



Post Access Report

Physical Model Validation of a GA Optimized Hull Geometry

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EXECUTIVE SUMMARY

Through this TEAMER work, OPI experimentally evaluated a new hull geometry for the Triton wave energy converter. The candidate geometry had been developed in collaboration with the University of Edinburgh using genetic-algorithm optimization. The preceding numerical study predicted an approximately 10% power-performance improvement in directional waves relative to the baseline hull.

The primary objective of the assistance was to validate the numerical model and hydrodynamic coefficients. Secondary objectives included identifying optimal PTO settings and examining load and power performance in short-crested seas.

Experiments were conducted in September 2021 at the Oregon State University Directional Wave Basin, with testing completed on September 24. The baseline and candidate models were tested side-by-side in the same incoming wave field, with separation reported to be sufficient to avoid interaction. Device 5 was selected to represent the baseline because it provided the best baseline data. Three representative US West Coast wave conditions were evaluated in head-on long-crested waves, 15-degree off-axis long-crested waves, and head-on short-crested waves.

The candidate hull performed worse than the baseline in all nine irregular-wave comparisons plotted in the completed-work summary. The expected numerical improvement was therefore not demonstrated experimentally. Subsequent comparison of WAMIT and NEMOH hydrodynamic results showed broad agreement but did not establish the cause of the prediction discrepancy. The robustness of the rapid white-noise AEP metric remained under investigation at the time of that summary.

The testing provided a direct experimental comparison of the optimized and baseline hulls and evidence to guide further model development. Recommended follow-on work is to reconcile the numerical fitness metric with the tank-test results before using the approach to select further geometries.

1 INTRODUCTION TO THE PROJECT

Oscilla Power (OPI) is developing the Triton wave energy converter architecture. This system is a two-body, multi-mode point absorber consisting of a surface float connected to a submerged ring via three tendons. As the surface float is articulated by waves, the two bodies react against each other in all modes of motion to capture mechanical power. The resulting tension variation in each tendon is transmitted to power take-offs (PTO's) housed inside the surface float. The system has the ability to submerge in extreme waves to mitigate storm loadings, a strategy that has been validated both numerally and in physical experiments. OPI is developing different WEC variants based on the Triton architecture that will share these core operating principles. At the time of the TEAMER testing, there were two variants, the Triton (MW-scale) and the Triton-C (100kw), which are differentiated by their size and drivetrain design. The Triton (MW) has a linear input driving a hydraulic power conversion system, while the Triton-C has a rotary input driving an electrical conversion system.

Our work preceding the test plan on the Triton Utility system had been focused on numerical geometry optimization. This involved a collaboration with the University of Edinburgh. We had been exploring the use of a genetic algorithm to optimize the hull geometry to maximize power performance. Similar work has been done previously in the literature in the frequency domain (using WAMIT) with good success. We had taken this work further by developing a novel fast time-domain evaluation algorithm and incorporating it into the optimization routine. By using a time-domain approach, our expectation is that we can increase confidence in the results through a more accurate representation of the WEC.

Our initial work had generated a significantly different hull geometry that (numerically) provides a substantial AEP improvement over our existing hull shape. Further optimization with different evaluation conditions was planned to identify whether a global maximum had been found. The code used, WAMIT, is extremely well-validated for 'conventional' shapes typically found in the marine environment. However, the unconventional geometries produced through this GA approach are possibly less well explored. It is thus extremely important that a reference physical model validation of the generated shape is produced to confirm the results.

The approved test plan specified a minimum 1:50 scale physical model of the Triton with a representative PTO and an accurately modeled hull geometry in the multidirectional basin at the Hinsdale Laboratory at Oregon State University. The September 2021 campaign provided a side-by-side comparison of the existing baseline hull and the new candidate hull. Both models were 3D printed at OPI and fitted with representative power takeoffs and sensors for measuring power capture. The model-development programme selected 1:50 scale as an existing baseline model was available at this scale for direct comparison.

2 FACILITY, EQUIPMENT, SOFTWARE, AND TECHNICAL EXPERTISE

- Operation of the Directional Wave Basin wavemaker
- Acquisition of data from wave gauges and synchronization signals
- Post processing of data into engineering units

The OSU Directional Wave Basin was used to test the two models in common incident waves, including regular, white-noise, long-crested irregular and short-crested conditions. The comparative irregular-wave programme included 0-degree and 15-degree long-crested headings and 0-degree short-crested waves. WAMIT and OrcaFlex supported the preceding optimization workflow, and NEMOH was used in the subsequent hydrodynamic cross-check.

The Directional Wave Basin dimensions are 48.8 m × 26.5 m × 1.3 m deep. The models used representative three-point moorings, onboard LabJack T7 data acquisition, and concurrent six-degree-of-freedom optical motion measurements using a qualisis motion tracking system, and wave probes at key locations in the basin. Appendix D provides the model-development and basin-calibration figures.

3 TEST OR ANALYSIS ARTICLE DESCRIPTION

Two physical models were evaluated: the existing baseline hull (green) and the genetically optimized candidate hull (black). Both models were 3D printed at OPI and equipped with representative PTOs and power-measurement sensors. The 1:50 optimized model candidate is shown in Figure 2; construction and drivetrain details are in Appendix D. Earlier 1:30 illustrative photographs of the baseline model remain in Appendix A as Figure 1.



Figure 2. Candidate hull used in the completed-work summary: exterior geometry (left) and internal PTO/sensor arrangement (right). Adapted from source Figure 17.

OPI used existing hardware and in-house 3D printing to construct the models. ABS was used for the hull and reaction-ring segments, with an ABS-slurry exterior seal for watertightness and a thin transparent lid to prevent water ingress. This construction differs from the fiberglass/epoxy coating specified in the approved test plan, but was selected to minimize costs. Lead ballast was used in the printed reaction-ring segments to obtain the required submerged properties.

Each model also had three representative, instrumented drivetrains. A mechanical extension spring supported the reaction-ring load, while a rotary dashpot represented the generator load. Together they reproduced the principal kinematic and dynamic forces of the full-scale PTO. Three sensors per drivetrain measured displacement, damper force and spring force.

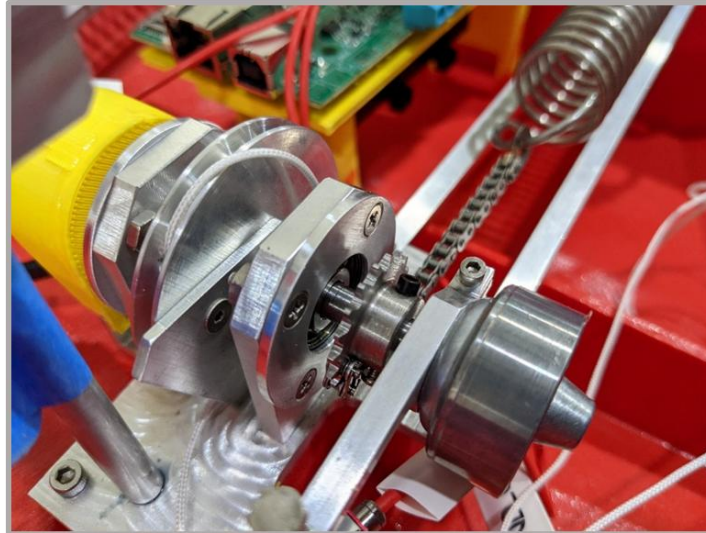


Figure D1b. Instrumented drivetrain installed in the model. Source Figure 12 in the additional notes.

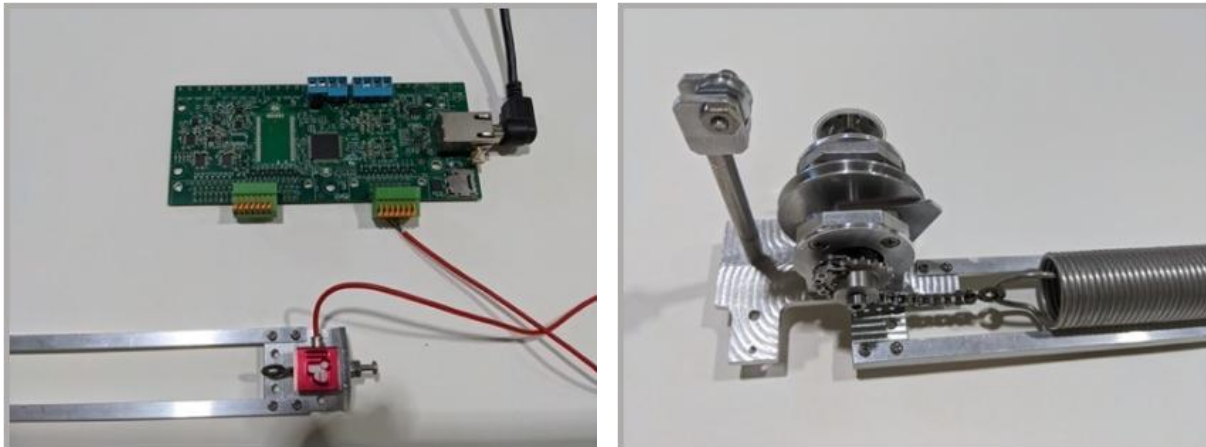


Figure D2a. LabJack T7 DAQ board and drivetrain hardware prepared for installation. Source Figure 14 in the additional notes.

The model platform used fixed spring and damping characteristics selected in the middle of the typical operating range. This was a compromise associated with model scale and the number of units. The notes explain that these settings were suitable for numerical validation but did not allow each model to produce optimum power. Comparisons therefore describe performance under the installed PTO settings, rather than a demonstrated optimum for each hull.

4 WORK PLAN

The September 2021 campaign compared the baseline and candidate hulls in the same incident wave field.

4.1 EXPERIMENTAL SETUP, DATA ACQUISITION SYSTEM, AND INSTRUMENTATION

The models were tested side-by-side to compare power performance in the same incoming wave field. The models were separated sufficiently to avoid interaction. The green hull was the baseline and the black hull was the optimized candidate. Figure 3 shows the basin arrangement during the campaign.

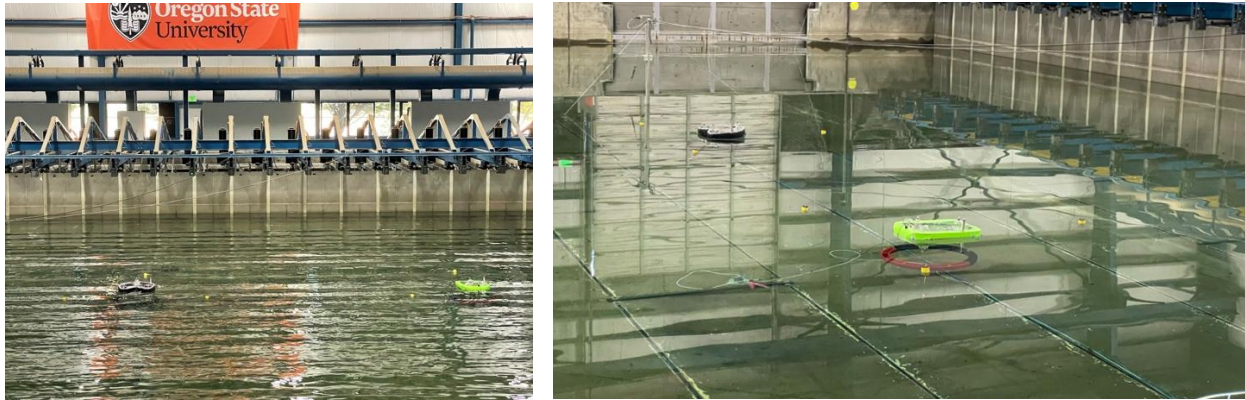


Figure 3a. Baseline (green) and candidate (black) models positioned in the OSU Directional Wave Basin. Source Figure 17, middle photograph.

Each model recorded nine drivetrain channels: six load-cell channels and three position-encoder channels. Damper forces were measured by an S-beam load cell attached to a 100 mm torque arm; spring forces were measured with an inline S-beam load cell. An incremental optical encoder on each drivetrain shaft measured tendon position, from which velocity was determined. Tendon load was derived from the spring and damper measurements, with friction to be quantified, rather than measured directly by a separate tendon load cell.

Table 1: List of instrumentation being captured by OPI DAQ

		Load Cell Values			T7 Supply Voltage	5v	T7 Maximum range		+/- 10v		
Channel	Sensor	Max Load (lb)	Typ Excitation (V)	Output (mV/V)	Actual T7 Excitation (V)	Max ExptForce (lb)	Max LC Output (mV)	T7 Max Input (V)	Internal T7 Gain	T7 FSD (V)	T7 Channel
DT1 Damper	FUTEK LSB200	1	5	2	4	0.9	7.2	5	1000	7.2	AIN 0/1
DT1 Spring	FUTEK LSB200	25	5	2	4	18	5.76	5	1000	5.76	AIN 2/3
DT2 Damper	FUTEK LSB200	1	5	2	4	0.9	7.2	5	1000	7.2	AIN 4/5
DT2 Spring	FUTEK LSB200	25	5	2	4	18	5.76	5	1000	5.76	AIN 6/7
DT3 Damper	FUTEK LSB200	1	5	2	4	0.9	7.2	5	1000	7.2	AIN 8/9
DT3 Spring	FUTEK LSB200	25	5	2	4	18	5.76	5	1000	5.76	AIN 10/11
		Resolution (CPR)	Lin Resolution (mm)	Max Speed (RPM)	maximum counts/sec	Index pulse required					
DT1 Displacement	HEDS9140 / HEDS5140	500	0.251327412	200	1666.666667	Yes - to zero position output					
DT2 Displacement	HEDS9140 / HEDS5140	500	0.251327412	200	1666.666667	Yes - to zero position output					
DT3 Displacement	HEDS9140 / HEDS5140	500	0.251327412	200	1666.666667	Yes - to zero position output					

Each model carried an onboard LabJack T7 DAQ board providing load-cell amplification and encoder quadrature decoding. A single small Ethernet cable streamed data in real time to an onshore control computer and supplied power for the DAQ and sensors. The control computer collected and time-synchronized the model data. This arrangement simplified cable management across the wider seven-

model programme and reduced the influence of instrumentation umbilicals on model motion. The approved plan specified a T7 and a 2.8 mm ultra-flexible cable.

While the original intention was to use load cells to be used to measure forces in the mooring lines, due to misunderstanding, and a lack of available equipment, this was not possible.

Wave calibration was performed without WECs in the basin using 16 probe locations to measure surface elevation concurrently for all wave conditions. During the wider device-testing programme, a reference probe remained at location 2 to check the incoming wave field. The probe and WEC coordinates are reproduced in Appendix D.

All model data were captured concurrently with six-degree-of-freedom optical motion measurements. The model channels were time-synchronized by the onshore computer. OSU wave data was collected in time-stamped text files and a UTC-referenced test/wave-generation start time for alignment with OPI DAQ

4.2 NUMERICAL MODEL DESCRIPTION

The preceding optimization study, conducted with the University of Edinburgh, used 11 control points and 22 variable coordinates to define candidate hulls with a bicubic B-spline surface. WAMIT supplied hydrodynamic coefficients to OPI's OrcaFlex time-domain model. A genetic algorithm ranked candidate shapes by an AEP-based fitness measure, applying selection, recombination and mutation while constraining displaced volume around the baseline value of 1,950 m³. The numerically selected candidate predicted an approximately 10% power-performance improvement in directional waves.

To reduce the computational cost of ranking shapes, OPI developed a rapid AEP method based on a single white-noise OrcaFlex simulation. PTO-velocity response spectra were combined with the spectrum of each sea state to estimate absorbed power, and the resulting matrix was weighted by the occurrence probabilities for Humboldt Bay, California. In the preceding numerical assessment, this approach agreed with the long-form AEP method to within 8% on average, with most power-matrix bins within 10%, while reducing evaluation time from roughly one day to one hour. These comparisons were numerical method-development results, not experimental validation of the candidate hull.

4.3 TEST AND ANALYSIS MATRIX AND SCHEDULE

The models were tested on the 23 and 24th September 2021 in the wave conditions reproduced in Table 3. Three representative US West Coast irregular-wave conditions were evaluated at 0-degree long-crested, 15-degree long-crested and 0-degree short-crested incidence. The completed-work table also lists seven regular-wave conditions and a flat-spectrum white-noise condition. The original planned matrix and 12-day schedule are retained in Appendix B for comparison with the executed programme. Testing was completed on September 24, 2021.

TEAMER Tests				Full Scale (prototype)	
Reference	Spectra	Spreading (Cos ² s)	Paddle Direction	T [s]	H [m]
Regular Waves					
WC-R1	Monochromatic	∞	0	4	0.50
WC-R2	Monochromatic	∞	0	6	0.70
WC-R3	Monochromatic	∞	0	8	1.25
WC-R4	Monochromatic	∞	0	10	2.00
WC-R5	Monochromatic	∞	0	12	2.75
WC-R6	Monochromatic	∞	0	14	3.75
WC-R7	Monochromatic	∞	0	16	5.00
Irregular Waves				TP [s]	Hs [m]
WC-WN	White Noise (flat)	∞	0	4 - 20	1.5
WC-LC1	Breitschneider	∞	0	9.2	1.75
WC-LC2	Breitschneider	∞	0	10.6	2.75
WC-LC3	Breitschneider	∞	0	13.4	2.75
WC-LC5	Breitschneider	∞	15	9.2	1.75
WC-LC6	Breitschneider	∞	15	10.6	2.75
WC-LC7	Breitschneider	∞	15	13.4	2.75
Short Crested Waves					
WC-SC1	Breitschneider	20	0	9.2	1.75
WC-SC2	Breitschneider	20	0	10.6	2.75
WC-SC3	Breitschneider	20	0	13.4	2.75

Table 3. Wave conditions reported for the September 2021 OSU campaign; periods and heights are shown at full (prototype) scale. Reproduced from source Table 4.

Calibration results for the six long-crested irregular-wave conditions are summarized in Table 4. The measured ranges are model-scale significant wave heights across the basin. Head-on conditions generally achieved the target Hs, while 15-degree conditions were mostly below target. These spatial ranges describe wave-field variation and are not confidence intervals or device-specific incident-wave estimates. Detailed per-probe and interpolated spatial plots are reproduced in Appendix D.

Table 4. Target irregular waves and measured basin Hs ranges. FS denotes full scale and MS denotes 1:50 model scale. Source: Additional TEAMER testing Notes, Table 3.

Wave	Tp FS (s)	Hs FS (m)	Tp MS (s)	Hs MS (m)	Dir (deg)	Min Hs MS (m)	Max Hs MS (m)
WC-LC1	9.2	1.75	1.3	0.035	0	0.0330	0.0366

Wave	Tp FS (s)	Hs FS (m)	Tp MS (s)	Hs MS (m)	Dir (deg)	Min Hs MS (m)	Max Hs MS (m)
WC-LC2	10.6	2.75	1.5	0.055	0	0.0520	0.0575
WC-LC3	13.4	2.75	1.9	0.055	0	0.0534	0.0579
WC-LC5	9.2	1.75	1.3	0.035	15	0.0253	0.0356
WC-LC6	10.6	2.75	1.5	0.055	15	0.0389	0.0588
WC-LC7	13.4	2.75	1.9	0.055	15	0.0389	0.0606

4.4 SAFETY

The applicant and OSU facility staff were required to follow all relevant safety procedures and protocols outlined in Appendix C, as defined by the OH Hinsdale Safety Plan 2020. This document describes the comprehensive and proactive safety plan in use at the O.H. Hinsdale Wave Research Laboratory (HWRL) at Oregon State University (OSU). The plan is built upon the principles of involvement, identification, rules, and training. The plan applies to anyone and everyone conducting work at the facility, including but not limited to faculty, instructors, post-docs, researchers, staff, and students, whether University employees or visitors.

The facility adheres to the University safety policy as described below. The policy requires everyone to follow safe working practices and procedures. It applies to all Oregon State University employees, students, and any other individuals conducting business on OSU property. The policy states the following:

Effective management of health and safety at Oregon State University is fundamental to delivering excellence in research and teaching. Health and safety should be a concern to everyone since our mutual efforts and vigilance are necessary to eliminate incidents that result in personal injury and loss of property. The majority of injuries and property loss are costly and preventable. Through the dedicated efforts of everyone involved, we can maintain a safe and healthy environment while accomplishing the mission of the University. 2 Oregon State University will make reasonable efforts to provide a safe and healthful working environment for all employees, students and others who may utilize the University's facilities and grounds. All University departments/units will develop and implement safety policies and procedures that promote an injury free environment. Anyone engaged in University related activities must exercise personal responsibility and care to prevent injury and illness to themselves and others who may be affected by their acts or omissions. No person shall intentionally interfere with or misuse anything provided by the University in the interests of health and safety. Individuals are required to have the proper training for the safe operation and use of university facilities, equipment and supplies as well as animal handling. Faculty and staff administrators will be held accountable for fulfilling their safety responsibilities. Flagrant disregard of the University safety policies and procedures may result in disciplinary action. Priority should be given to safe working conditions and job safety practices in the planning, budgeting, direction and implementation of University activities. The OSU Health and Safety Policy should be read in conjunction with SAF 103: OSU Safety Program and other safety policies contained in the OSU Safety (SAF) Policy and Procedure Manual.

All visitors, researchers and clients performing an activity within HWRL were required to undergo a specific and documented Safety Training, reviewing general safety procedures, rules and hazards.

Temporary visitors were required to use yellow safety vests for best identification and awareness and should use safety shoes at all times while working on the laboratory floor. Other safety protocols were to be reviewed with the client during the Safety Training.

Safety Briefings were required at the beginning of the project and every time a safety hazard or activity is identified. HWRL staff and visitors are required to attend each and every briefing.

4.5 CONTINGENCY PLANS

N/A.

4.6 DATA MANAGEMENT, PROCESSING, AND ANALYSIS

4.6.1 Data Management

Model data were streamed in real time from the onboard DAQs to the onshore control computer, where they were collected and time-synchronized. Physical model test data has been uploaded to MHKDR with a suitable moratorium period.

Data submitted to MHKDR for each wave condition:

Data	Format
Wave elevation time-series for each wave condition	Raw text file
Power time-series for each tendon	Raw text file
Tendon force for each tendon	Raw text file

4.6.2 Data Processing

OPI used MATLAB to process data. The following procedures were specified to ensure high quality data collection and post-processing:

- 1) A reference wave test was to be completed at the start and end of each day of testing to confirm consistent device response
- 2) A random test was to be repeated each day
- 3) Data were to be inspected after each test to confirm all sensors functioning
- 4) Data collection for each test was to start in calm water, which was to be used during analysis to define Instrumentation zeros. In post-processing, the initial 5 wave periods of dynamic data were to be discarded to remove device's initial transient response.
- 5) Sensor spot checks were to be conducted each day, where possible. The reaction ring is a known mass, so this can be used as a calibration mass during testing

For irregular-wave calibration, H_s was calculated from the measured surface-elevation record at each probe. Runs were longer than the wave repeat time so that the full Bretschneider spectrum was represented, but H_s was calculated only over the repeat interval. Bilinear interpolation of the probe values was used to construct the spatial wave-height surfaces in Appendix D.

4.6.3 Data Analysis

The approved plan specified MATLAB processing and Froude scaling to prototype values. The installed drivetrain instrumentation measured spring force, damper force and shaft-encoder position. Tendon

velocity was obtained from position, and tendon load was derived from spring and damper forces with a friction contribution to be quantified. Mechanical PTO power was to be calculated from instantaneous damping force and tendon velocity. The force conversion from the 100 mm torque-arm measurement, encoder-to-tendon conversion, differentiation/filtering and averaging procedures must be documented to reproduce this calculation.

Experimental results were to be directly compared with the numerical model and an error established. For scalar values, a single percentage difference was to be reported.

5 PROJECT OUTCOMES

5.1 RESULTS

Candidate hull and baseline power comparison

The candidate hull performed worse than the baseline in the September 2021 OSU comparison. Figure 4 shows lower candidate power in each of the nine plotted comparisons across three wave conditions and three heading/spreading cases. This contradicted the improvement predicted by the numerical optimization. The tests therefore did not demonstrate a power-performance benefit from the selected candidate geometry.

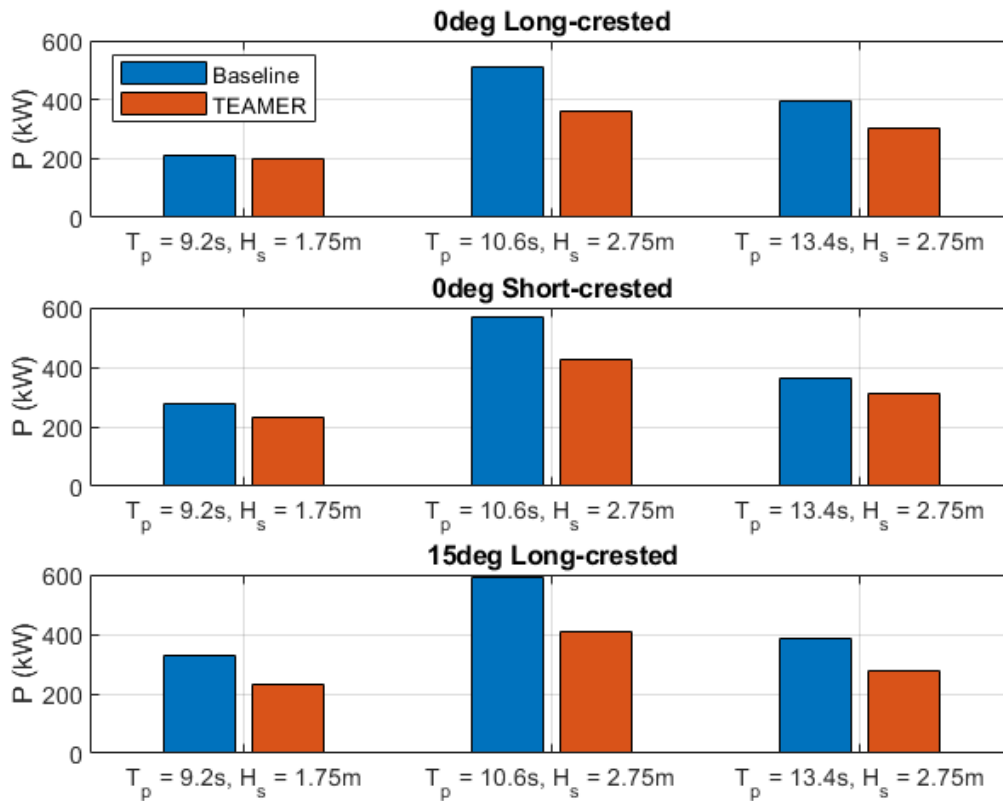


Figure 4. Baseline-versus-candidate power comparison in head-on long-crested, head-on short-crested and 15-degree long-crested waves. The orange series labeled “TEAMER” denotes the candidate hull. Reproduced from source Figure 18; power is labeled in kW in the source.

Hydrodynamic model cross-check

One hypothesis was that BEM inaccuracies for unconventional geometries caused the genetic algorithm to favor unsuitable shapes. WAMIT and NEMOH predictions for the candidate hull were therefore compared. Figure 5 shows broad agreement in the principal surge, heave and pitch response features, with localized differences in damping and phase. This comparison did not establish whether WAMIT was

accurate or whether both codes shared a limitation, and it did not identify the cause of the experimental performance shortfall. It is also possible that shape-dependent scaling of moment of inertia and drag area as possible sources of error.

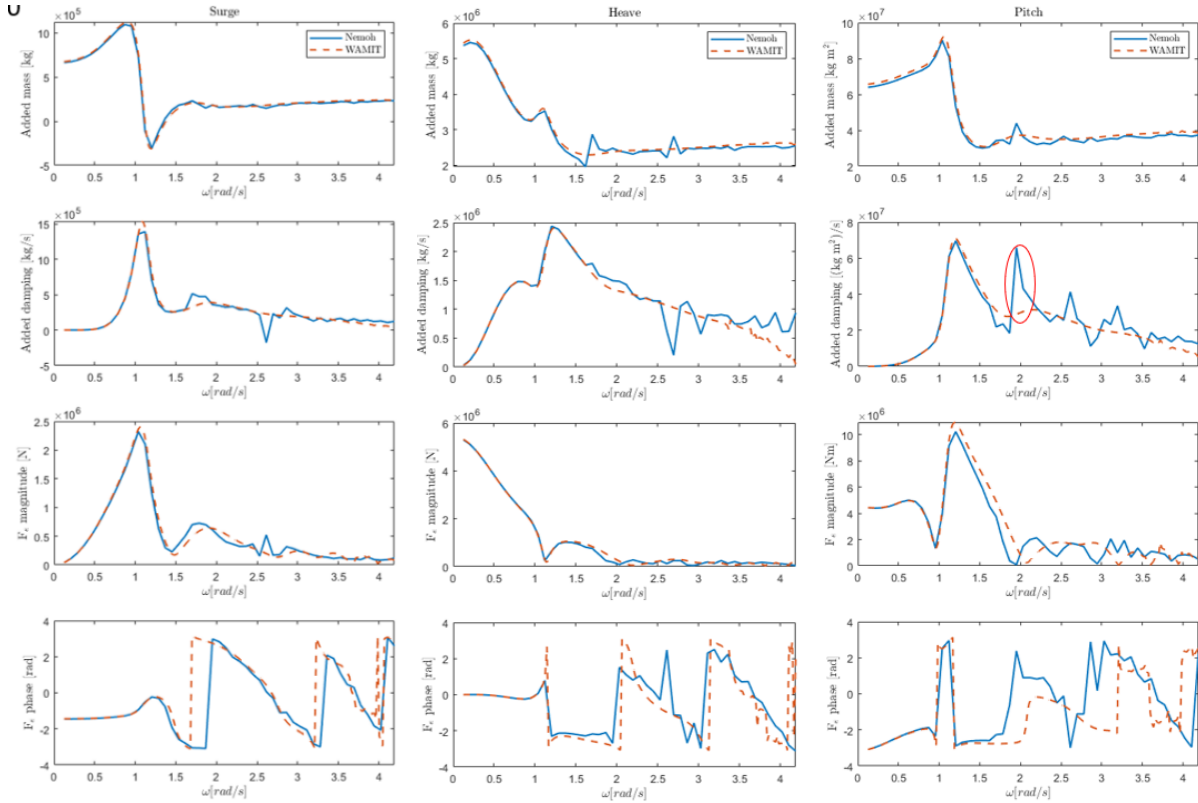


Figure 5a. WAMIT/NEMOH comparison for candidate-hull surge (left), Heave (middle), pitch (right): Top to bottom: added mass, damping, excitation magnitude and phase.

Following the tank tests, NEMOH was used as an independent BEM implementation to compare hydrodynamic predictions with WAMIT. The results are presented in Figure 5. Broad agreement between the codes did not exclude common modeling limitations or errors in the rapid AEP fitness metric.

Additional hypotheses for the numerical–experimental disagreement concern approximations embedded in the optimization code, including how moments of inertia and drag areas were scaled for different hull shapes. WAMIT output and the accuracy of the rapid AEP proxy for some geometries were also identified for investigation. These remain proposed explanations; we have not yet been able to establish a root cause.

Assessment against the project objectives

Hull-performance improvement was not demonstrated: the candidate underperformed the baseline in the reported comparisons. Directional-sea comparisons were completed for the three heading/spreading cases. The results exposed a numerical prediction discrepancy and supported diagnostic comparisons, but full model validation against a quantitative acceptance threshold remains to

be established. Fixed spring and damping settings were used and an optimal-PTO search is therefore not demonstrated by these tests. Tendon loads were derived from the drivetrain sensors.

5.2 LESSONS LEARNED AND TEST PLAN DEVIATION

The completed-work summary documents a side-by-side baseline/candidate comparison, rather than only the single optimized-model validation described in the approved plan. Its wave table adds 15-degree long-crested comparisons and a white-noise condition. Regular-wave heights also differ: for periods of 6, 8, 10, 12, 14 and 16 s, the completed-work table lists 0.70, 1.25, 2.00, 2.75, 3.75 and 5.00 m, versus 0.50, 0.50, 1.00, 1.00, 1.00 and 1.00 m in the approved plan.

The principal lesson was that a geometry selected for improved numerical performance did not deliver that benefit in physical tests.. Checking WAMIT against NEMOH was a useful diagnostic, but code-to-code agreement alone could not establish root cause. The rapid AEP fitness metric, based on a single white-noise simulation, remained a possible source of non-robust geometry ranking. Future optimization should be checked against experimental response and power data before relying on predicted gains.

The hardware programme demonstrated the practicality of in-house ABS printing, slurry sealing and onboard networked DAQ for compact models. Fixed spring and damper settings simplified construction and operation, while limiting conclusions about optimum power.

6 CONCLUSIONS AND RECOMMENDATIONS

The September 2021 TEAMER campaign established that the numerically optimized candidate hull did not outperform the existing baseline in the tested irregular-wave cases. The predicted improvement of approximately 10% was not supported by the comparative tank-test results. The campaign supplied evidence for improving the numerical optimization process and for assessing performance across wave heading and spreading conditions.

Follow-on work should reconcile measured and predicted responses, quantify uncertainties, and test the rapid white-noise AEP metric over a wider set of shapes and sea states. Check shape-dependent moments of inertia and drag areas, mesh convergence and experimental validation of BEM predictions. Quantify device friction and local incident waves, particularly for the 15-degree seas. Match the installed fixed PTO settings in numerical comparisons before drawing conclusions about optimal hull performance.

7 REFERENCES

A. Garcia-Teruel, B. DuPont, and D. I. M. Forehand, “Hull geometry optimisation of wave energy converters: On the choice of the optimisation algorithm and the geometry definition,” *Applied Energy*, vol. 280, p. 115952, Dec. 2020, doi: [10.1016/j.apenergy.2020.115952](https://doi.org/10.1016/j.apenergy.2020.115952).

A. P. McCabe, G. A. Aggidis, and M. B. Widden, “Optimizing the shape of a surge-and-pitch wave energy collector using a genetic algorithm,” *Renewable Energy*, vol. 35, no. 12, pp. 2767–2775, 2010, doi: [10.1016/j.renene.2010.04.029](https://doi.org/10.1016/j.renene.2010.04.029).

8 ACKNOWLEDGEMENTS

The experimental campaign received support from the US TEAMER program and was conducted at Oregon State University’s Directional Wave Basin. The preceding hull-optimization work was performed in collaboration with the University of Edinburgh.

This work was also supported by the Department of Energy under agreement DE-EE0008625

9 DATA AVAILABILITY

Project data are available at <https://mhkdr.openei.org/submissions/742>

10 APPENDIX

Appendix A Illustrative test-plan model

The following photographs and caption are retained from the approved test plan as background. They depict an earlier 1:30-scale model and are not substitutes for the September 2021 campaign photographs in Figures 2 and 3.

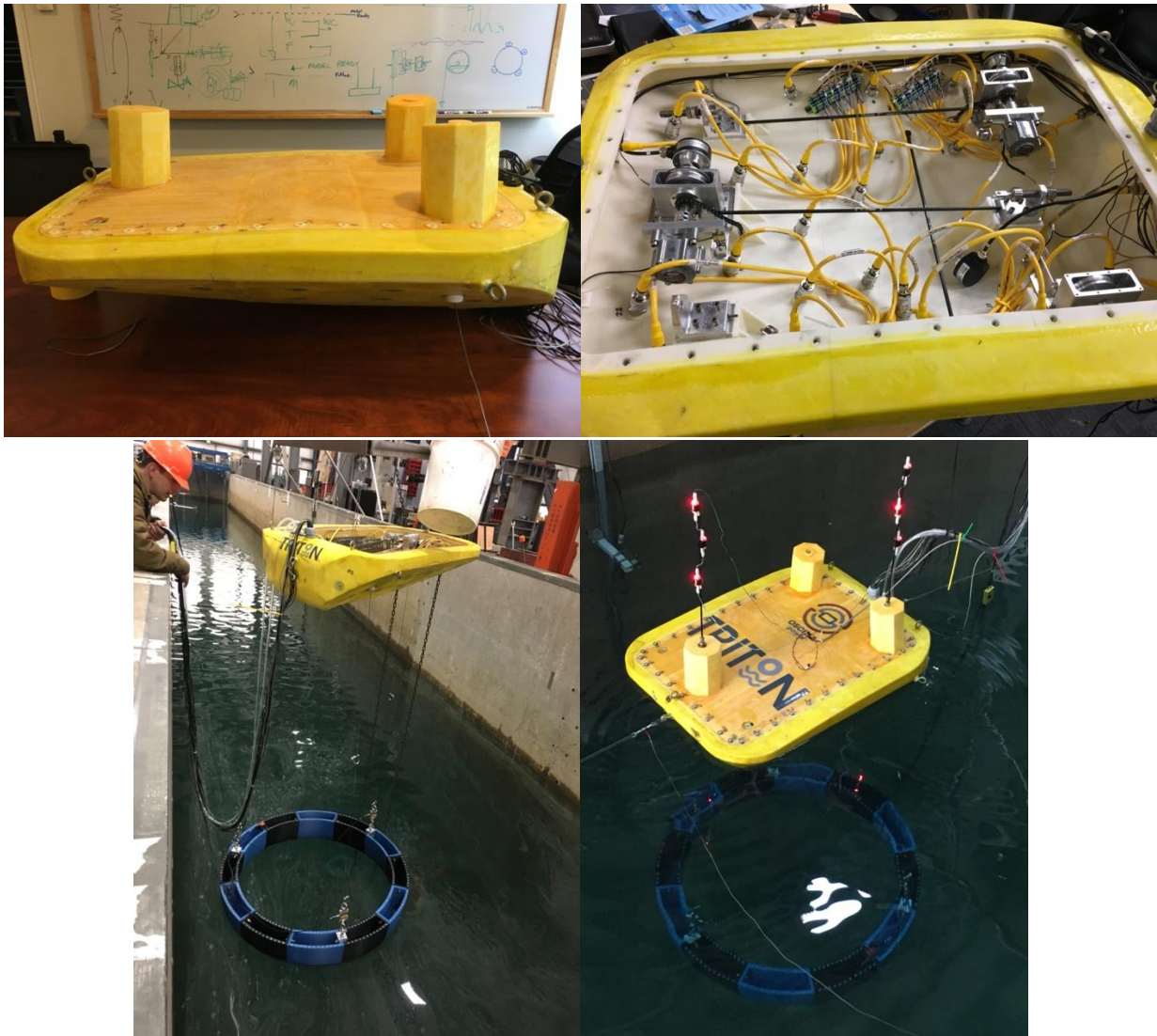


Figure 1: Images of 1:30 scale model shown in the test plan. The 1:50th scale model was intended to be very similar. The drivetrain was intended to be substantially identical (but smaller) and the hull/reaction ring were intended to continue to utilize 3d printing.

Appendix B Approved test matrix and planned schedule

The following matrix and schedule reproduce the approved-plan basis for comparison with Section 6.3. They show intended tests and timing, not confirmation of execution.

Wave Calibration Tests										
Reference	Spectra	Spreading (Cos ² Zs)	Paddle Direction	Desired Calibration Accuracy	Full Scale		1:50 Model Scale		Notes	
					T [s]	H [m]	T [s]	H [mm]		
Regular Waves										
WC-R1	Monochromati	=	0	10% or better	4	0.5	0.6	10	Calibration take at model centre (without model)	
WC-R2	Monochromati	=	0	10% or better	6	0.5	0.8	10		
WC-R3	Monochromati	=	0	10% or better	8	0.5	1.1	10		
WC-R4	Monochromati	=	0	10% or better	10	1	1.4	20		
WC-R5	Monochromati	=	0	10% or better	12	1	1.7	20		
WC-R6	Monochromati	=	0	10% or better	14	1	2.0	20		
WC-R7	Monochromati	=	0	10% or better	16	1	2.3	20		
Irregular Waves										
WC-LC1	Breitschneider	=	0	5%	Tp [s]	Hs [m]	Tp [s]	Hs [mm]	Spreading exponents in Cos ² 2s derived from: Babarit, Chapter 1 - Potential: Energy Resource and Markets, Wave Energy Conversion, Elsevier, 2017, Pages 1-35, https://doi.org/10.1016/B978-1-78548-264-9.50001-X . Duration suitable to confirm spectral shape and Hs	
WC-LC2	Breitschneider	=	0	5%	9.2	1.75	1.3	35		
WC-LC3	Breitschneider	=	0	5%	10.6	2.75	1.5	55		
					13.4	2.75	1.9	55		
Short Crested										
WC-SC1	Breitschneider	20	0	within 2% of WC-LC1	9.2	1.75	1.3	35		
WC-SC2	Breitschneider	20	0	within 2% of WC-LC2	10.6	2.75	1.5	55		
WC-SC3	Breitschneider	20	0	within 2% of WC-LC3	13.4	2.75	1.9	55		
WC-SC4	Breitschneider	10	0	within 2% of WC-LC1	9.2	1.75	1.3	35		
WC-SC5	Breitschneider	10	0	within 2% of WC-LC2	10.6	2.75	1.5	55		
WC-SC6	Breitschneider	10	0	within 2% of WC-LC3	13.4	2.75	1.9	55		

Device Tests						
Free Decay/Static Tests	PTO Settings		Wave Reference	Mooring Configuration	Test Duration	System Configuration / Notes
	Damping	Spring				
ST0	=	=		Free Floating		Static Waterline Tests (Initial Zeros)
ST1	=	=		Moored - 0 degrees		Mooring Offset Tests Surge
ST2	=	=		Moored - 0 degrees		Mooring Offset Tests Sway
Monochromatic Tests	PTO Settings		Wave Reference	Mooring Configuration	Test Duration	System Configuration / Notes
	Damping	Spring				
WTR1	TBD	TBD	WC-R1	0 degrees	Duration TBD - 20 consistent wave cycles	
WTR2	TBD	TBD	WC-R2	0 degrees		
WTR3	TBD	TBD	WC-R3	0 degrees		
WTR4	TBD	TBD	WC-R4	0 degrees		
WTR5	TBD	TBD	WC-R5	0 degrees		
WTR6	TBD	TBD	WC-R6	0 degrees		
WTR7	TBD	TBD	WC-R7	0 degrees		
Validation to Earlier Tests	PTO Settings		Wave Reference	Mooring Configuration	Test Duration	System Configuration / Notes
	Damping	Spring				
DT-LC1	TBD	TBD	WC-LC1	0 degrees	20 minutes	
DT-LC2	TBD	TBD	WC-LC2	0 degrees	25 minutes	
DT-LC3	TBD	TBD	WC-LC3	0 degrees	30 minutes	
Power Performance	PTO Settings		Wave Reference	Mooring Configuration	Test Duration	System Configuration / Notes
	Damping	Spring				
DT-SC1	TBD	TBD	WC-SC1	0 degrees	20 minutes	
DT-SC2	TBD	TBD	WC-SC2	0 degrees	25 minutes	
DT-SC3	TBD	TBD	WC-SC3	0 degrees	30 minutes	
DT-SC4	TBD	TBD	WC-SC4	0 degrees	20 minutes	
DT-SC5	TBD	TBD	WC-SC5	0 degrees	25 minutes	
DT-SC6	TBD	TBD	WC-SC6	0 degrees	30 minutes	

Task	Title	Duration (days)	Week 1					Week 2					Week 3				
			M	T	W	Th	F	M	T	W	Th	F	M	T	W	Th	F
1	Directional Wave Basin Setup	4															
1.1	Wave gauge setup	1.5															
1.2	Load cells setup	0.5															
1.3	Mooring setup	0.5															
1.4	Qualisys setup	1															
1.5	Survey and calibrations	0.5															
2	Testing	7															
2.1	System ID (free decay and static load)	1															
2.2	Regular Waves	1															
2.2	Validation of earlier tests	2															
2.3	Power performance	3															
3	Decommissioning	1															
3.1	Device removal	0.5															
3.2	Instrument removal	0.5															
	Total	12															

Appendix D Model hardware and wave calibration

The figures below document the model platform and calibration used in the broader OSU testing programme. The accompanying notes describe seven-model array work, wake measurements for SNL-SWAN validation and two-device interaction tests. They provide hardware and wave-field context for the TEAMER hull comparison.

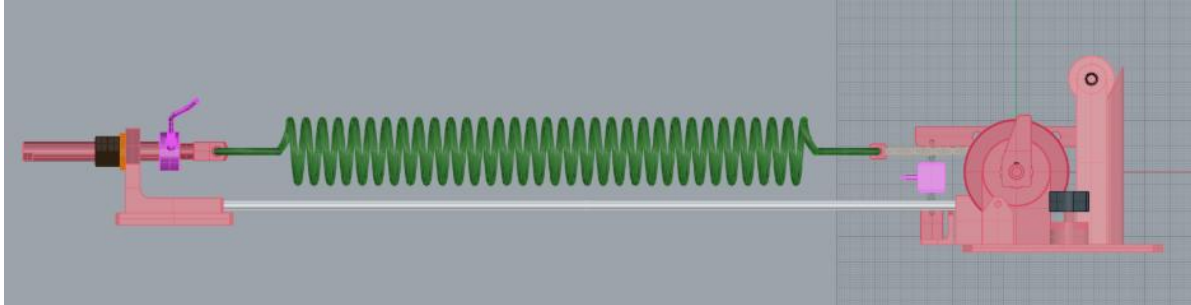


Figure D1a. CAD side view of the 1:50 drivetrain with extension spring and rotary damper. Source Figure 11 in the additional notes.



Figure D2b. The 1:50 physical model with transparent lid and submerged reaction ring. Source Figure 16 in the additional notes.

Mooring and wave probe arrangement

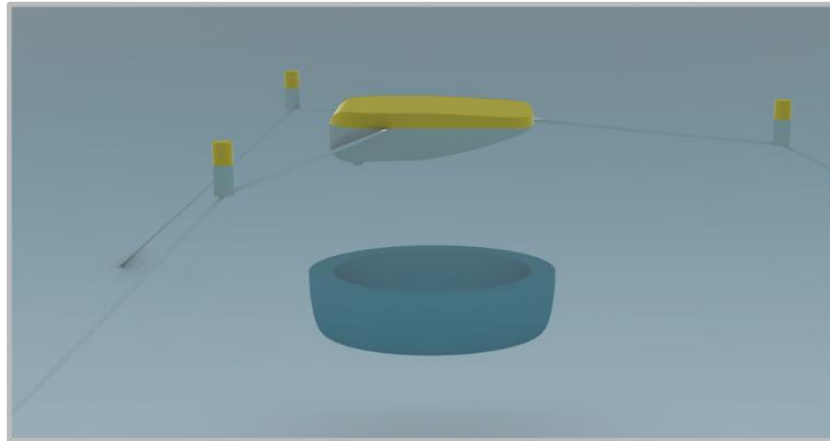


Figure D3. Representative model mooring arrangement. Source Figure 17 in the additional notes.

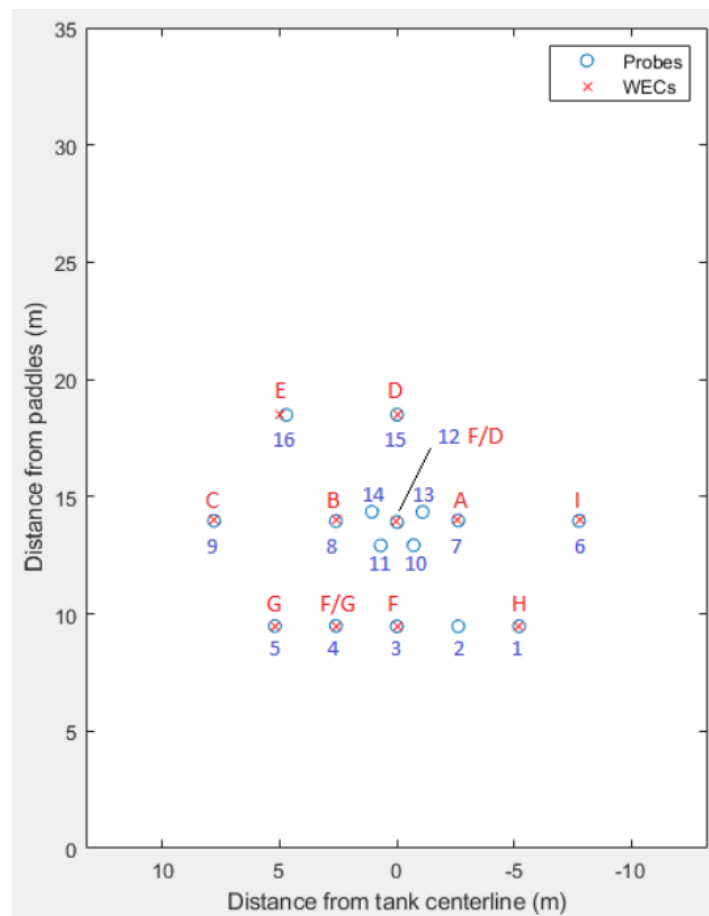


Figure D4. Wave-probe calibration locations and WEC test positions in the wider programme. Paddles are at the bottom and waves propagate upward. Source Figure 19 in the additional notes.

notes.

Spatial variation of significant wave height

Bilinear interpolation of probe measurements shows the spatial variation of H_s . Red circles denote probes. The dips near probe 12 may represent a physical basin effect or a calibration error; the notes do not resolve the cause.

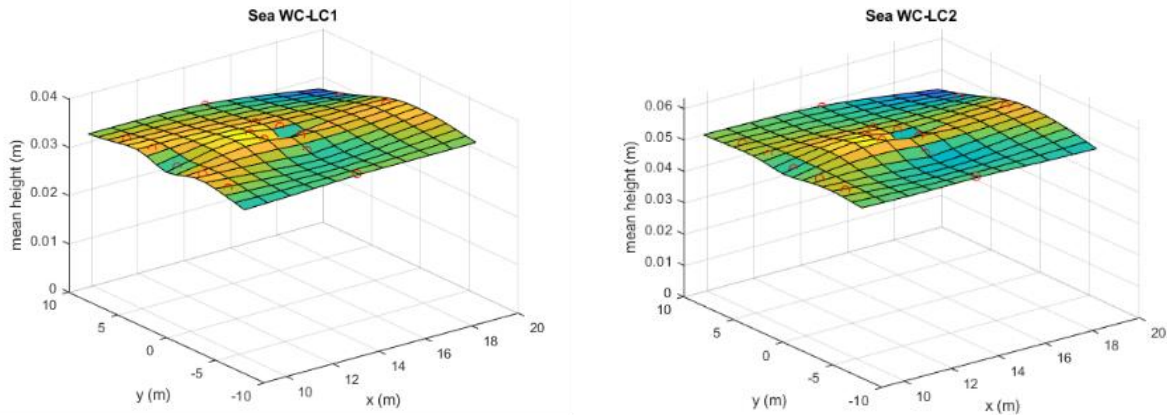


Figure D6a. Model-scale H_s surfaces for WC-LC1 and WC-LC2. Source Figure 21 in the additional notes.

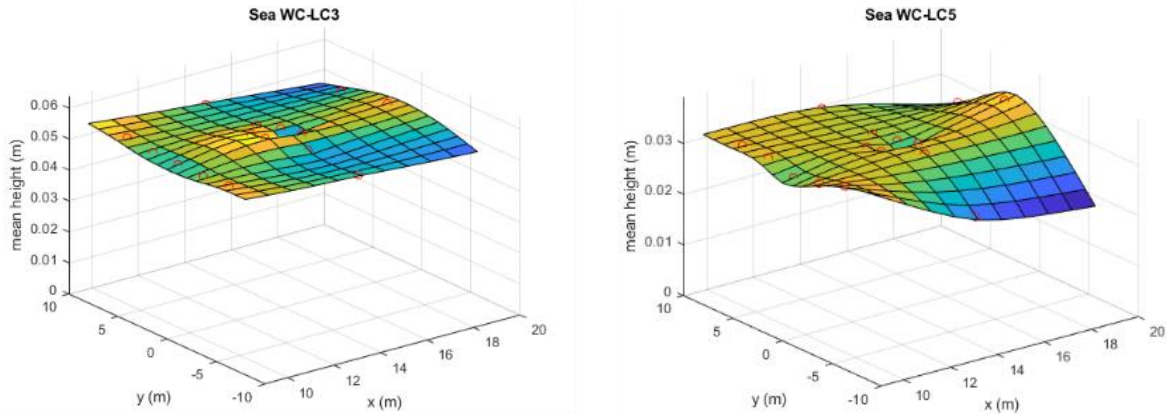


Figure D6b. Model-scale H_s surfaces for WC-LC3 and WC-LC5. Source Figure 21 in the additional notes.

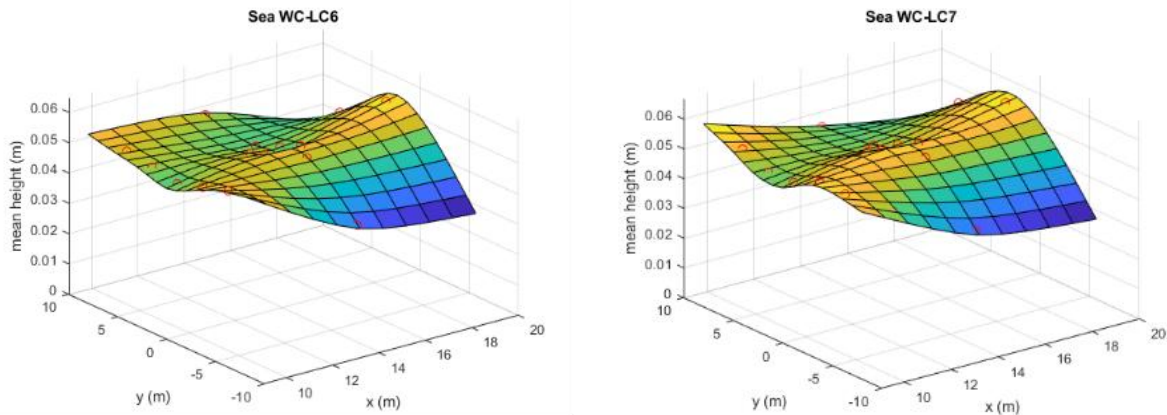


Figure D6c. Model-scale H_s surfaces for WC-LC6 and WC-LC7. Source Figure 21 in the additional notes.