



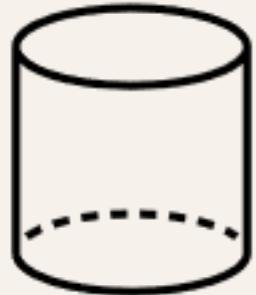
MDOcean: an Open-Source Software for Efficient Simulation and Optimization of WECs

Rebecca McCabe, Madison Dietrich, Maha Haji

Symbiotic Engineering and Analysis Laboratory, Cornell University



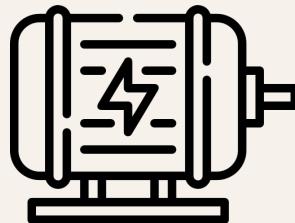
Wave Energy Converters are Multidisciplinary



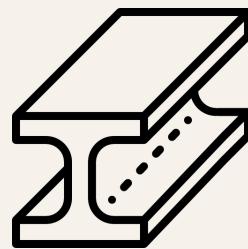
Geometry



Hydrodynamics



Dynamics & Control



Structures

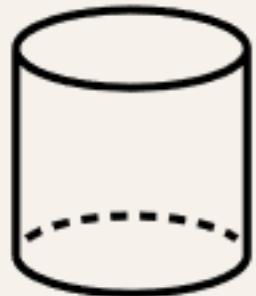


Economics

Problem 1: high computation time to optimize many interacting subsystems

Solution 1: semi-analytical models, clever optimization formulation

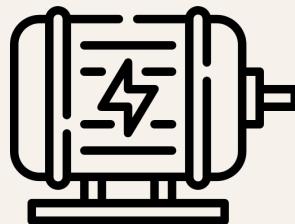
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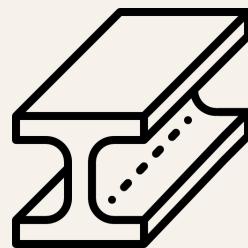
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Structures

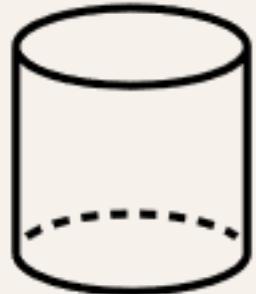


Economics

Problem 2: high uncertainty in cost model

Solution 2: multi-objective optimization and sensitivity analysis

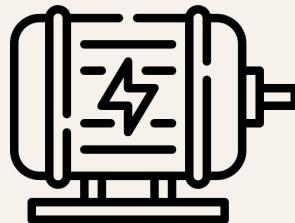
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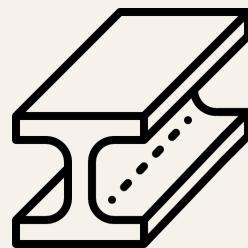
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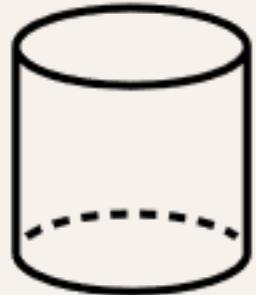


Economics

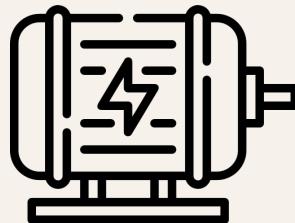
Problem 3: lack of replicability and comparison between models and designs

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

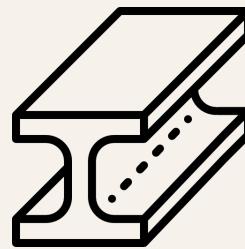
Wave Energy Converters are Multidisciplinary



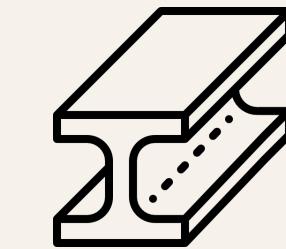
Geometry



Hydrodynamics



Dynamics & Control



Structures

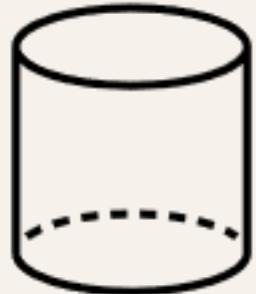


Economics

Matched Eigenfunction Expansion Method leverages cylindrical symmetry

Semi-analytical: complex derivation, fast execution

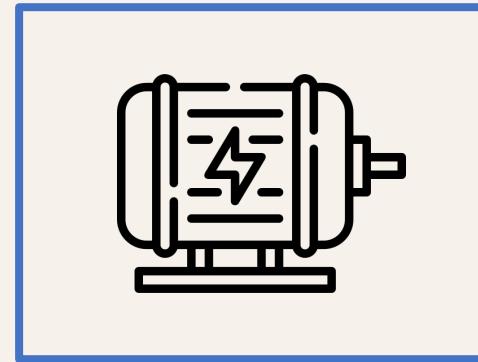
Wave Energy Converters are Multidisciplinary



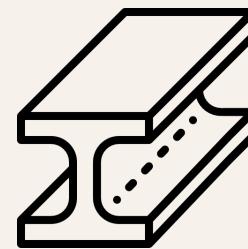
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Structures

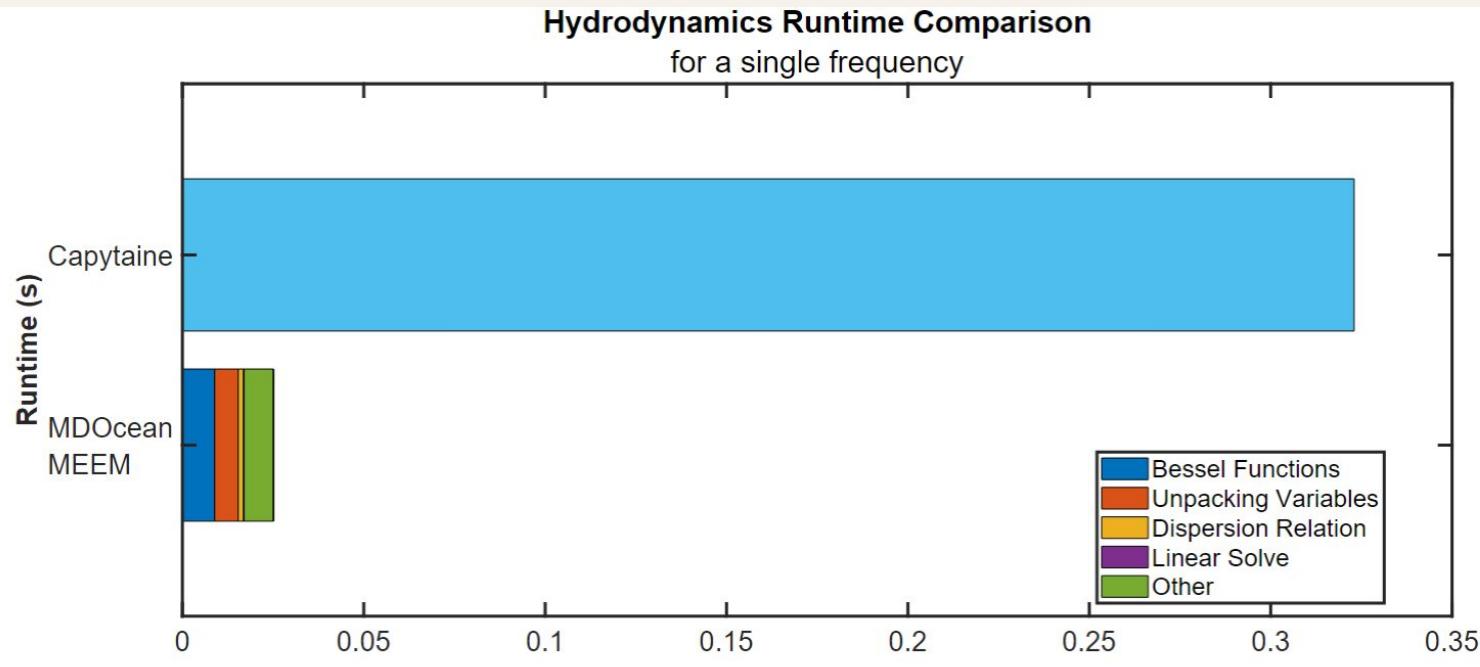


Economics

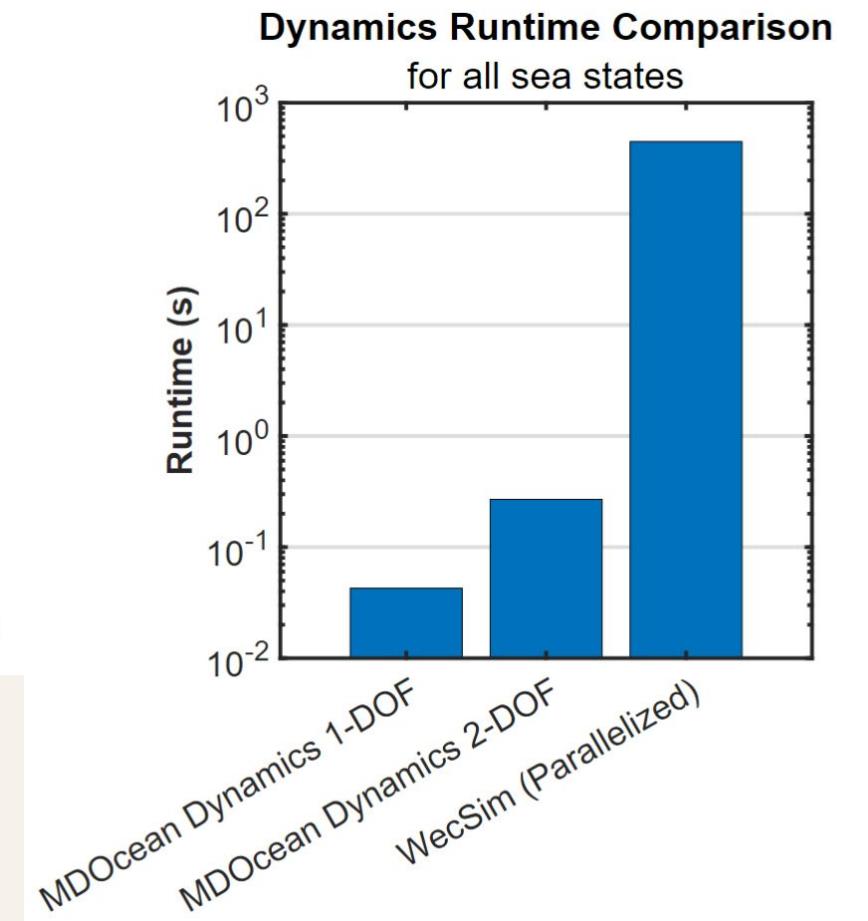
Quasi-linearize drag and saturation nonlinearities with **describing functions**

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

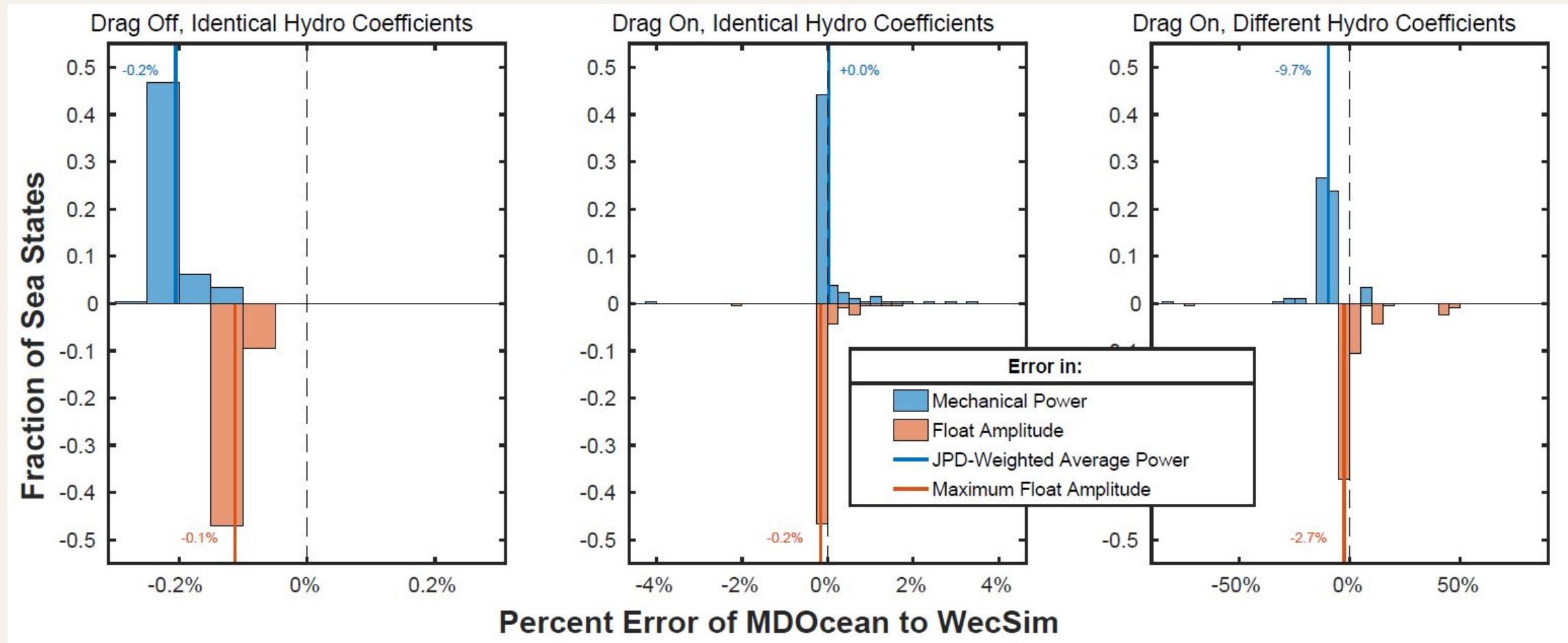
Both Models Achieve Significant Speedup



10x faster hydro, 1000x faster dynamics



Both Models are Accurate within 10%



Clever Optimization Formulation

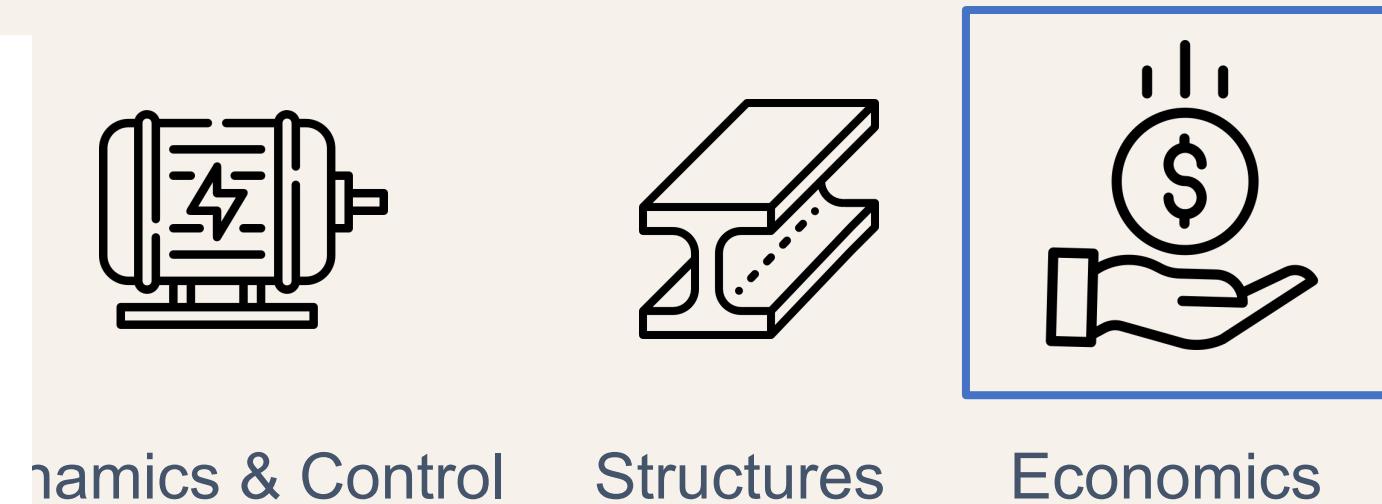
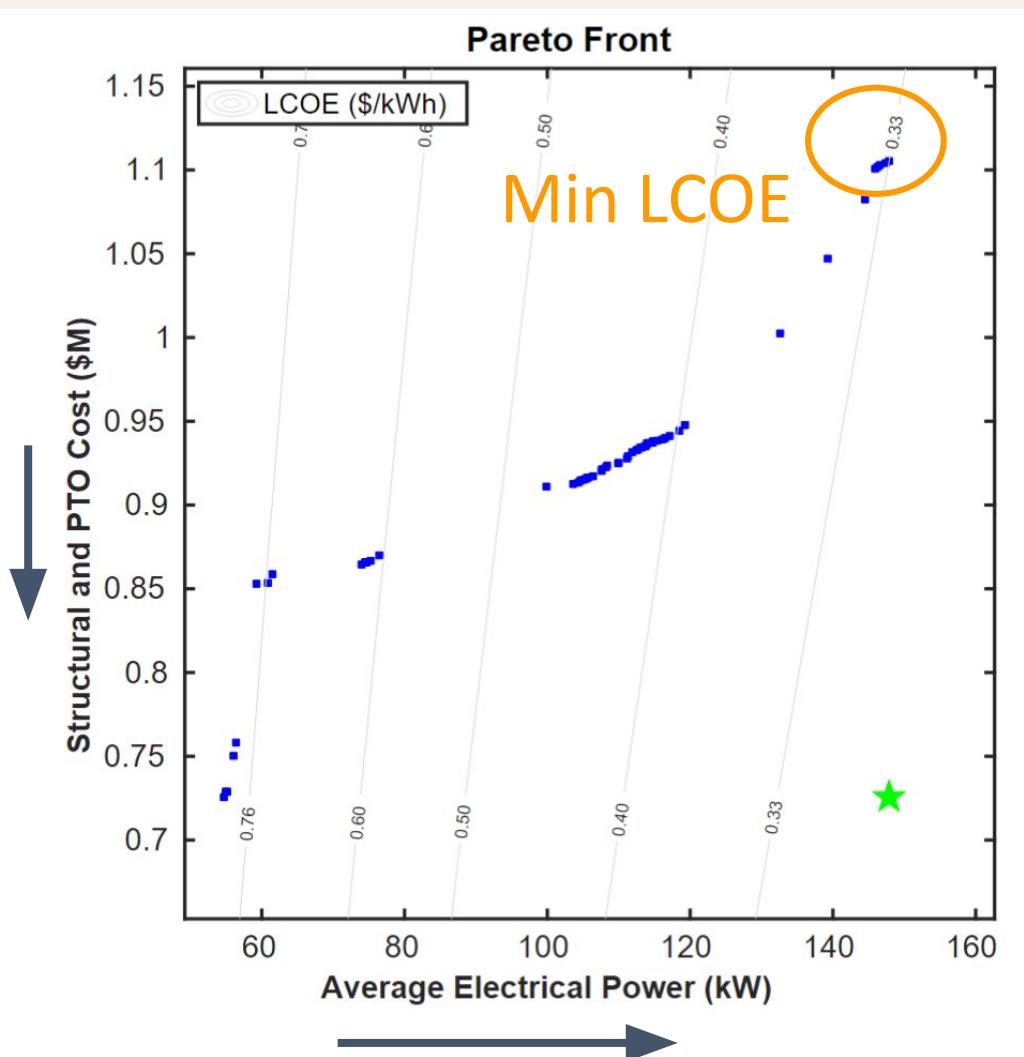
Prioritize requirements by model validity

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

Automatic design variable scaling to keep hessian well-conditioned

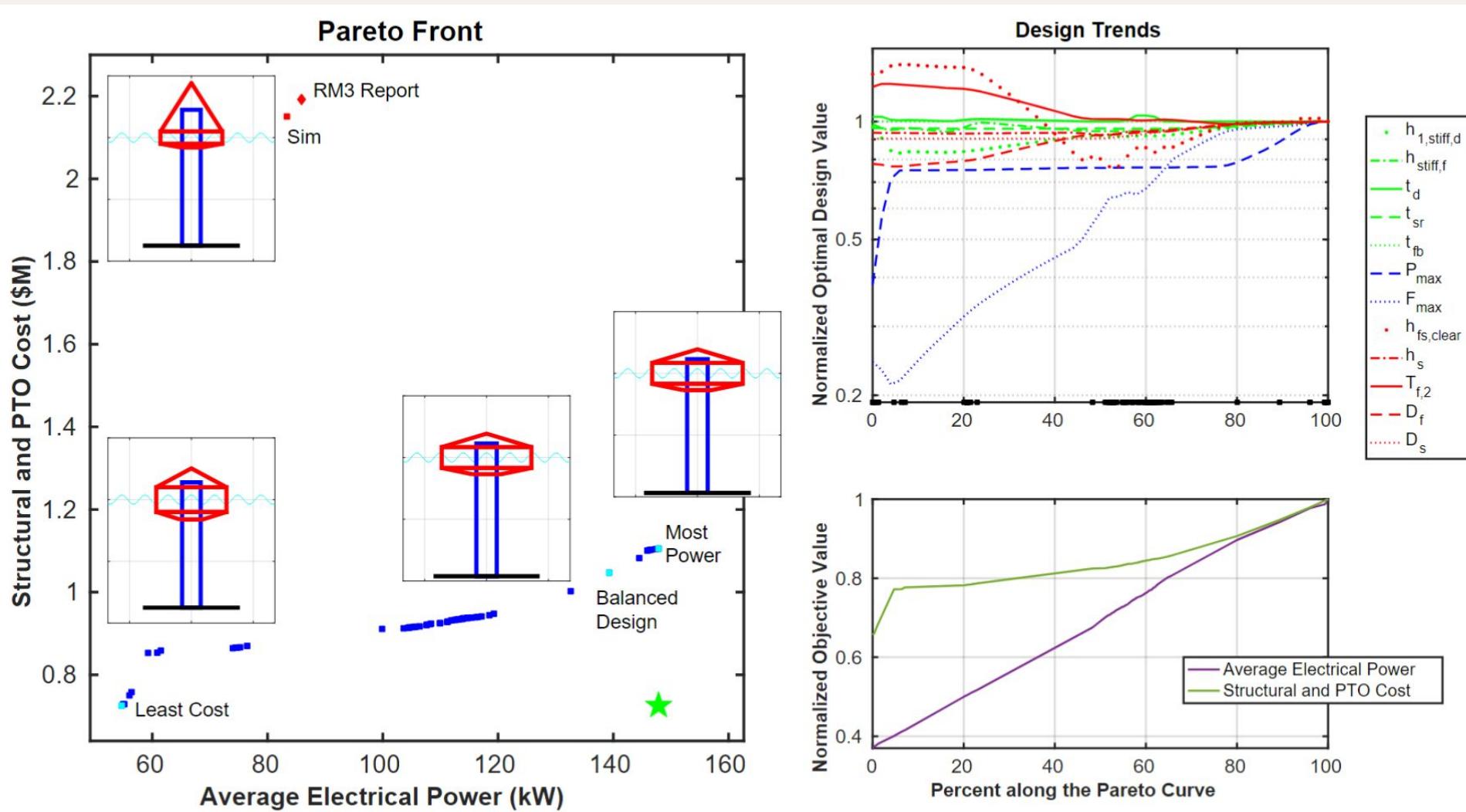
Epsilon-constraint seeds to leverage gradients in multi-objective

Pareto Analysis to Address Economic Uncertainty



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

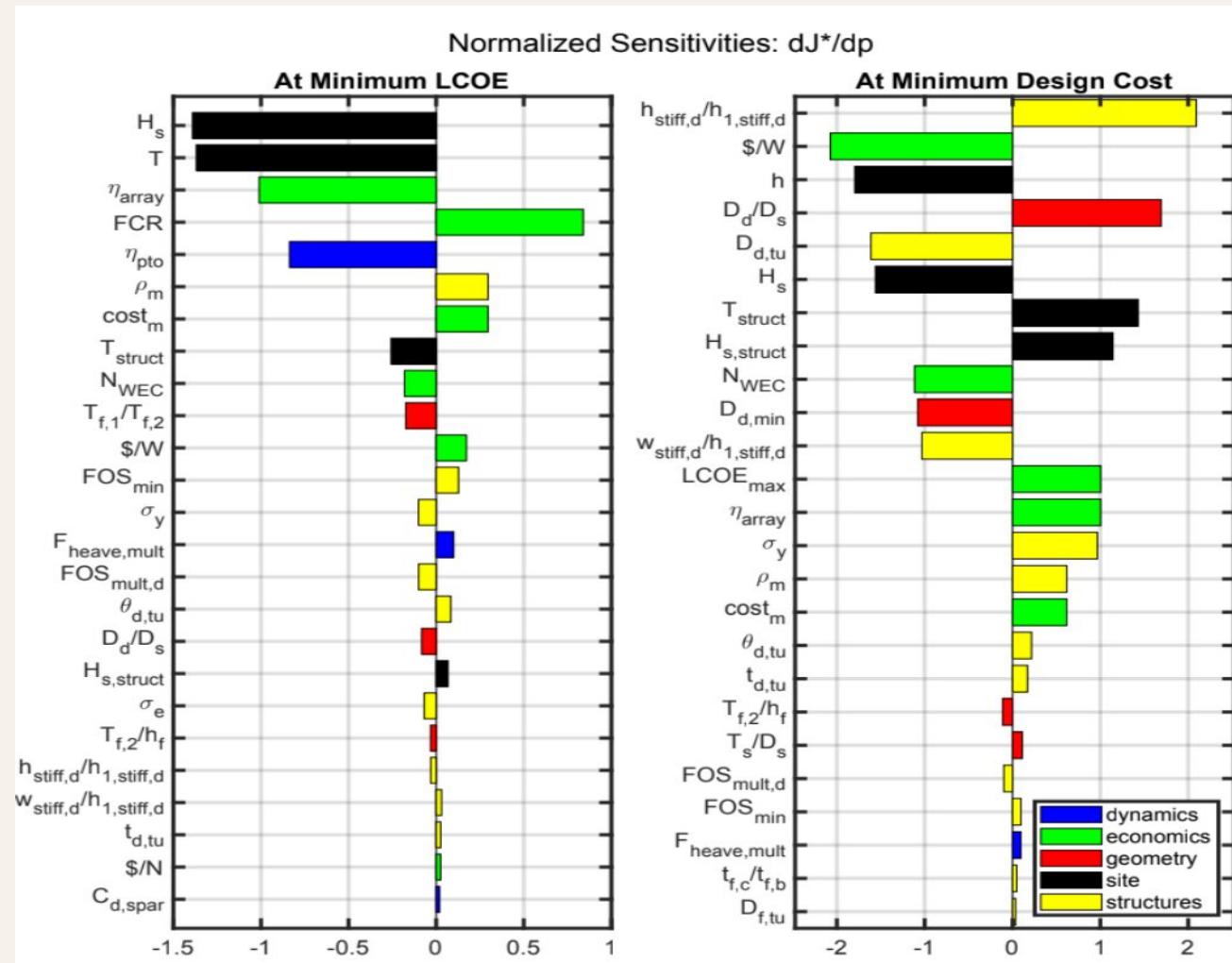
Pareto Analysis to Address Economic Uncertainty



Min LCOE design:

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

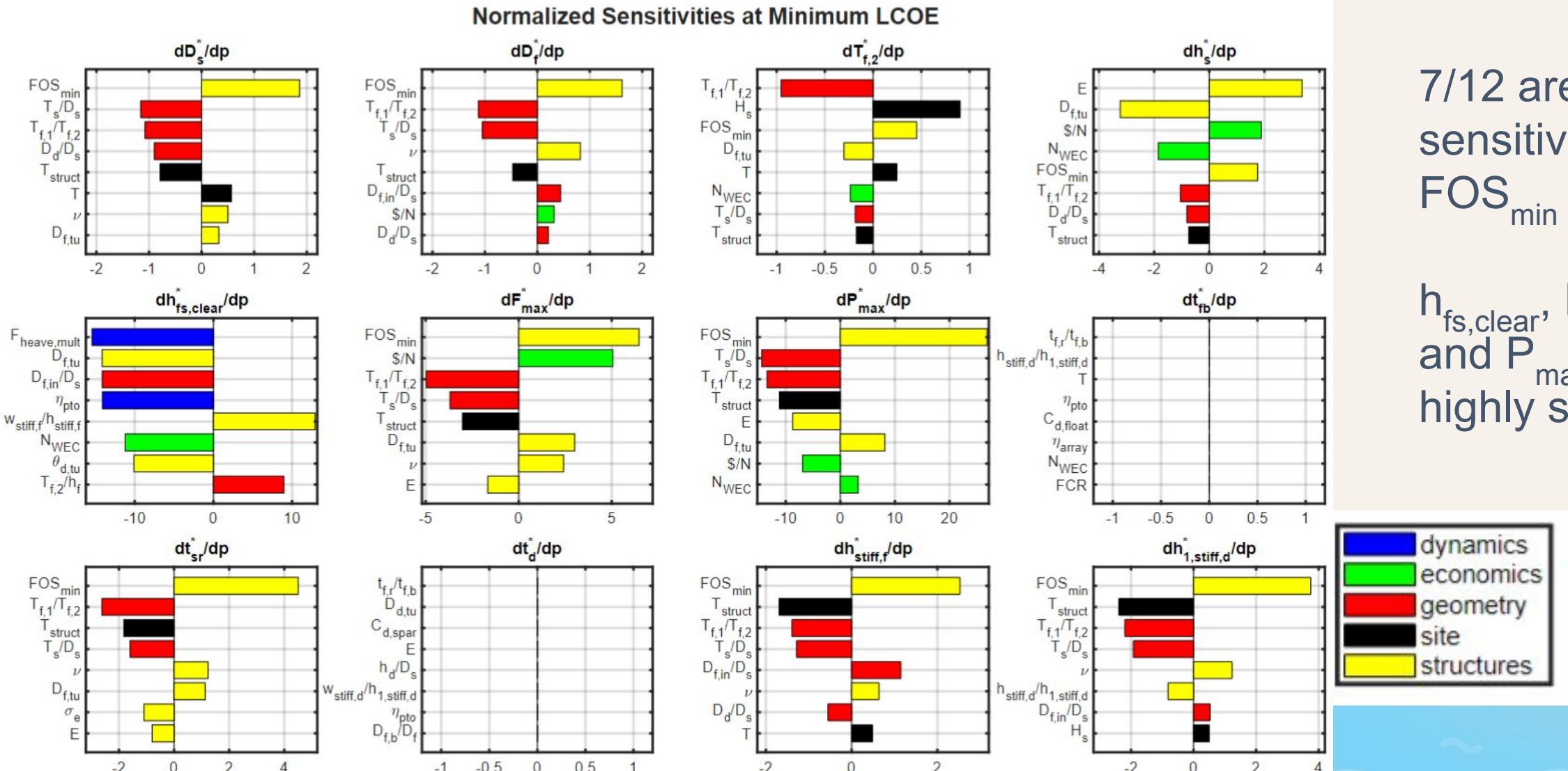
Sensitivity Analysis to Address Economic Uncertainty



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



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:

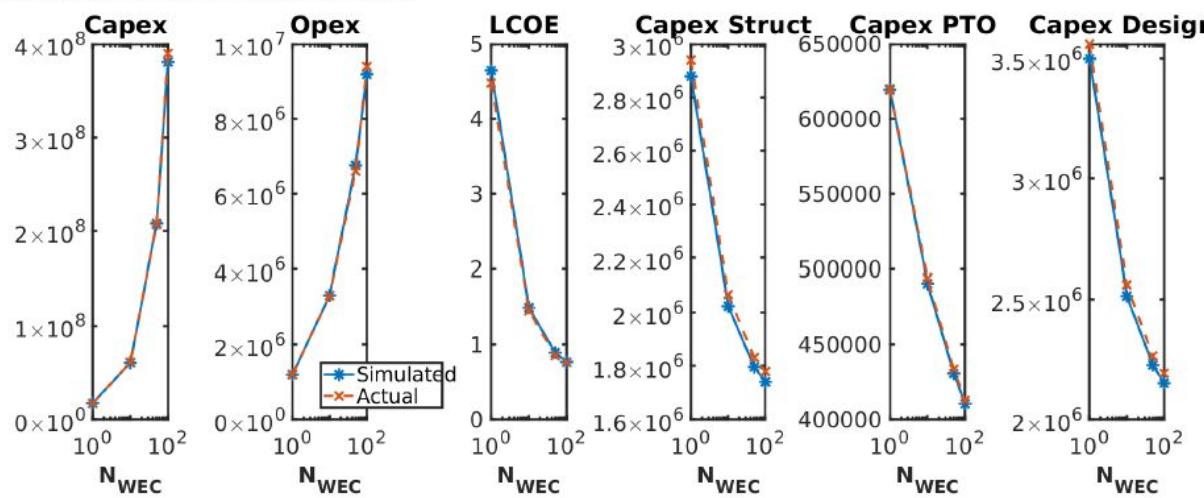
Verification passed.

Test Diagnostic:

Figure saved to:

--> /home/becca/Documents/git/actions-runner/_work/MD0cean/MD0cean/MD0cean/test-results/2025-04-25_12.46.53/dfcb388c-bc25-4cc0-9161-a2f449c17929/econ_validation_reportafc1974-3169-4d25-be89-4c5f34f8b680.fig

--> /home/becca/Documents/git/actions-runner/_work/MD0cean/MD0cean/MD0cean/test-results/2025-04-25_12.46.53/dfcb388c-bc25-4cc0-9161-a2f449c17929/econ_validation_reportafc1974-3169-4d25-be89-4c5f34f8b680.png



Framework Diagnostic:

verifyEqual passed.

--> The error was within relative tolerance.

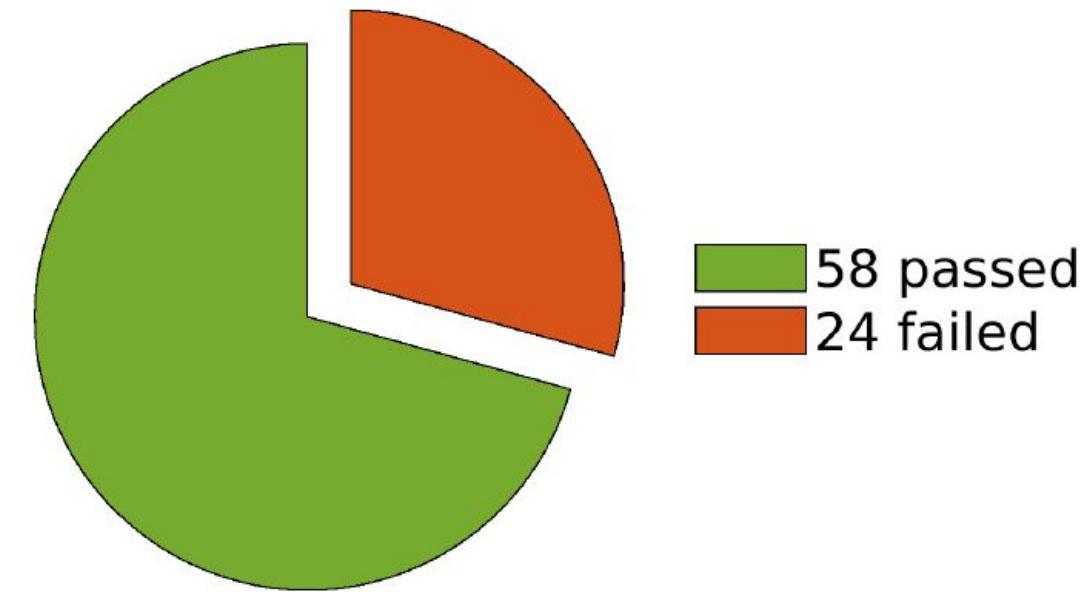
Actual Value:

4.647303820626163 1.492688733038334 0.890516519108912 0.767758969576778

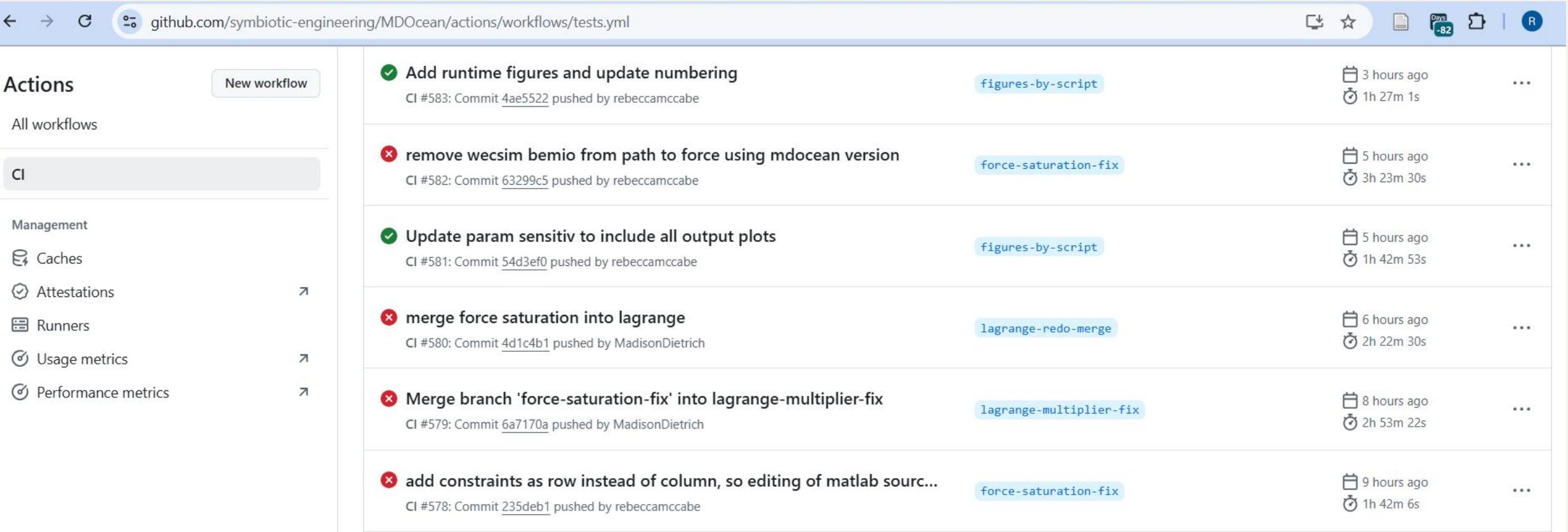
Expected Value:

4.480000000000000 1.450000000000000 0.850000000000000 0.760000000000000

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



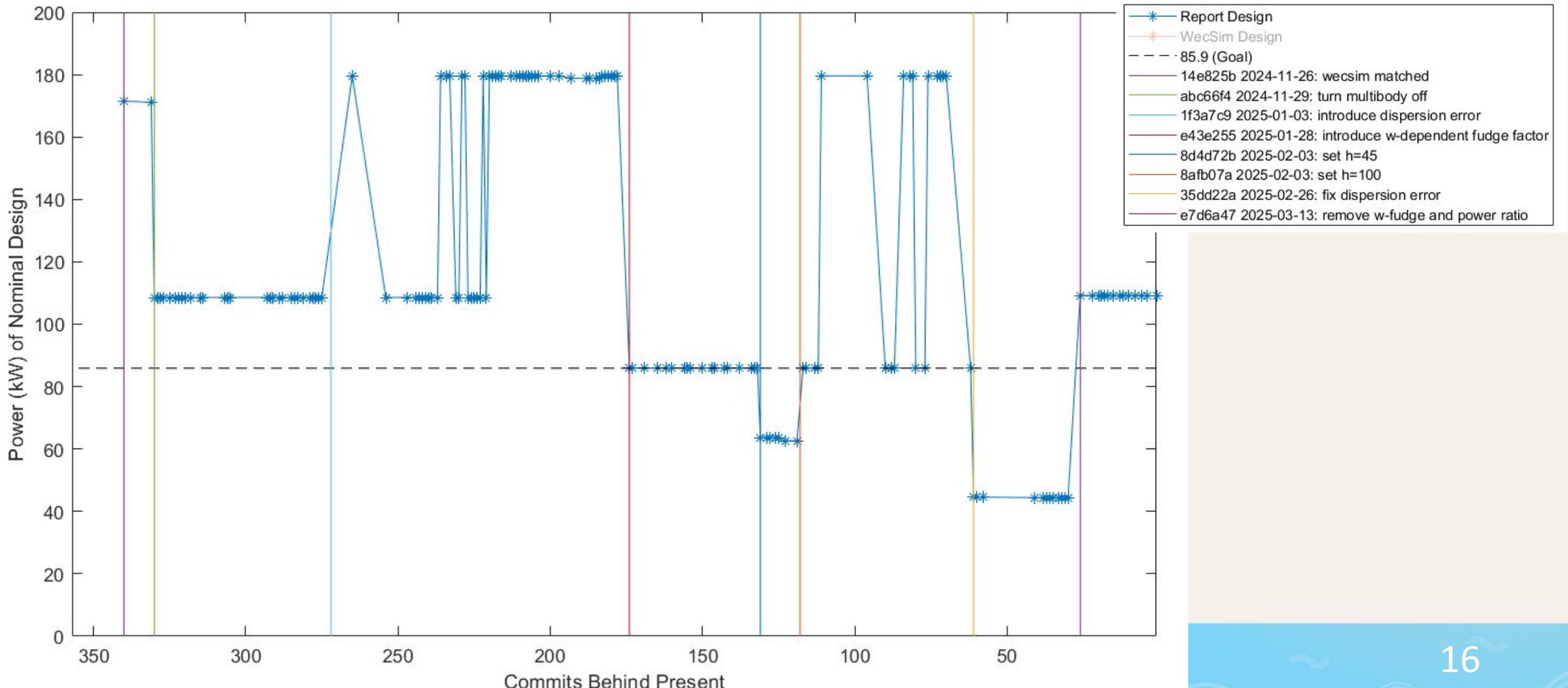
Continuous Integration to Catch Problems Early



The screenshot shows a GitHub CI pipeline for the repository `github.com/symbiotic-engineering/MDOcean/actions/workflows/tests.yml`. The pipeline consists of several jobs, each with a status indicator (green checkmark for success, red X for failure), a description, a commit link, a pushed-by user, a label, and a timestamp.

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

MDOcean

Navigation

API

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- [inputs.validation](#)
- [inputs.wave_conditions](#)
- [optimization](#)
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- [optimization.multiobjective](#)
- [plots](#)
- [plots.util](#)
- [simulation](#)
- [simulation.modules](#)
- [simulation.modules.dynamics](#)
- [simulation.modules.econ](#)
- [simulation.modules.MEE](#)
- [simulation.modules.structure](#)
- [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

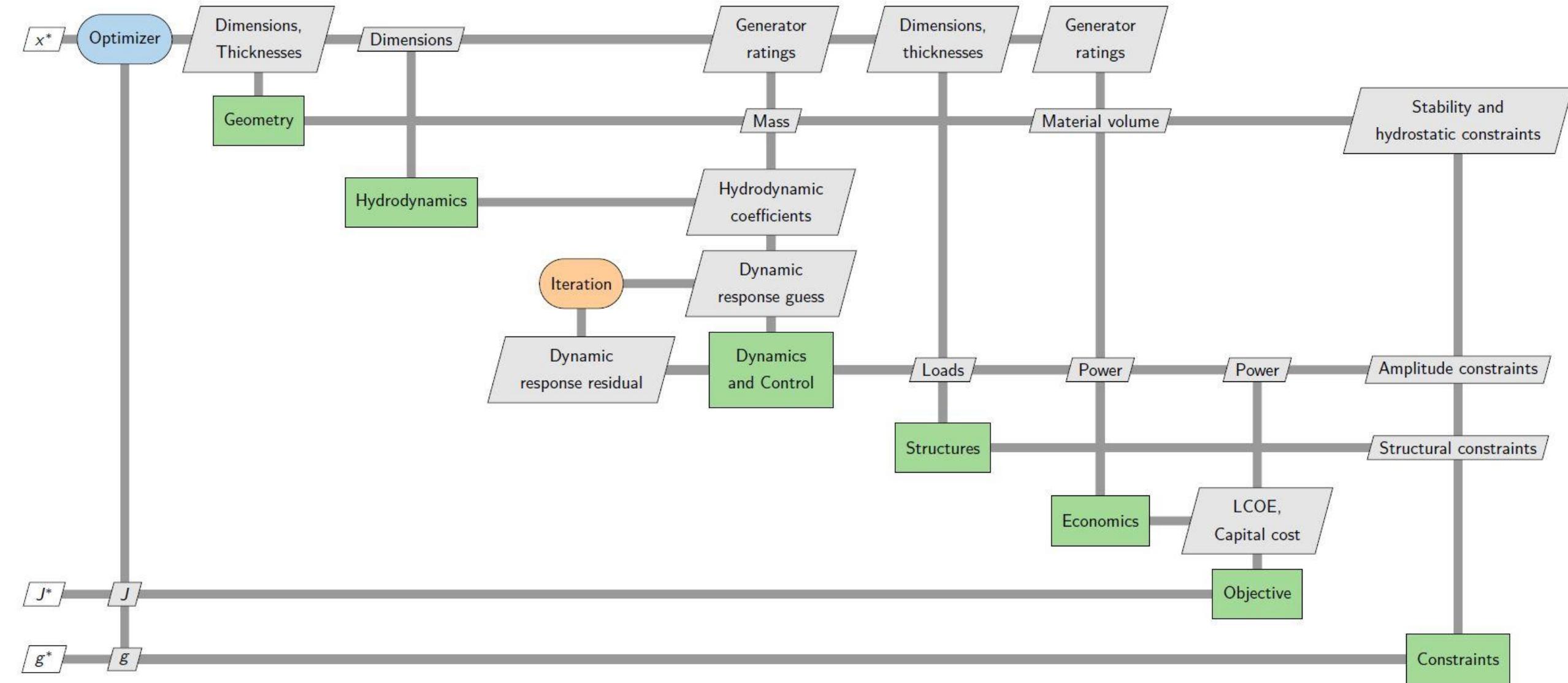
Final-year PhD student seeking next role
Symbiotic Engineering and Analysis Lab
Cornell University
rgm222@cornell.edu

GitHub link

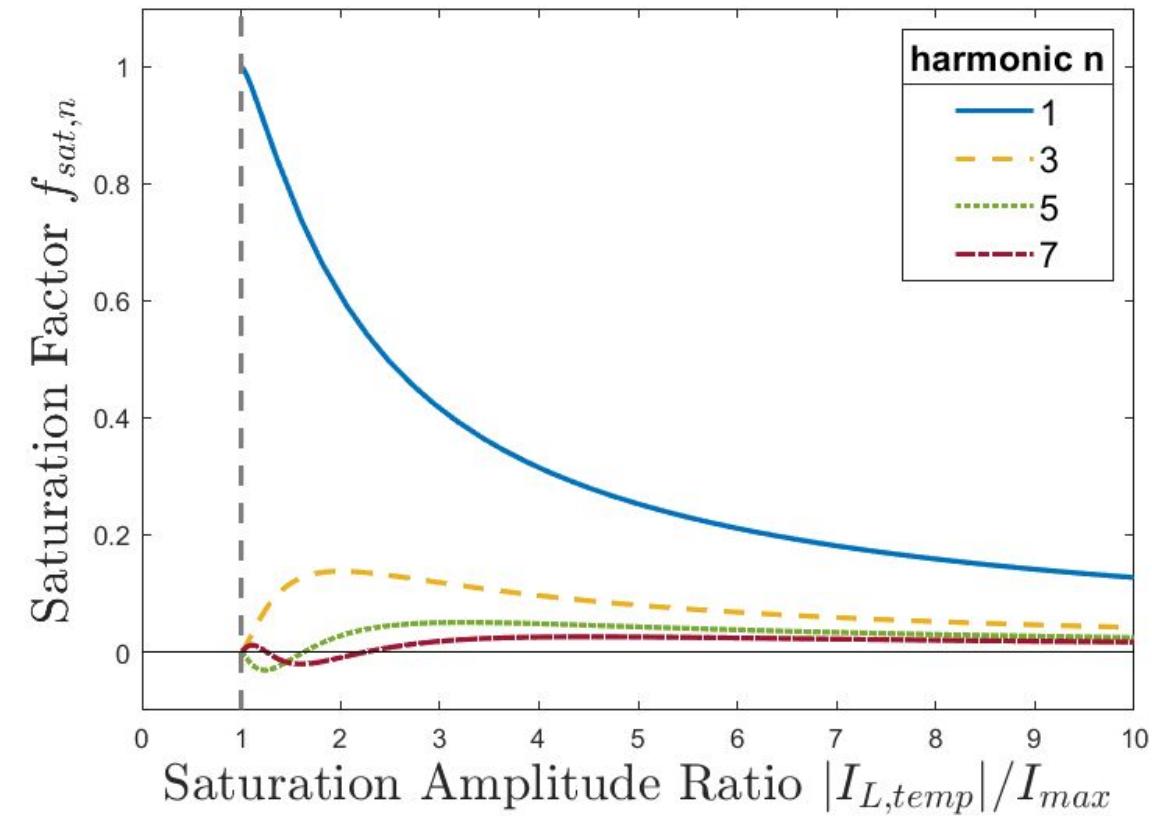
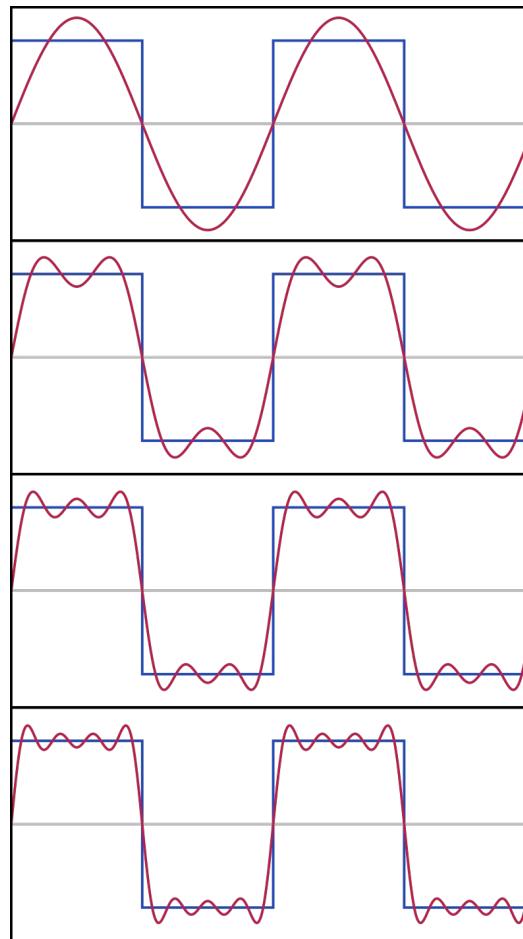
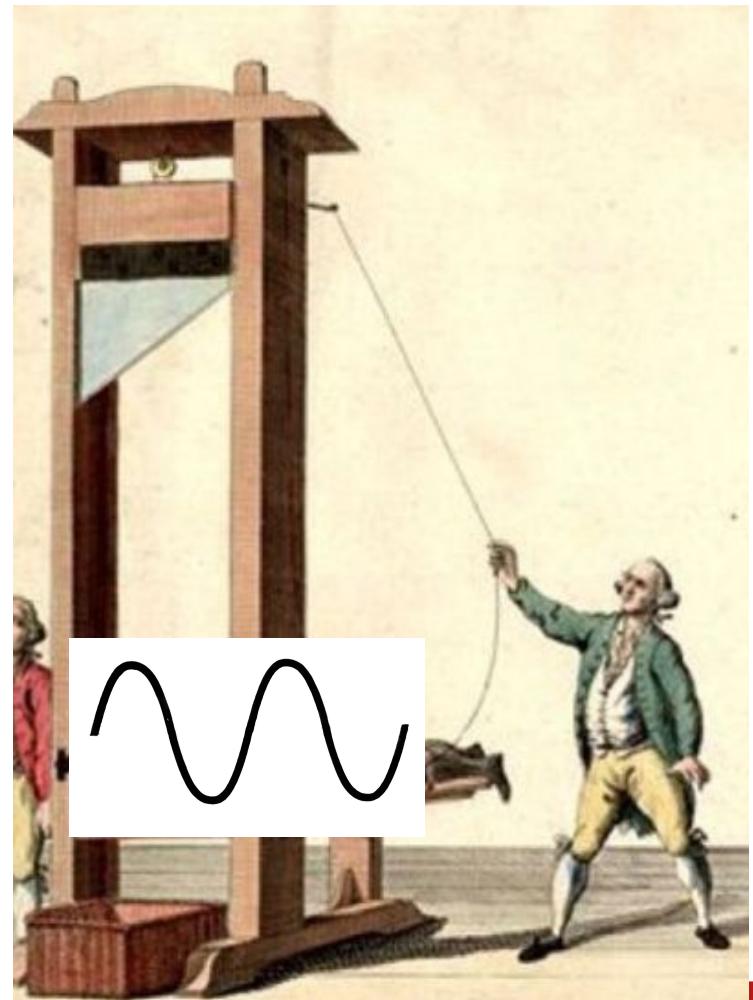


Draft paper link





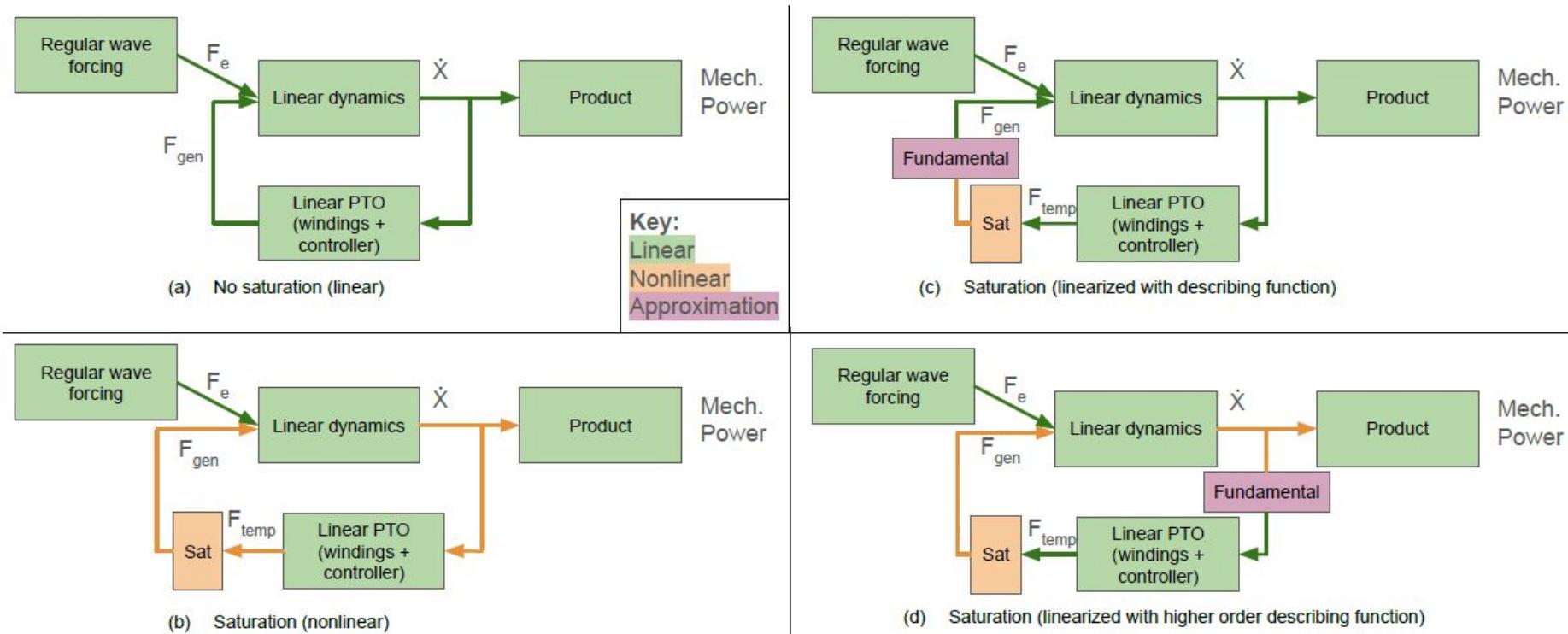
The Saturated Sinusoid



Cornell University

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

