Connect

- github.com/symbiotic-engineering/MDOcean MATLAB version
- github.com/symbiotic-engineering/WEC-DECIDER Python version in progress
- Code is open-source and user-friendly!

Rebecca McCabe

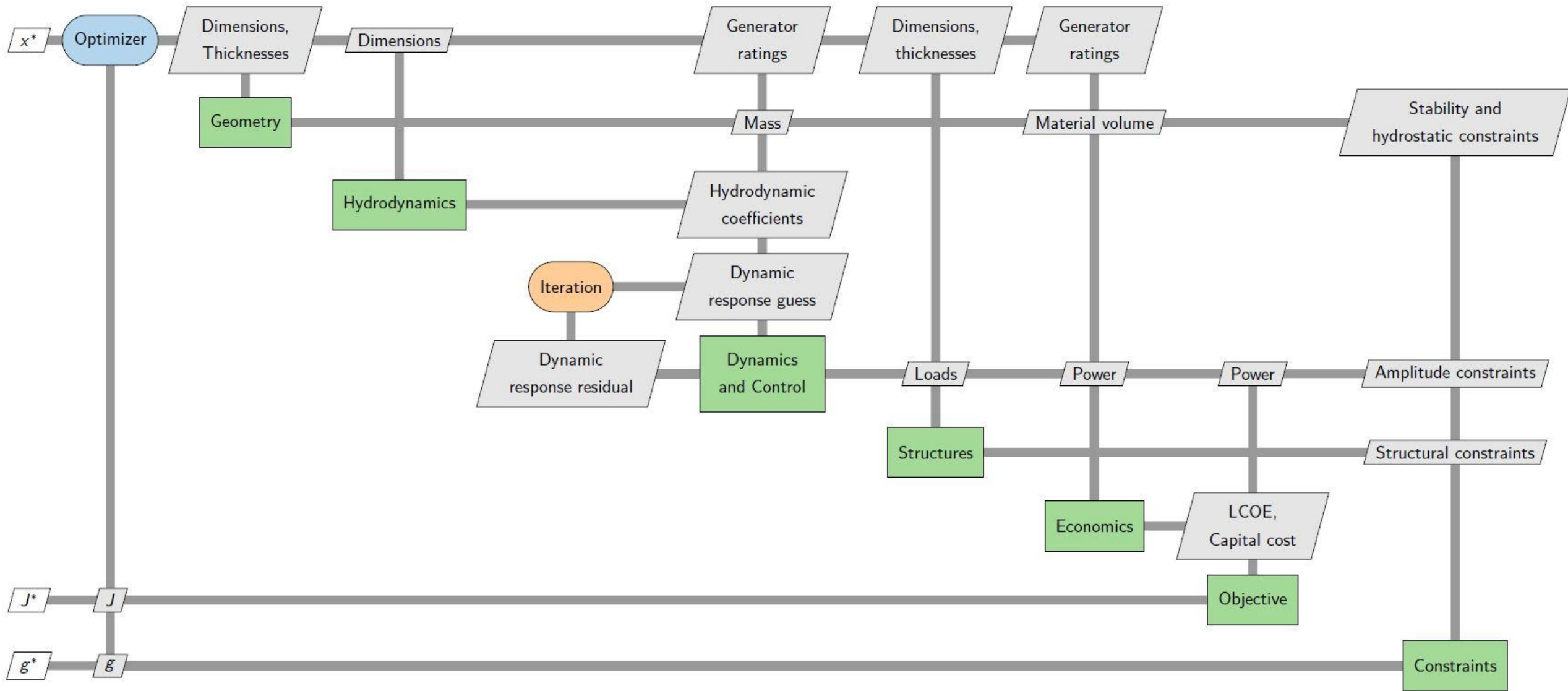
Final-year PhD student seeking next role
Symbiotic Engineering and Analysis Lab
Cornell University
rgm222@cornell.edu

GitHub link

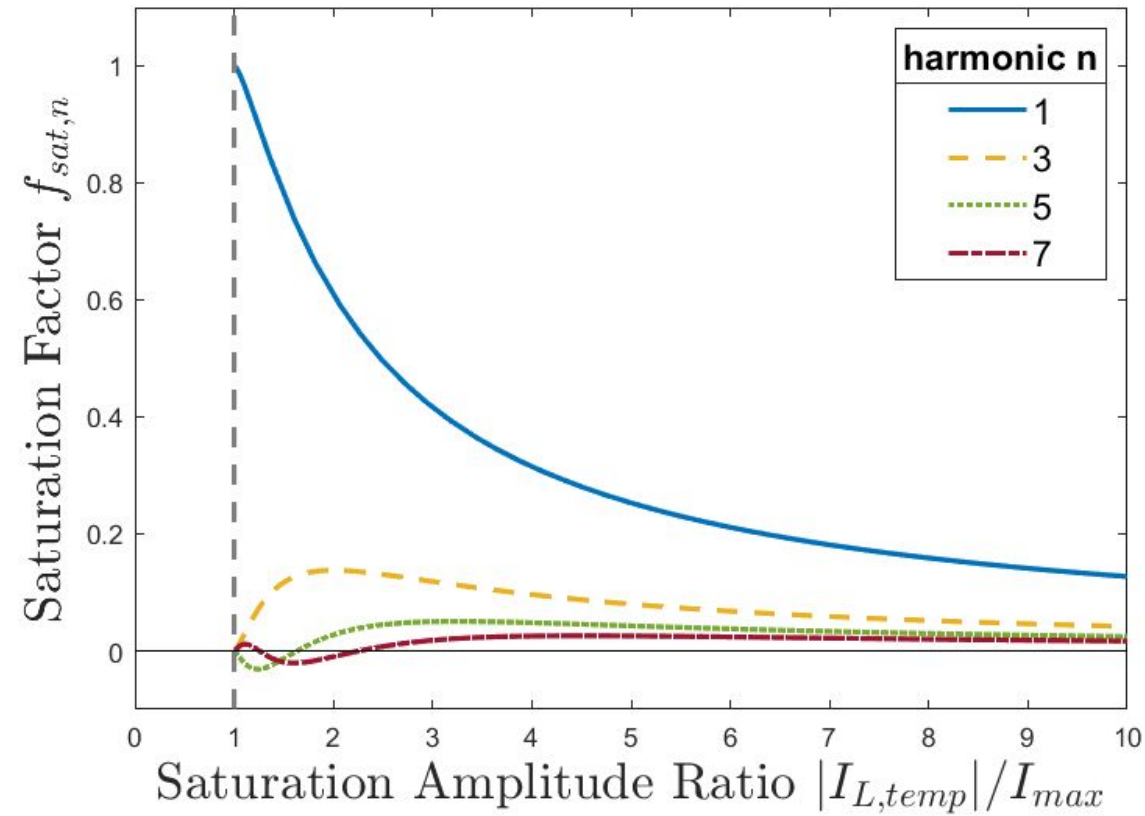
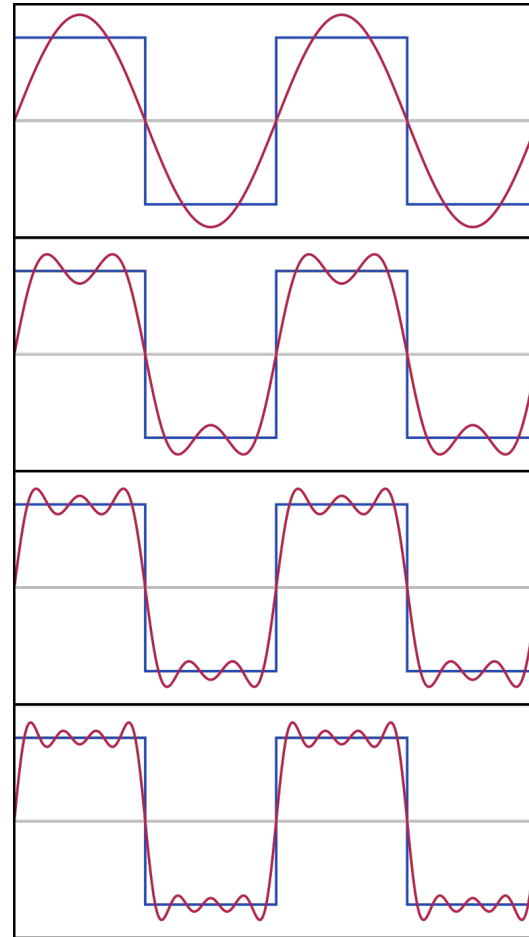
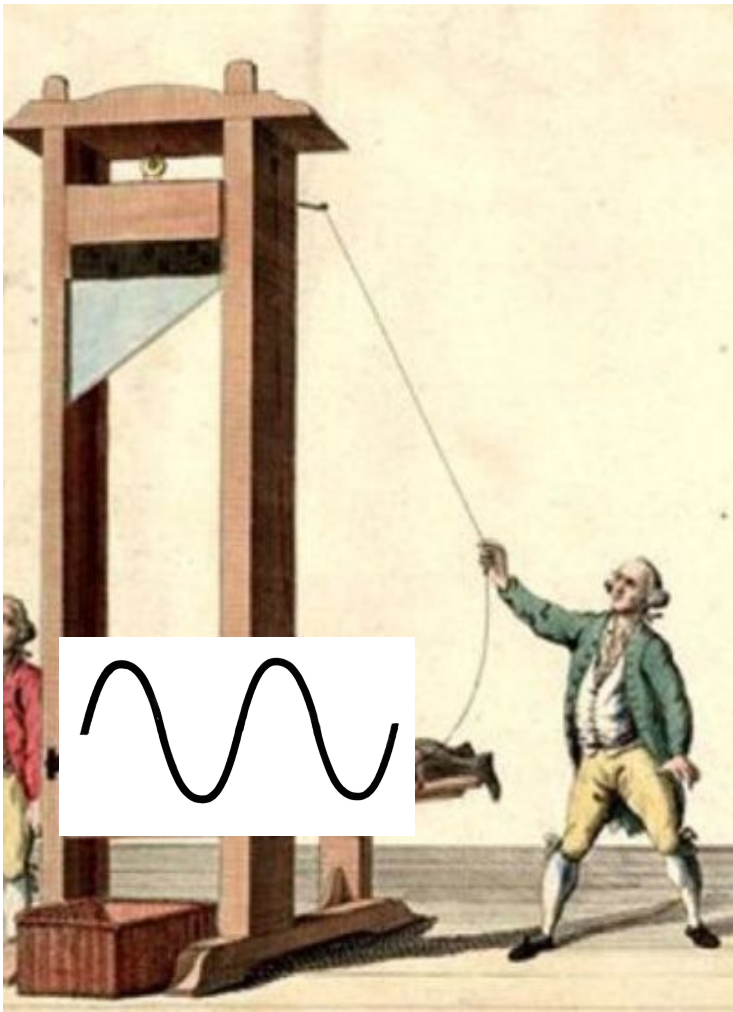


Draft paper link



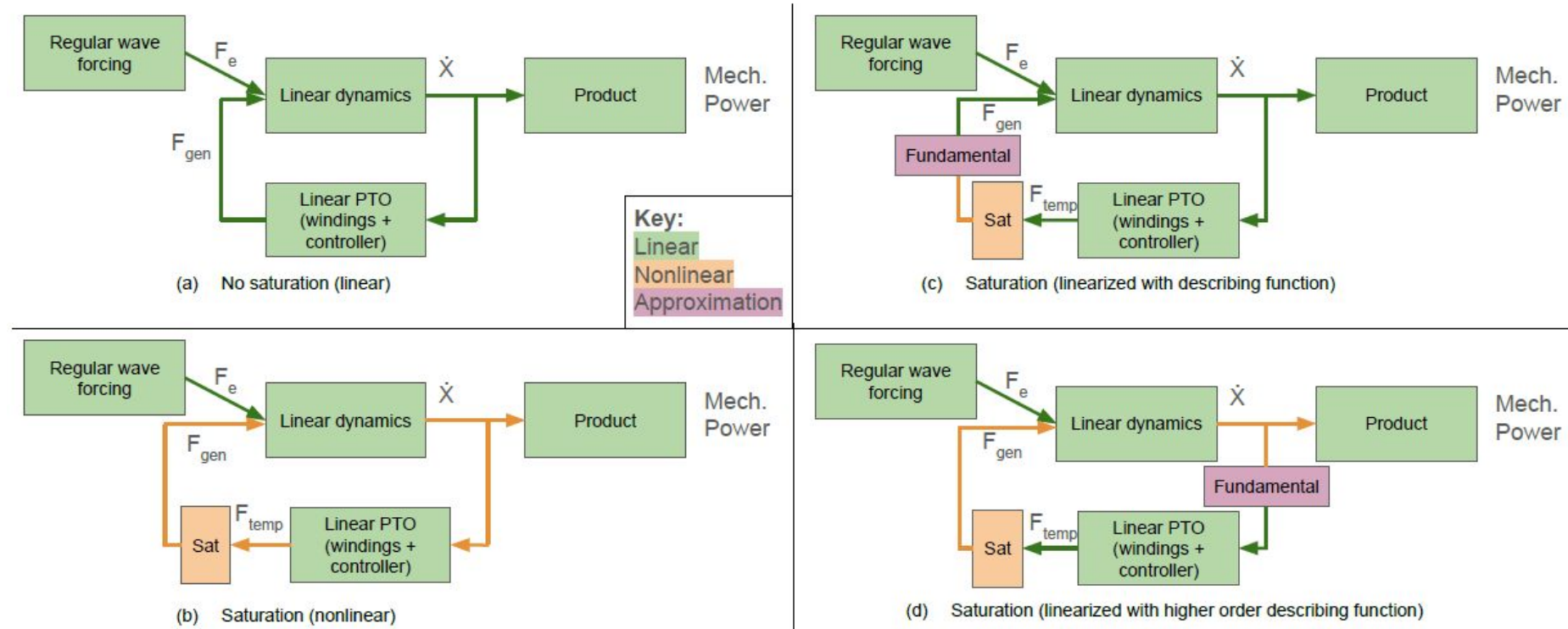


The Saturated Sinusoid



Describing Functions use the Fundamental Harmonic

Assumption: higher force harmonics have a negligible effect on power because they are low-pass-filtered out by the plant



Wave Energy Converter Dynamics

