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MaRINET2

MaRINET2

ABOUT MARINET

The MaRINET2 project is the second iteration of the successful EU funded MaRINET Infrastructures Network, both of which are coordinated and managed by Irish research centre MaREI in University College Cork and avail of the Lir National Ocean Test Facilities.

MaRINET2 is a €10.5 million project which includes **39 organisations** representing some of the top offshore renewable energy testing facilities in Europe and globally. The project depends on strong international ties across Europe and draws on the expertise and participation of **13 countries**. Over 80 experts from these distinguished centres across Europe will be descending on Dublin for the launch and kick-off meeting on the 2nd of February.

The original MaRINET project has been described as a *"model of success that demonstrates what the EU can achieve in terms of collaboration and sharing knowledge transnationally"*. Máire Geoghegan-Quinn, European Commissioner for Research, Innovation and Science, November 2013

MARINET2 expands on the success of its predecessor with an even greater number and variety of testing facilities across offshore wind, wave, tidal current, electrical and environmental/cross-cutting sectors. The project not only aims to provide greater access to testing infrastructures across Europe, but also is driven to improve the quality of testing internationally through standardisation of testing and staff exchange programmes.

The MaRINET2 project will run in parallel to the MaREI, UCC coordinated EU marinerg-i project which aims to develop a business plan to put this international network of infrastructures on the European Strategy Forum for Research Infrastructures (ESFRI) roadmap.

The project will include at least 5 trans-national access calls where applicants can submit proposals for testing in the online portal. Details of and links to the call submission system are available on the project website www.marinet2.eu

European Commission

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Table of Contents

Table of Contents 4
1 Introduction & Background 5
1.1 Introduction 5
1.2 Development So Far 5
1.2.1 Stage Gate Progress 5
1.2.2 Plan For This Access 6
2 Outline of Work Carried Out 7
2.1 Setup 7
2.2 Tests 9
2.2.1 Test Plan – Overview 9
2.2.2 Decay tests 10
2.2.3 Linear PTO (spring) 10
2.2.4 Hydraulic PTO 10
2.2.5 Extreme conditions 11
2.2.6 Empty wave tank 11
2.3 Results 12
2.3.1 Decay tests 12
2.3.2 Linear PTO (spring) 12
2.3.3 Hydraulic PTO 13
2.3.4 Extreme Conditions 14
2.4 Analysis & Conclusions 15
2.4.1 PTO behavior 15
2.4.2 Buoy Shape 15
2.4.3 Extreme Conditions Tests 15
3 Main Learning Outcomes 16
3.1 Progress Made 16
3.1.1 Progress Made: For Marine Renewable Energy Industry 16
3.2 Key Lessons Learned 16
4 Further Information 16
4.1 Scientific Publications 16
4.2 Website & Social Media 16
5 Appendices 17
5.1 Stage Development Summary Table 17

1 Introduction & Background

1.1 Introduction

Oneka Technologies is a company that is on the track to commercialize wave-powered desalination units. The access to fresh water is a growing issue all around the world and desalination of seawater is getting more and more used. The Oneka units are an environmentally friendly solution for places with ocean exposure in need of fresh water, such as tropical islands.

The main technological advantage of the systems, compared to other similar wave energy converters, is that they collect power and resources at the same place. The patented system is mechanical, there is no electricity involved.

The company is based in Sherbrooke, QC, Canada, where research, bench testing, design and development takes place. An experimental test site is located in Florida and a demonstrator is deployed in the Atlantic Ocean to produce fresh water autonomously in real conditions.

1.2 Development So Far

A full-scale prototype has been designed and is currently being tested at sea. It is a point absorber driving a piston pump that pressurized water and pushes it through a hydraulic power take off (PTO) and then to the reverse osmosis membranes. It has worked and produced fresh water within the expected range of 10 000 liters per day.

A numerical model of the entire system was developed based on the test bench and prototype's data. It takes into account the buoy's response to wave inputs, the behavior of the hydraulic system and the mechanics of the piston pump.

1.2.1 Stage Gate Progress

Previously completed: ✓

Planned for this project: ➲

STAGE GATE CRITERIA	Status
Stage 1 – Concept Validation	
• Linear monochromatic waves to validate or calibrate numerical models of the system (25 – 100 waves)	➲
• Finite monochromatic waves to include higher order effects (25 –100 waves)	
• Hull(s) sea worthiness in real seas (scaled duration at 3 hours)	✓
• Restricted degrees of freedom (DofF) if required by the early mathematical models	
• Provide the empirical hydrodynamic co-efficient associated with the device (for mathematical modelling tuning)	➲
• Investigate physical process governing device response. May not be well defined theoretically or numerically solvable	➲
• Real seaway productivity (scaled duration at 20-30 minutes)	➲
• Initially 2-D (flume) test programme	
• Short crested seas need only be run at this early stage if the devices anticipated performance would be significantly affected by them	
• Evidence of the device seaworthiness	➲
• Initial indication of the full system load regimes	✓
Stage 2 – Design Validation	
• Accurately simulated PTO characteristics	✓
• Performance in real seaways (long and short crested)	✓
• Survival loading and extreme motion behaviour.	➲
• Active damping control (may be deferred to Stage 3)	
• Device design changes and modifications	➲
• Mooring arrangements and effects on motion	✓
• Data for proposed PTO design and bench testing (Stage 3)	✓
• Engineering Design (Prototype), feasibility and costing	✓
• Site Review for Stage 3 and Stage 4 deployments	✓
• Over topping rates	✓
Stage 3 – Sub-Systems Validation	
• To investigate physical properties not well scaled & validate performance figures	✓

STAGE GATE CRITERIA	Status
• To employ a realistic/actual PTO and generating system & develop control strategies	✓
• To qualify environmental factors (i.e. the device on the environment and vice versa) e.g. marine growth, corrosion, windage and current drag	✓
• To validate electrical supply quality and power electronic requirements.	
• To quantify survival conditions, mooring behaviour and hull seaworthiness	➲
• Manufacturing, deployment, recovery and O&M (component reliability)	✓
• Project planning and management, including licensing, certification, insurance etc.	✓
Stage 4 – Solo Device Validation	
• Hull seaworthiness and survival strategies	➲
• Mooring and cable connection issues, including failure modes	✓
• PTO performance and reliability	✓
• Component and assembly longevity	✓
• Electricity supply quality (absorbed/pneumatic power-converted/electrical power)	✓
• Application in local wave climate conditions	✓
• Project management, manufacturing, deployment, recovery, etc	✓
• Service, maintenance and operational experience [O&M]	✓
• Accepted EIA	
Stage 5 – Multi-Device Demonstration	
• Economic Feasibility/Profitability	
• Multiple units performance	
• Device array interactions	
• Power supply interaction & quality	
• Environmental impact issues	
• Full technical and economic due diligence	
• Compliance of all operations with existing legal requirements	

1.2.2 Plan For This Access

These tests are complementary to the full-scale demonstrator we are currently performing at sea with our prototype. The main advantage here was having a controlled environment with wave sensors that gave us the exact wave inputs, and precise motion capture.

Main objectives:

1. Acquire data for numerical model calibration
2. Compare performance for different shapes of buoys
3. Compare performance PTO settings
4. Measure loads in extreme wave conditions

2 Outline of Work Carried Out

2.1 Setup

The main experimental setup consisted of a single action piston pump (Figure 2.1) driven by a buoy. The pump loads were controlled by adjusting valves that were accessible by the team during the tests. The moving cylinder of the pump was connected to the buoy with a universal joint and its rod to a steel cable to the anchor.

The full-scale device is located nearshore (depth of 15-20m) so the scaled anchor was elevated from the ground. The anchor was a rigid structure that positioned the anchoring point about 2 m under the surface (3 m above ground).

The steel cable went through a pulley on the anchor structure and had one end on the facility bridge where it could be tightened or released. This allowed for fast and easy enough buoy changes (around 20 min).

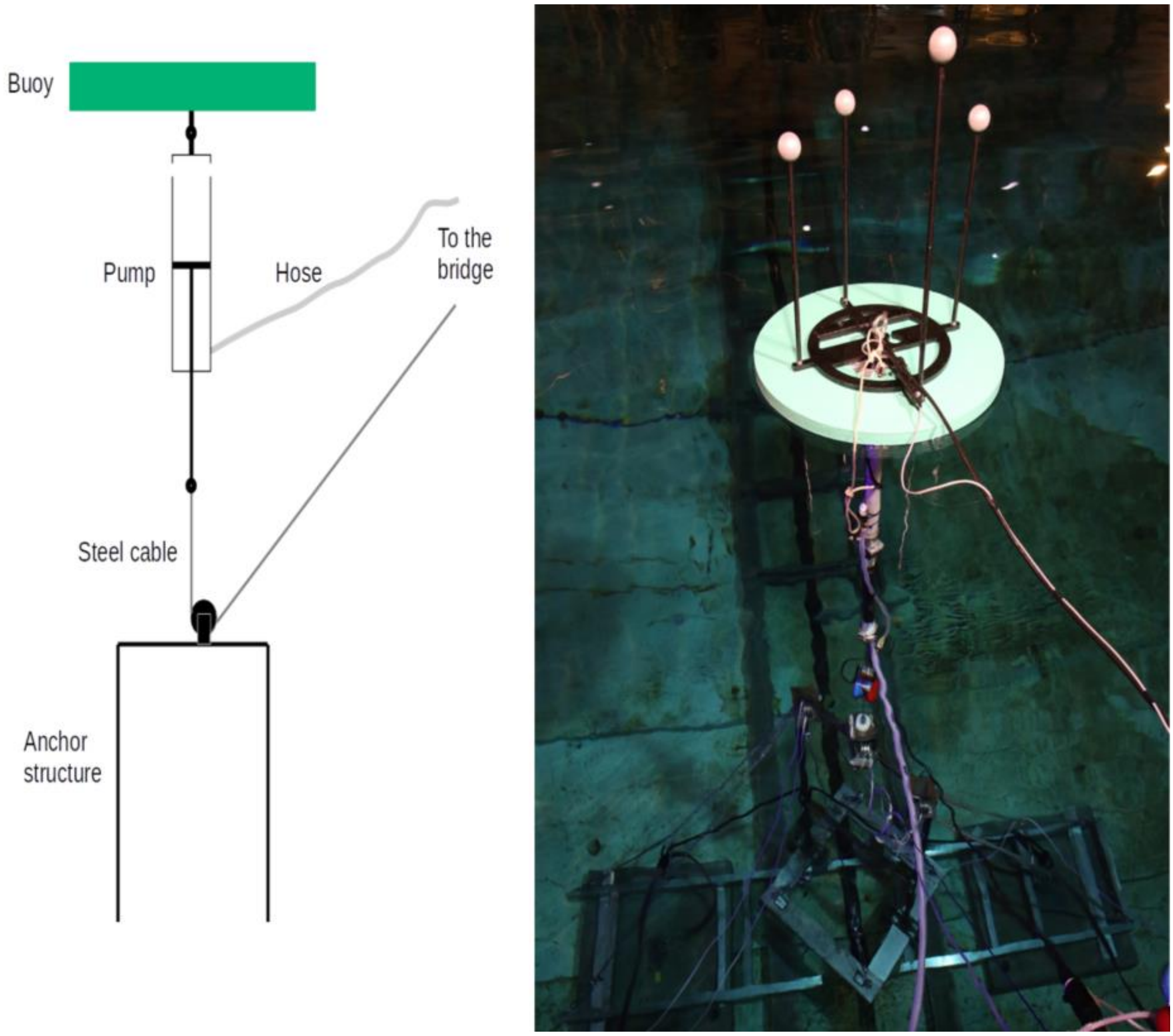


Figure 2.1 Main setup

The pump's chamber was hydraulically connected to the PTO located on the bridge. The PTO consisted of two water tanks held at different heights with the crane. The idea was to use gravity to regulate the pressure from those tanks. The lowest one was feeding water, the highest was receiving. The behavior is similar to the hydraulic load (pressure) of the full-scale reverse osmosis membranes. When the waves go up, the pumps inject water in the membrane and when it goes down, the pump is filled.

A pressurized water feed was necessary to fill the pump's chamber and keep the mooring line in tension during intake. Two check valves were making sure flow went in the right direction (Figure 2.2). A restriction was added to the PTO to increase pressure at the cylinder when pushing water up as the water column was not high enough.

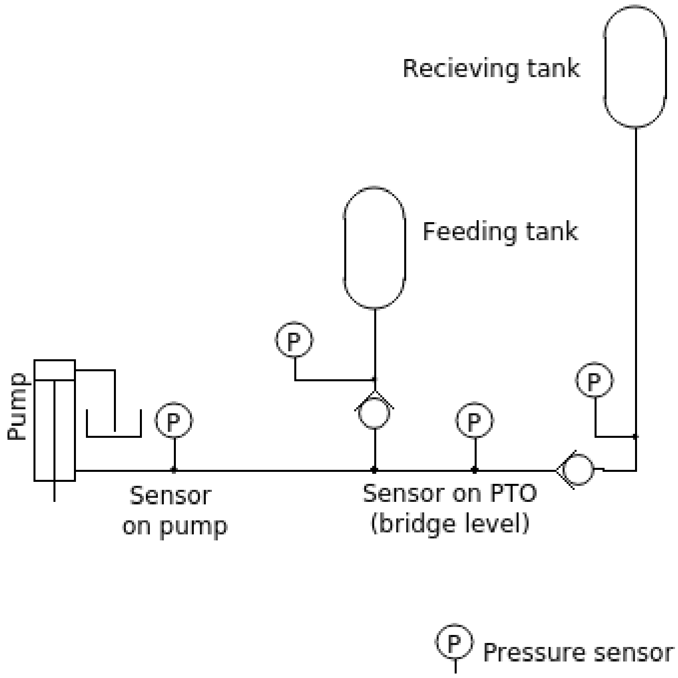


Figure 2.2 Simplified hydraulic PTO schematic

A black metal plate was placed on top of the buoy (Figure 2.1) and represents the mass of the on-board equipment of the full-scale buoy. It was also holding the 4 rods with the markers used by the trajectography system at their end. That allowed us to define the rigid body to track only once, no matter the buoy geometry used.

This scale model got us as close to our real size prototype as we could with a simple enough PTO. Actual desalination was not an option here because of the small pressure produced. The membranes' behavior was mimicked by the breakdown pressure due to the elevated receiving tank and the check valve. We could calculate power from pressure and flow measurements.

A simpler, non-hydraulic setup consisting of a dummy pump (aluminum cylinder) and a spring was also used for simplified response tests (RAO) and survival tests. The objective was to avoid the uncertainties of the main PTO and focus on the buoys' behavior, mostly for numerical model calibration purposes.

4 different geometries of buoys were tested and all of them have axial symmetry (Figure 2.3). The goal was to evaluate their performances on a broad range of waves.

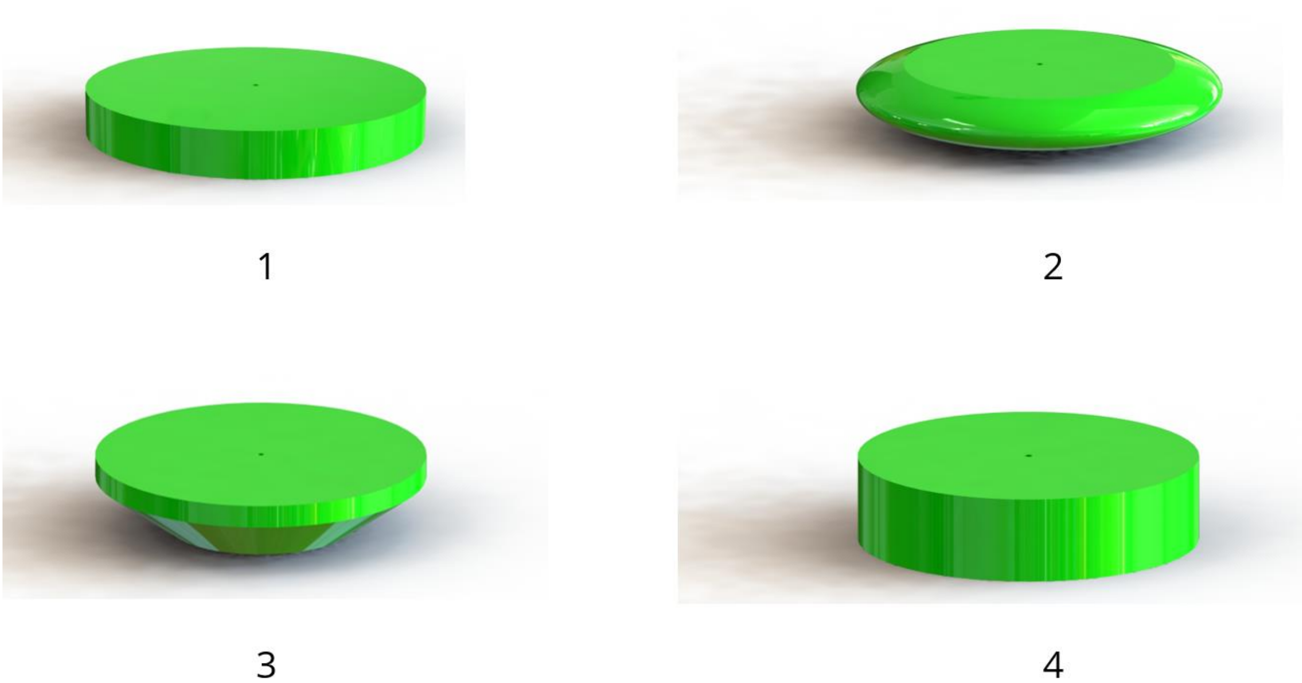


Figure 2.3 Buoy shapes

The following measurements were made (when applicable) :

- Wave elevation on each side of the buoy, aligned with the wave maker
- 6 DOF buoy motions by trajectography
- Pump cylinder and pump rod motion with underwater trajectography (6DOF)
- Pressure at 4 locations on the hydraulic PTO
- 3-axis forces at each end of the pump
- Water tanks weight (water flow in the pump)

2.2 Tests

The waves we get on our full-scale test site usually have two peak periods. One around 4 s and one around 9 s. We focused on those for our tests in the wave tank. Wave heights might appear smaller than those usually used for testing point absorbers. That is because our full-scale system is designed for a near-shore installation, in tropical areas where waves are quite small; except during storms.

In the following, parameters are given at the wave tank scale unless otherwise specified. H and T refer to wave heights (peak to peak) and period for regular waves; Hs and Tp refer to significant wave heights and peak period for irregular waves.

2.2.1 Test Plan – Overview

The following table provides an overview of test plan.

Date	Activity
10th -12th of December	Installation in tank, Qualisys calibration
13th	Hydraulic PTO installation and configuration
14th – 15th	Decay tests
18th	Linear PTO tests
19th - 20th	Hydraulic PTO tests
21th	Extreme tests
22th	Empty tank tests and wrap up

Table 2.1 Day-by-day test schedule at Centrale Nantes Tank (HOET)

2.2.2 Decay tests

Decay tests were performed for each buoy in 3 DOFs: heave, surge and pitch. In each case, the buoy was held in an out of equilibrium position by a thin string and suddenly released by burning that string. These tests will be used for the calibration of the buoy's hydrodynamic models. Each one was repeated at least 3 times.

2.2.3 Linear PTO (spring)

For these tests, the simplified PTO with a spring described above was used. The mooring line was pre-tensioned to 40 N. A series of regular waves and a large spectrum irregular wave were used.

2.2.3.1 Regular waves

Wave no	H	T	H full-scale	T full-scale	Description
#1	12 cm	1.23 s	0.72 m	3 s	Buoys 1-4
#2	12 cm	1.64 s	0.72 m	4 s	Buoys 1-4
#3	12 cm	2.04 s	0.72 m	5 s	Buoys 1-4
#4	12 cm	3.28 s	0.72 m	8 s	Buoys 1-4
#5	12 cm	3.70 s	0.72 m	9 s	Buoys 1-4
#6	12 cm	4.54 s	0.72 m	11 s	Buoys 1-4

Table 2.2 Regular waves test plan for linear PTO

2.2.3.2 Irregular waves

The following regular waves are JONSWAP spectrums (ɣ = 3.3)

Wave no	Hs	Tp	Hs full-scale	Tp full-scale	Description
#7	16 cm	2.45 s	0.96 m	6 s	Buoys 1-4

Table 2.3 Irregular waves test plan for linear PTO

2.2.4 Hydraulic PTO

For these tests, the tanks were positioned so as to get 0.31 bar from the feeding tank and 0.55 bar from the receiving tank (pressures taken 1 m above water level, on the bridge). The 3-axis load cell between the pump and the cylinder got damaged and was replaced with a 1-axis load cell.

Every buoy was tested with the same PTO settings for the following wave conditions.

2.2.4.1 Regular waves

Wave no	H	T	H full-scale	T full-scale	Description
#8	12 cm	1.64 s	0.72 m	4 s	Buoys 1-4
#9	12 cm	3.7 s	0.72 m	9 s	Buoys 1-4
#10	17 cm	1.64 s	1.02 m	4 s	Buoys 1-4
#11	17 cm	3.7 s	1.02 m	9 s	Buoys 1-4
#12	12 cm	2.44 s	0.72 m	6 s	Buoy 1
#13	17 cm	2.44 s	1.02 m	6 s	Buoy 1
#14	24 cm	2.04 s	1.44 m	5 s	Buoy 1
#15	24 cm	3.7 s	1.44 m	9 s	Buoy 1
#16	12 cm	1.64 s	0.72 m	4 s	Buoy 1 5 PTO settings
#17	12 cm	3.7 s	0.72 m	9 s	Buoy 1 5 PTO settings
#18	17 cm	1.64 s	1.02 m	4 s	Buoy 1 5 PTO settings
#19	17 cm	3.7 s	1.02 m	9 s	Buoy 1 5 PTO settings

Table 2.4 Regular waves test plan for hydraulic PTO

2.2.4.2 Irregular waves

The following regular waves are JONSWAP spectrums (ɣ = 3.3)

Wave no	Hs	Tp	Hs full-scale	Tp full-scale	Description
#20	17 cm	2.04 s	1.02 m	5 s	Buoys 1-4,
#21	17 cm	4.08 s	1.02 m	10 s	Buoys 1-4

Table 2.5 Irregular waves test plan for hydraulic PTO

2.2.5 Extreme conditions

For these tests, buoy #1 was used with the dummy pump. There was no spring. Two tests were performed with different initial conditions (submerged or not). The wave height was increased progressively during the tests.

Wave no	H	T	H full-scale	T full-scale	Description
#22	0-55 cm	2 s	0-3.3 m	5 s	Buoy 1 At the surface
#23	0-55 cm	2 s	0-3.3 m	5 s	Buoy 1 Submerged

Table 2.6 Regular waves test plan for extreme conditions

2.2.6 Empty wave tank

The waves used were run with a probe instead of a buoy, at its location, for measurements of undisturbed sea states.

2.3 Results

2.3.1 Decay tests

Simple analytical models fit decay results quite well. More sophisticated models could be used for an even better fit though. Main setup Figure 2.4 shows an example of 2 decay tests and a fitted analytical model curve.

It can be noticed from the heave test that the resonance frequency is high. That is the case with each buoy and was to be expected due to their high hydrostatic restoring force.

Resonance is out of the exposed frequency range and it is not the aim of Oneka product development. Oneka aims to produce fresh water out of resonant range since frequency of a point absorber is narrow and needs sophisticated control to be resonant in multiple periods. Complex control requires lots of expensive components and wave predictability and this is contradictory with Oneka values since the product needs to be cheap, reliable and simple.

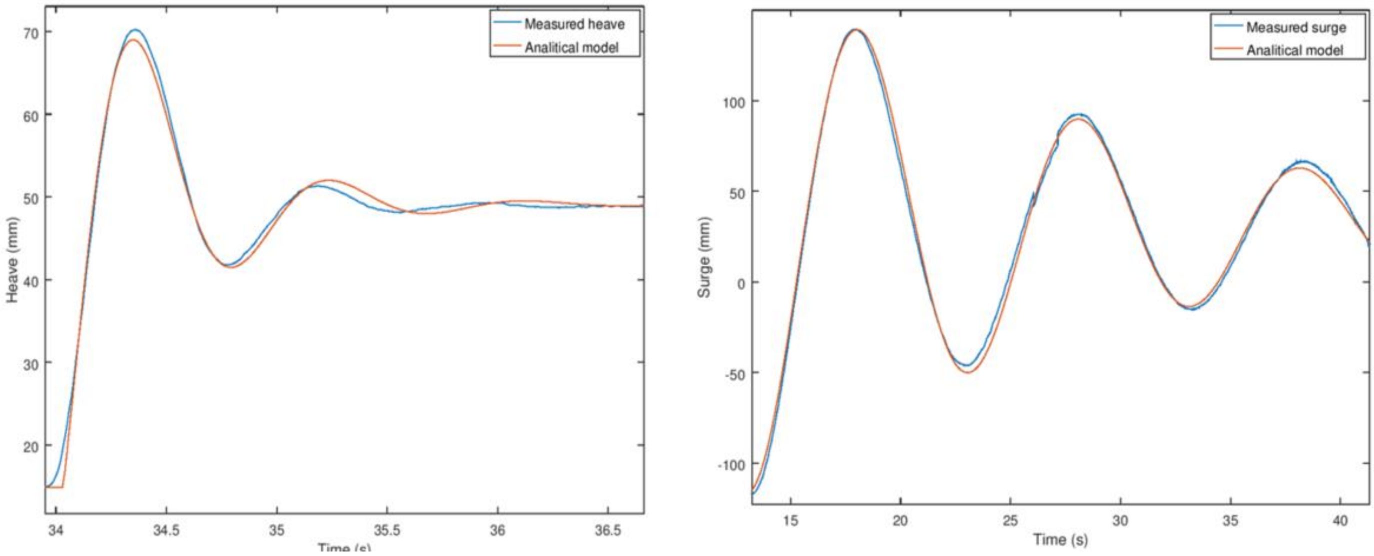


Figure 2.4 Heave decay test buoy #1 (left) and surge decay test buoy #4 (right)

2.3.2 Linear PTO (spring)

Discrete RAOs were computed for the force along the dummy pump and the buoy's vertical position from results in regular waves (Figure 2.5). Buoy #4 got only 5 runs instead of 6 due to issues and time constraints during the tests. RAOs were computed with the results from the irregular wave test for each buoy (Figure 2.6).

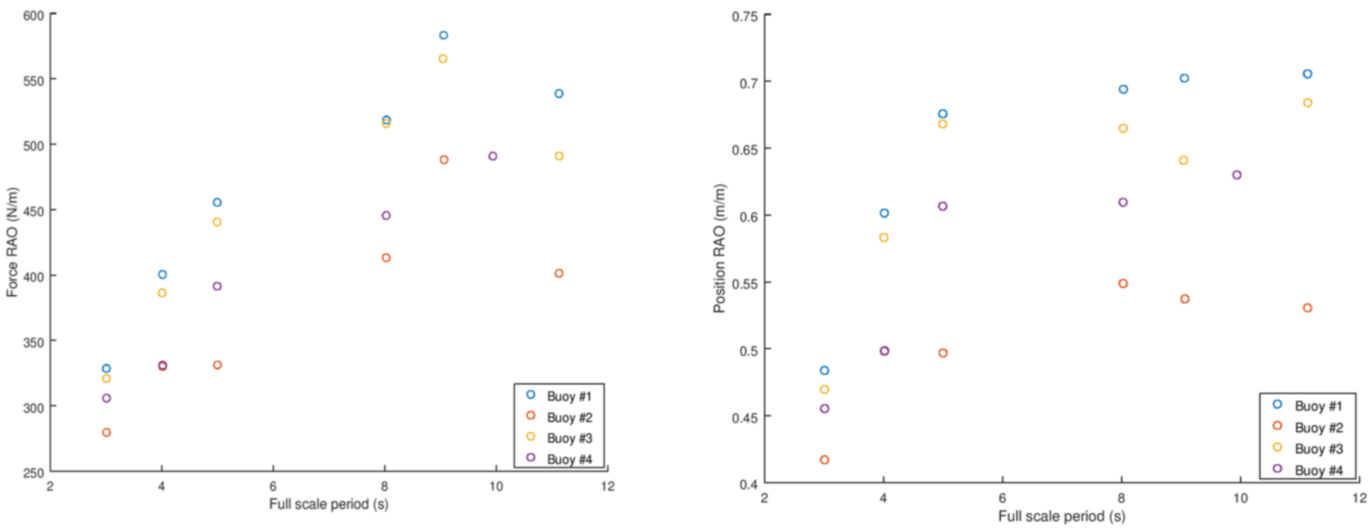


Figure 2.5 Discrete force RAO (left) and discrete Z position RAO (right)

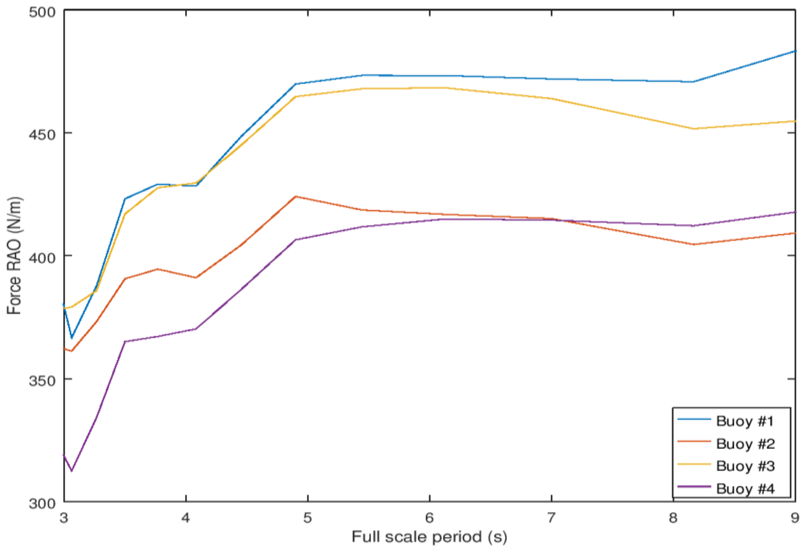


Figure 2.6 Force RAO for each buoy tested

2.3.3 Hydraulic PTO

2.3.3.1 Power extraction for different buoy geometries in regular waves

The power results for buoy #1 in regular waves are given in Figure 2.7. It was calculated from the effort and the piston's displacement.

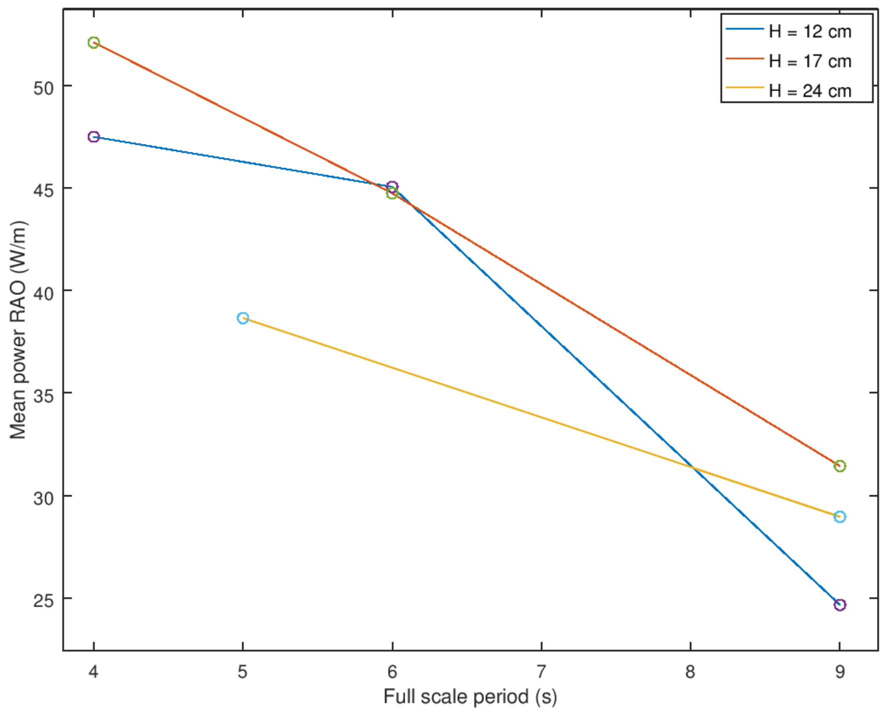


Figure 2.7 Mean absorbed power for regular waves with buoy #1

2.3.3.2 Power extraction for different buoy geometries in irregular waves

The production results with irregular wave tests are given in Table 2.7 Absorbed wave energy by the 4 buoy geometries for irregular waves. They have been computed from mean pressure in the PTO and volume pumped in the receiving tank, over a 500 s period of time. The data of one run with buoy #4 was missing. All the buoys had the same buoyancy (volume).

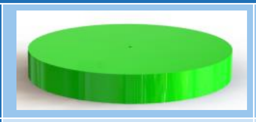
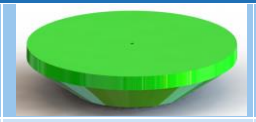
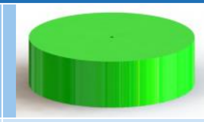
Buoy #	Buoy 1	Buoy 2	Buoy 3	Buoy 4
Test conditions				
Hs 17cm Tp 2.04 s	655 J	548 J	721 J	553 J
Hs 17 cm Tp 4.08s	552 J	531 J	614 J	

Table 2.7 Absorbed wave energy by the 4 buoy geometries for irregular waves

2.3.3.3 Power extraction for different PTO settings in irregular waves

PTO settings comparison with buoy #1 are given in Figure 2.8 Mean absorbed hydraulic power, different PTO settings. The orifice has been fully open then progressively closed for a total of 4 settings for these tests. Hydraulic power has been calculated from the pressure and piston displacement.

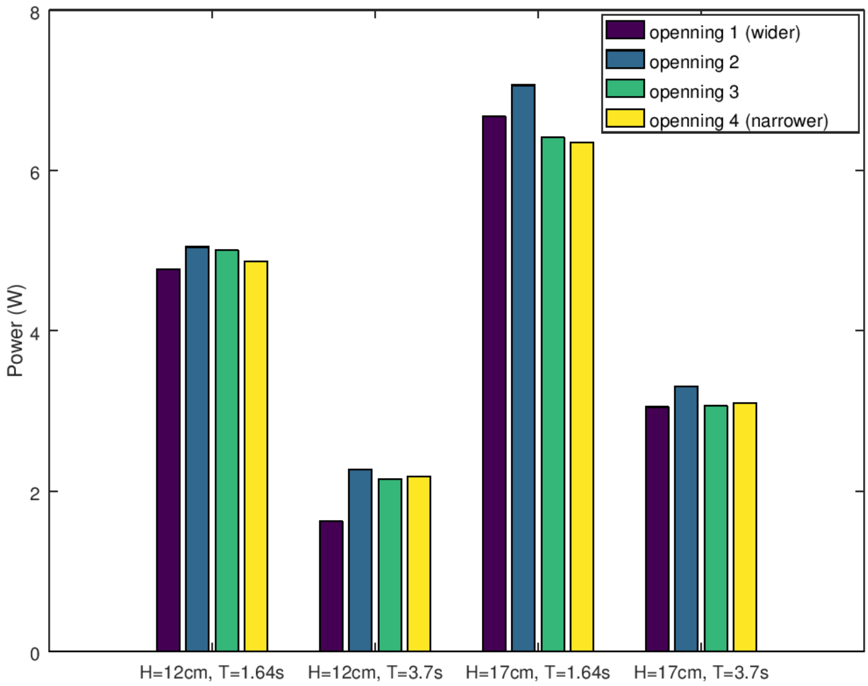


Figure 2.8 Mean absorbed hydraulic power, different PTO settings

Orifice opening variation results are not as conclusive as we would have hoped, but still show a point of operations that delivers more power for that pump. This will now have to be correlated to RO membranes behavior for us to determine the most efficient setup on our full-scale system. The orifice opening creates a load on the system that corresponds to the cylinder pump area and membrane configuration on the full-scale system.

The load variations from the orifice did not show large variations in performance and this means further designs could use a broad range of effective pumping area and membrane configurations. This will lead to more flexibility using membranes in their good range of operations (for example less damping would lower the peak flows for similar hydraulic power production).

2.3.4 Extreme Conditions

Table 2.8 give the maximum and RMS load for a given wave height. Z axis load was measured between the buoy and the cylinder, X and Y at the bottom of the cylinder. The motions of the buoy could not be fully recorded using the trajectography system as markers got hidden by water splashes.

	Horizontal load (N)				Vertical load (N)			
Position	Surface		Submerged		Surface		Submerged	
H (m)	RMS	PEAK	RMS	PEAK	RMS	PEAK	RMS	PEAK
0.31	4	10	2	3	99	209	26	105
0.37	5	12	2	4	11	257	65	124
0.44	7	22	3	6	140	402	81	185
0.56	7	28	4	9	155	410	100	223

Table 2.8 Loads in extreme conditions on the bottom of the pump

2.4 Analysis & Conclusions

2.4.1 PTO behavior

The nonlinear behavior of our hydraulic PTO is apparent with the regular wave tests (high pressure water is pumped when buoy move up only). Power would be proportional to the wave elevation squared with a linear PTO, it is not in our case. It can also be noticed that lower wave periods give more power. This was expected since the piston moves faster with lower period waves.

2.4.2 Buoy Shape

Linear PTO results show a clear performance difference between two groups of buoy shapes. Shapes 1 and 3 give better results than 2 and 4. Then, the hydraulic PTO shows better power performance with buoy #3. Buoys # 1, 2 and 3 have the same maximum diameter. Buoy # 4 has a smaller diameter.

As it was expected from prior calculations, a higher hydrostatic restoring force (i.e. a large water plane area) gives better results for our point absorber system, even though it also causes more drag and has more added mass. That explains the best performance of buoys # 1 and 3. The conic shape seems to help with better water flow underneath it (less drag). Buoy #3 which does not maintain a large diameter over its height got poorer performance, as well as buoy # 4 with its smaller diameter.

2.4.3 Extreme Conditions Tests

At real life scale, peak horizontal efforts are really important for waves 3.3 m high, over 6000 N. At the end of our piston rod, that could create a dangerous torque on our system. Vertical effort is also considerable, over 80 kN at 3.3m full scale. Those values are a bit higher than we were expecting and will help us with our future design.

Sinking the buoy as a survival strategy would cause about 3 times as less effort as the results show. This is one of the ways we are considering for dealing with extreme wave conditions. Although, the current strategy is getting the systems back to shore before a storm event (for example hurricanes) and the current demonstrator is built and designed to be disconnected in 10 minutes.

3 Main Learning Outcomes

3.1 Progress Made

Valuable data was collected for numerical model calibration (work in progress as of this writing).

The comparison between buoy shapes was conclusive.

Measurements of extreme conditions loads will be very useful for the design of our commercial product's structure.

Our hydraulic PTO did not allow us to test high waves. The piston was not sliding back fast enough to keep the mooring line in tension during intake for higher waves. That was due to important piston friction that had increased during the tests. The friction was tested weeks before wave tank tests but it has increased significantly without appropriate explanation at this time.

3.1.1 Progress Made: For Marine Renewable Energy Industry

- The string burning technique for sudden release during decay tests worked well.
- Measuring water flow with load cells and tanks was not as good as we had thought. Data was too noisy for instantaneous results. They allowed however good measurement of the average flow during a run.
- When working with multiple buoys, it helps and saves time to have a single structure holding the trajectography targets, that you can fix on those different buoys.
- A hydraulic PTO has the advantage of being easy to design, set up and instruments with sensors. The drawbacks were the loss of hydraulic head in the piston and the check valves (higher than expected), fluid inertia, leaks in the cylinder and the presence of air. Those could, however, be measured and we obtained satisfactory results.
- Anchoring our system 3 m above ground with a rigid structure was a success. We had minimal displacements of the anchoring point (around 3 mm).
- The hose between the pump and PTO caused an unavoidable effort on the system that affected surge and yaw. It doesn't appear to be a significant perturbation for the system performance in our case though.

3.2 Key Lessons Learned

- A conical shaped bottom (buoy #3) appears to get the best performance.
- A rounded shape (buoy #2) does not help.
- Extreme loads in the horizontal plane on the pump are quite significant.
- Mishaps happen all the time during experimental testing, everything takes longer than expected.
- Having backup equipment with us was essential.

4 Further Information

4.1 Scientific Publications

There is no scientific publications made from these tests

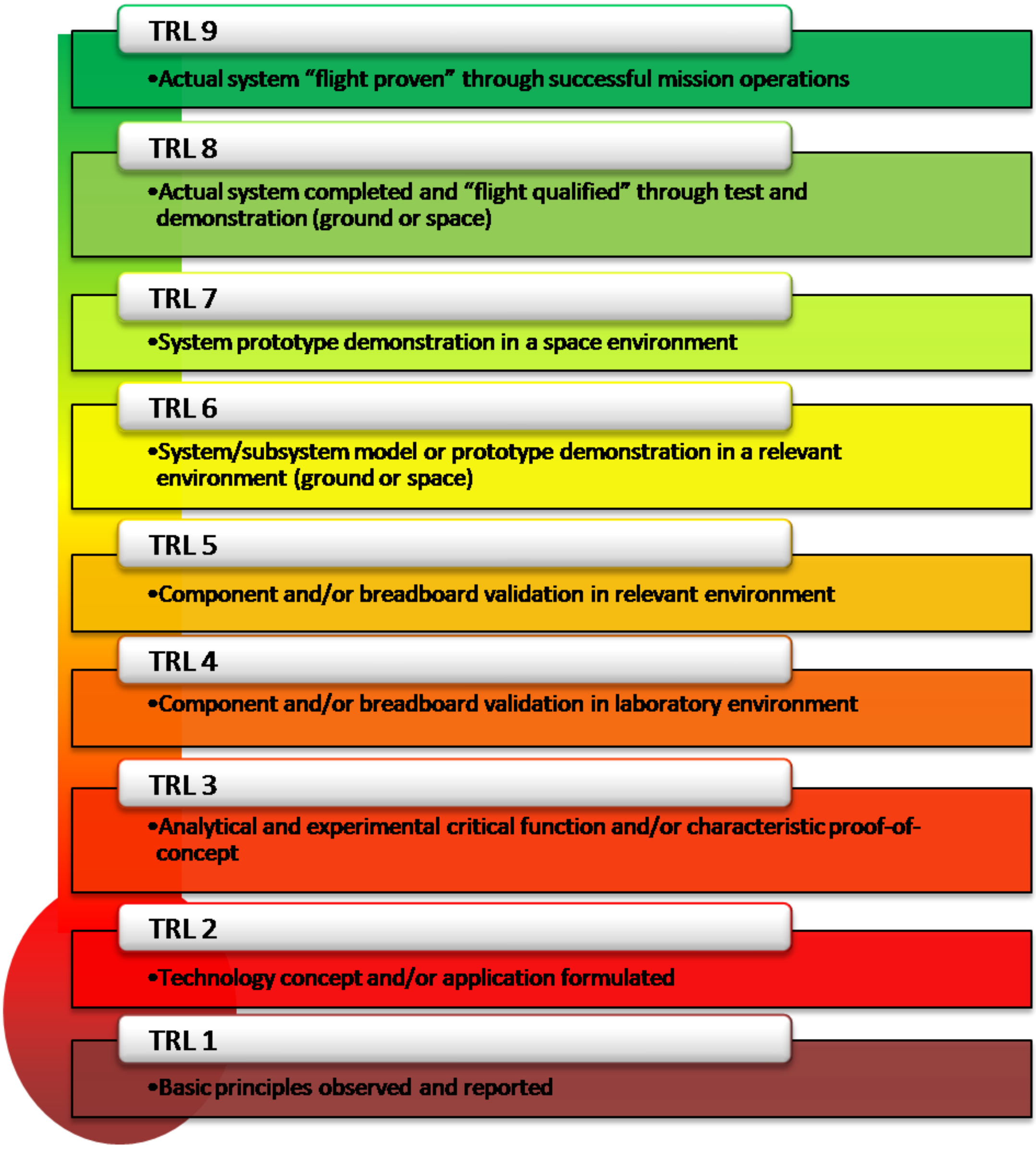
4.2 Website & Social Media

Website: www.onekawater.com

5 Appendices

5.1 Stage Development Summary Table

The table following offers an overview of the test programmes recommended by IEA-OES for each Technology Readiness Level. This is only offered as a guide and is in no way extensive of the full test programme that should be committed to at each TRL.



NASA Technology Readiness Levels[1]

NASA TRL Definition Hardware Description Software Description Exit Criteria

TRL	Definition	Hardware Description	Software Description	Exit Criteria
1	Basic principles observed and reported.	Scientific knowledge generated underpinning hardware technology concepts/applications.	Scientific knowledge generated underpinning basic properties of software architecture and mathematical formulation.	Peer reviewed publication of research underlying the proposed concept/application.

[1] https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html

2	Technology concept and/or application formulated.	Invention begins, practical application is identified but is speculative, no experimental proof or detailed analysis is available to support the conjecture.	Practical application is identified but is speculative, no experimental proof or detailed analysis is available to support the conjecture. Basic properties of algorithms, representations and concepts defined. Basic principles coded. Experiments performed with synthetic data.	Documented description of the application/concept that addresses feasibility and benefit.
3	Analytical and experimental critical function and/or characteristic proof of concept.	Analytical studies place the technology in an appropriate context and laboratory demonstrations, modelling and simulation validate analytical prediction.	Development of limited functionality to validate critical properties and predictions using non-integrated software components.	Documented analytical/experimental results validating predictions of key parameters.
4	Component and/or breadboard validation in laboratory environment.	A low fidelity system/component breadboard is built and operated to demonstrate basic functionality and critical test environments, and associated performance predictions are defined relative to the final operating environment.	Key, functionally critical, software components are integrated, and functionally validated, to establish interoperability and begin architecture development. Relevant Environments defined and performance in this environment predicted.	Documented test Performance demonstrating agreement with analytical predictions. Documented definition of relevant environment.
5	Component and/or breadboard validation in relevant environment.	A medium fidelity system/component brassboard is built and operated to demonstrate overall performance in a simulated operational environment with realistic support elements that demonstrates overall performance in critical areas. Performance predictions are made for subsequent development phases.	End-to-end software elements implemented and interfaced with existing systems/simulations conforming to target environment. End-to-end software system, tested in relevant environment, meeting predicted performance. Operational environment performance predicted. Prototype implementations developed.	Documented test performance demonstrating agreement with analytical predictions. Documented definition of scaling requirements.
6	System/sub-system model or prototype demonstration in an operational environment.	A high fidelity system/component prototype that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate operations under critical environmental conditions.	Prototype implementations of the software demonstrated on full-scale realistic problems. Partially integrate with existing hardware/software systems. Limited documentation available. Engineering feasibility fully demonstrated.	Documented test performance demonstrating agreement with analytical predictions.
7	System prototype demonstration in an operational environment.	A high fidelity engineering unit that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate performance in the actual operational environment and	Prototype software exists having all key functionality available for demonstration and test. Well integrated with operational hardware/software systems demonstrating operational feasibility. Most software bugs removed. Limited documentation available.	Documented test Performance demonstrating agreement with analytical predictions.

		platform (ground, airborne, or space).		
8	Actual system completed and "flight qualified" through test and demonstration.	The final product in its final configuration is successfully demonstrated through test and analysis for its intended operational environment and platform (ground, airborne, or space).	All software has been thoroughly debugged and fully integrated with all operational hardware and software systems. All user documentation, training documentation, and maintenance documentation completed. All functionality successfully demonstrated in simulated operational scenarios. Verification and Validation (V&V) completed.	Documented test performance verifying analytical predictions.
9	Actual system flight proven through successful mission operations.	The final product is successfully operated in an actual mission.	All software has been thoroughly debugged and fully integrated with all operational hardware/software systems. All documentation has been completed. Sustaining software engineering support is in place. System has been successfully operated in the operational environment.	Documented mission operational results