CORA Cork Open Research Archive
Cartlann Taighde Oscailte Chorcaí

Title	Tidal flyer; innovation, design & evolution (TIDE)
Authors	Devaney, Theo;Holmes, Brian;Bhinder, Majid A.
Publication date	2017-09-01
Original Citation	Devaney, T., Holmes, B. and Bhinder, M. A. (2017) Tidal Flyer; Innovation, Design & Evolution (TIDE), Proceedings of the 12th European Wave and Tidal Energy Conference (EWTEC), Cork, Ireland, Cork, Ireland, 27 August - 1 September.
Type of publication	Conference item
Link to publisher's version	http://www.ewtec.org/proceedings/
Rights	© European Wave and Tidal Energy Conference 2017
Download date	2026-11-03 14:40:25
Item downloaded from	https://hdl.handle.net/10468/7755



UCC
University College Cork, Ireland
Coláiste na hOllscoile Corcaigh

Tidal Flyer; Innovation, Design & Evolution (TIDE)

Theo Devaney[#1], Brian Holmes[*2], Majid A Bhinder[^3]

[#]*Open Ocean Energy Ltd., U4 Wexford Enterprise Centre,*
Rosslare Rd., Wexford, Ireland.
[1]theo@open-ocean-energy.com

**Ocean Energy Consultant, Cork, Ireland.*
[2]b.holmes@ucc.ie

[^]*UCC Marine Renewable Energy Ireland (MaREI), Beaufort Building, Environmental Research Institute*
University College Cork, Haulbowline Road, Ringaskiddy, Co. Cork, Ireland
[3]mbhinder@ucc.ie

European Wave and Tidal Energy Conference (EWTEC) 2017

Abstract— **Open Ocean Energy (OOE) Ltd. is a tidal energy company developing a vertical hydrofoil based device, the *Tidal Flyer*. Following the initial years proving the concept and progressing the design of the system for the past 3 years OOE have been working intensively with Black & Veatch (B&V) on the techno-economic optimisation of the Tidal Flyer configuration. This paper will outline recently conducted Phase 1 physical testing of various aspects of the technical design evolving from the study. CFD work investigating critical features of the system dynamics was also undertaken but is not reported here. The Phase 1 testing was constructed to inform the design of a full, dynamic model due for testing at the combined wave and current tank, Flowave in Edinburgh, Scotland. The latter trials will be undertaken as a Phase 2 test programme. At the end of the physical test schedule, OOE will have completed up to TRL 4 and satisfied a series of pre-defined stage gates criteria.**

The programme of empirical testing involved two visits (8 testing days) to the IFREMER flow flume in Boulogne-sur-Mer, France.

The CFD analysis is being undertaken at UCC as part of the SFI funded Marine Renewable Energy Ireland [MaREI] scheme. Initially the empirical set-ups were simulated to verify the test plan.

Keywords— **Tidal Energy, Hydrofoils, Wake, Foil spacing, Lift & Drag**

I. Introduction

The tidal flyer device comprises a series of arrays of underwater foil-sails. A pair of sails (a Flyer) is connected to an additional hydrofoil, which acts as a self-trimming tail. Please refer to [1] for details of the Tidal Flyer system and its theoretical operation. Please also refer to [2] for details of self-trimming tail and its operation. A schematic of a solo Flyer system, comprising the two power foils and tail, is shown in Fig. 1.

A plan view showing the configuration of a full system, similar to that tested at the IFREMER flow tank in Boulogne-sur-Mer during 2012, for which power conversion data figures were obtained, is shown in Figure 2. Following this proof of concept empirical testing campaign, Open Ocean Energy contracted the engineering consultants, Black & Veatch, to conduct a techno-economic review of the design. The report concluded that the Tidal Flyer approach could be a viable system to extract tidal stream energy and that the levelised cost of energy (LCoE) could be reduced if the operating speed of the hydrofoils, relative to the water flow velocity (λ), was higher.

To achieve this increased λ ratio, some fundamental engineering design changes were required. Before undertaking a modified dynamic model build, it was decided to investigate the more critically identified component changes individually, to verify the functionality of the new design. These investigations were combined with a set of advanced tests that had already been recognised from the previous experimental programme.

The physical testing undertaken in 2017, therefore, was to inform and improve the system ready for full dynamic trials of the 'higher λ' model in the combined wave and current tank, FloWave, in Edinburgh, Scotland. They were, in general, a series of tests examining different aspects of the design to advance the development path through the Stage 2, (TRL4) level.

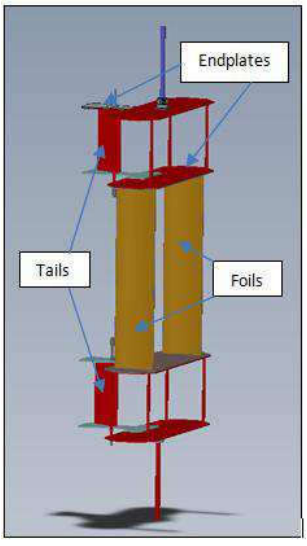


Fig. 1 A single Flyer showing power foils, control tail and end plates.

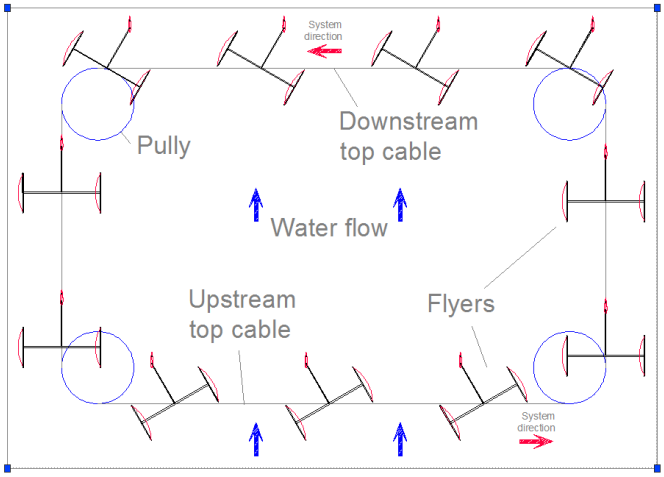


Fig. 2 Schematic plan showing a tidal flyer system comprising 11 flyers

The main angles and forces important to the Tidal Flyer system, and discussed in this paper are shown in Figure 3.

- F_L = Lift force;
- F_D = Drag force;
- F_R = Resultant force;
- F_C = Drive line force;
- α = Power foil angle of attack;
- β = Tail angle.

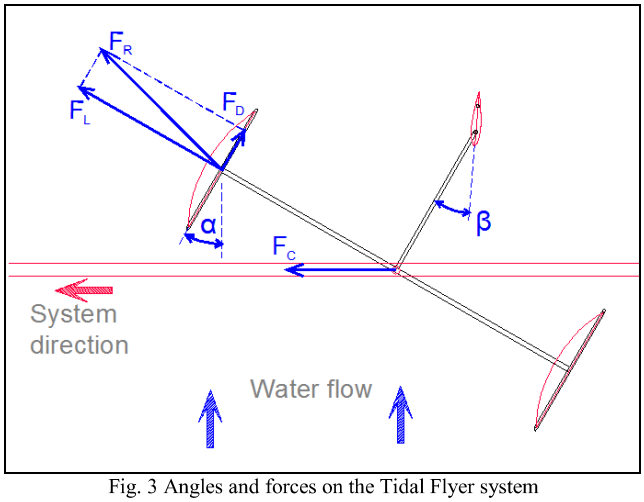


Fig. 3 Angles and forces on the Tidal Flyer system

II. Physical Testing

This first phase of the TRL4 programme was to build on previous testing to determine the behaviour of the Flyer units in both wave and current for operational and survival conditions. The primary objective was to informing the design and build of the full Phase 2 higher λ dynamic system for testing at Flowave.

A. Test Objectives

There were six sections to this first phase of the TRL4 physical test programme, investigating the following parameters:

1. Tail operation when located at the same elevation as the twin power foils using existing and new foil designs;
2. Tail angle relative to system control strategies;
3. The effect of having no endplates;
4. Optimal separation of the upstream and downstream cables (wake effects);
5. Extended wave tests (survival conditions) monitoring forces on a TF foil pair.
6. Transverse drag forces on the system at different operating speed ratios (λ).

All tests were again conducted in the flow flume at IFREMER, Boulogne sur Mer, France. Sections 1, 2, 3, 5 & 6 utilised the test facility's stock multi-axis load cells that had been used previously. Section 4 needed a special deployment frame.

The basic operation of the tests followed that successfully adopted on previous test campaigns at the same facility.

B. Test Programme

The full test schedule is shown in Figure 4. The programme was divided into two campaign separated by 2 months.

Specifically, the technical test plan per section was:

1 Tail operation; a set of re-designed, single tails of various area ratio, and different planforms, were tested at elevations directly astern of the power foils. New and existing power foils were used.

2 Angle Control; these tests investigated if different tail angles would achieve the desired reduction of forces on foils to inform the chosen control strategy for optimising and shedding power.

3 No endplates; investigating the effect of removing the upper and lower endplates on the lift and drag;

4 Wake; a set of up-stream foil pairs were located such that an extensive wake was produced across the flume. A single foil pair was then located in the wake. Three downstream distances and two transverse foil separations were examined to evaluate the wake effect in the static position. It is noted that this experiment did not take account of energy reduction/recovery in the flow since the up-stream Tidal Flyers were static.

5 Waves; a single foil pair was exposed to waves of appropriate scale to measure the forces and motions produced on the system. No, or only a light, current was generated to remove the issue of high turbulence discovered on the previous test campaign. Results can be compared with the previous visits.

6 Side channel drag; A tandem pair of foils were aligned longitudinally down the flume in the neutral (side channel) alignment. The rear foil pair was set in the multi-axis load cell such that the shadowing effect of the forward foil on the drag could be evaluated at the different relevant flow velocities and verify the theoretical values already calculated.

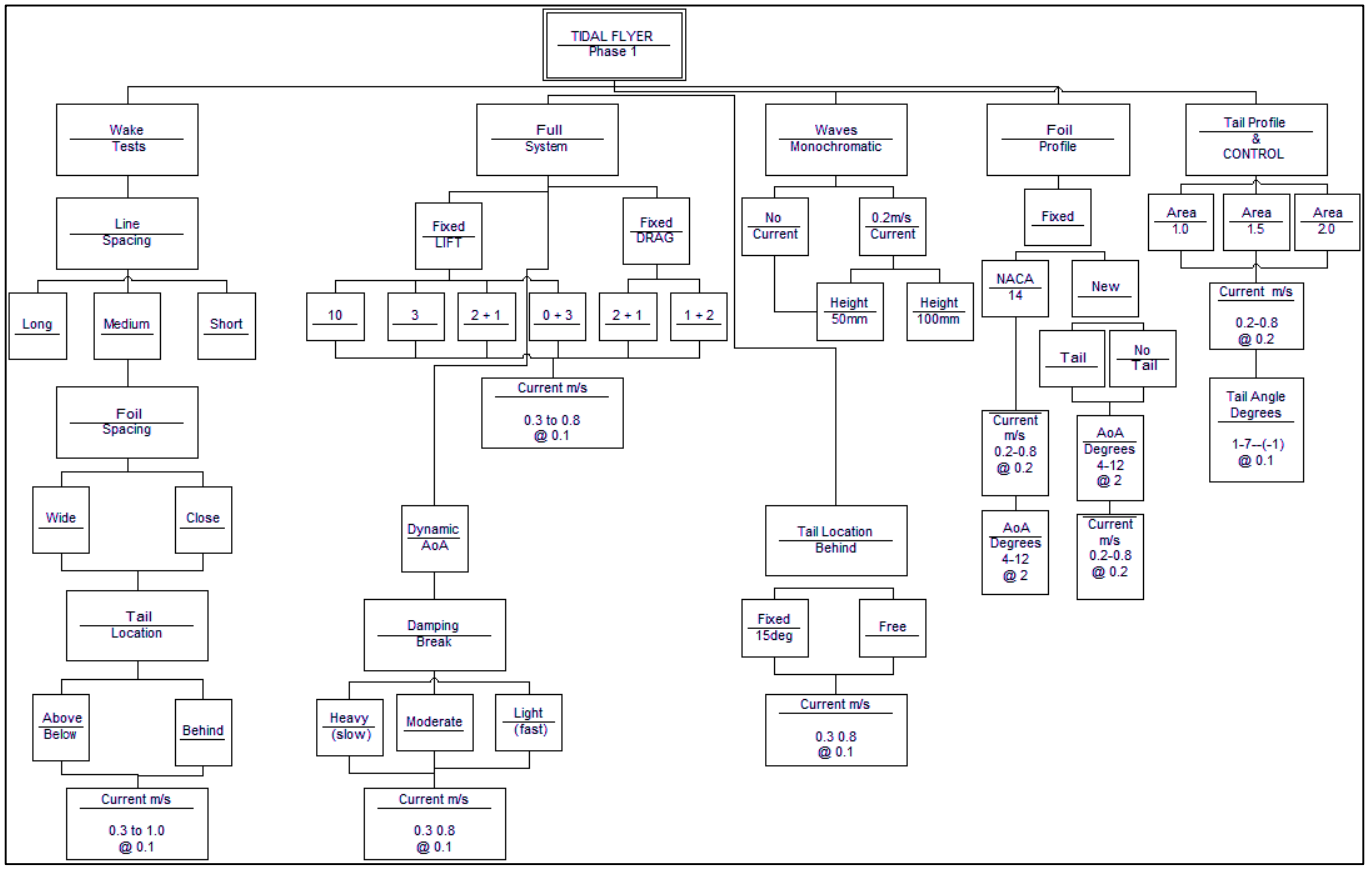


Fig. 4 The Full Test Schedule

C. *Test Setup and Equipment*

Each test setup and the equipment used are outlined below in chronological running order for each of the above 6 test runs. Tests 1-3 were concluded during the first visit and 4-6 the second

1) Wake Tests: A set of 3 Tidal Flyer hydrofoils were positioned across the flow flume. Two separations between the foil pairs were used in different runs. A close spacing represented the moderate system operating velocity previously tested and a wider setting, the proposed faster λ configuration to be trialled in the Flowave tank. A solo Tidal Flyer (TF) array was located downstream of the wake inducing line to monitor the influence of the turbulence on the performance. To measure the loads, the TF was located in a pair of 6 axes load cells, one upper and one lower. The set-up is shown in Figure 5 and the lower load cell in Figure 6.

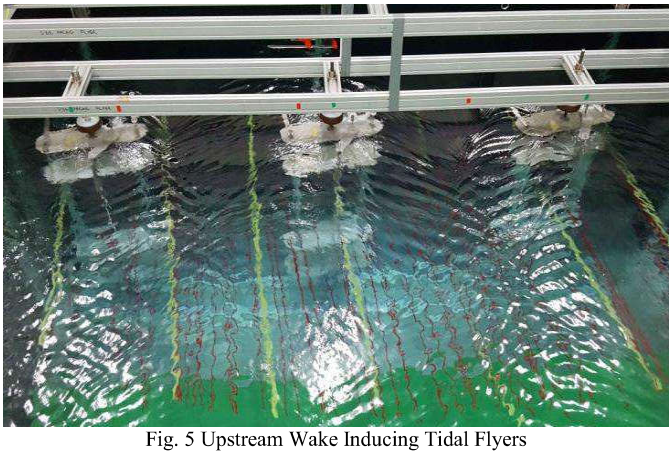


Fig. 5 Upstream Wake Inducing Tidal Flyers

Three longitudinal, or downstream, spacing's were tested:

- Long; represented that distance recommended for horizontal axis turbine;
- Medium; represented the separation of the two cables on the previously tested dynamic system;
- Short; represented a minimum spacing proposed in the literature for a river based hydrofoil system.

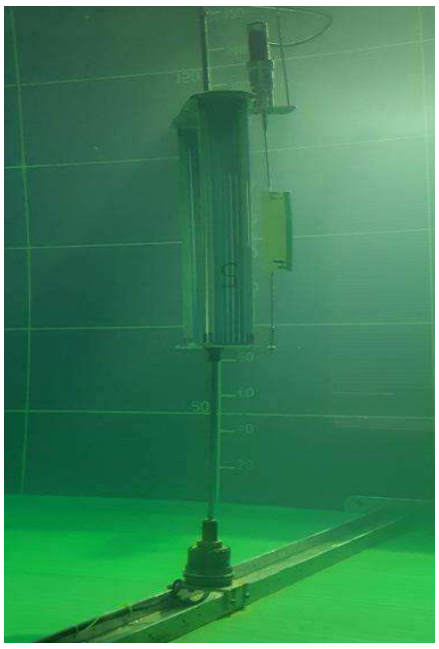


Fig. 6 The lower multi-axis load cell in situ.

Finally, two different self-trimming tail locations were tested. The first had an upper and lower tail positioned above and below the hydrofoils, i.e. in the free stream. For the second set-up a single tail was located directly astern of the foil pair, and therefore in the downwash.

Each set-up was exposed to flowing water from 0.3m/s to 1.0m/s in steps of 0.1m/s. When system stability was achieved data was gathered at 100Hz for 1 minute.

Load (lift & drag) measurements were made via the upper and lower six axis sensors. The hydrofoil angle of attack and rotational stability were manually monitored on a specially manufactured protractor scale.

During the trials, neutrally buoyant flow ribbons were deployed astern of the up-stream foils to visually display the downwash angle created by the foil line.

The full system, at the close downstream setting, and including the downwash visualisation ribbons is shown in Figure 7.

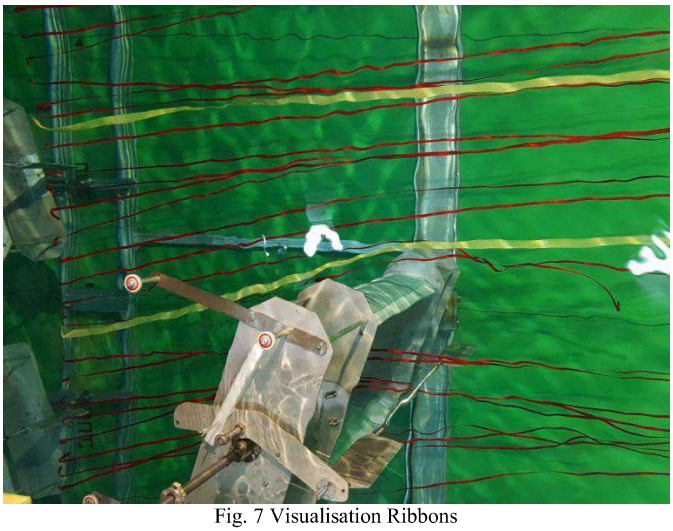


Fig. 7 Visualisation Ribbons

2) Full System Rig: The previously manufactured dynamic system frame was reused for two specific trials. Firstly, the system was fitted with one of the 6 degrees of freedom sensors which locked it against motion. Secondly, the system was fitted with a friction brake so the operating rotational speed per water velocity could be controlled. The frame is shown in Figure 8.

In the locked state, the load sensor was fitted in such a way so as to measure the total force transferred from the hydrofoils to the drive belt when water was flowing. The load cell is shown in Figure 9. Initially 6 Tidal Flyer pairs (12 foils), 3 along each drive line, were fitted so the maximum line tension was measured. The 3 downstream TF's were then removed and the tension of just one line was measured. This data would back-up the previous wake tests to inform on the effect of the up-steam foil turbulence on the downstream foil performance.

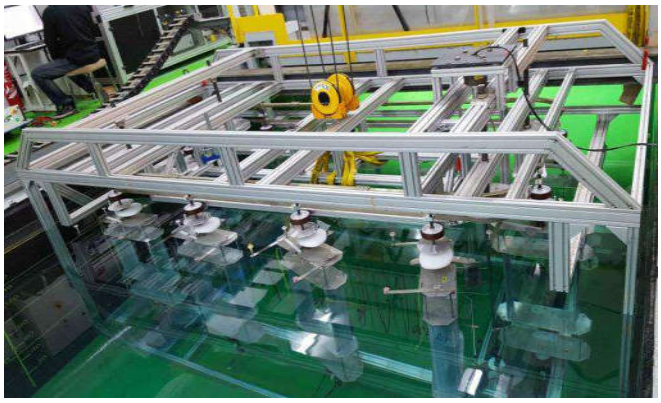


Fig. 8 Full Dynamic System



Fig. 9 Drive Belt & Load Cell

Initial system control runs were also conducted. Different combinations of the self-trimming tails were set to zero degree to verify if this approach could be used to reduce the power absorption capability of the system and offer a hydrodynamic control mechanism.

Finally, the parasitic drag created by the Tidal Flyers in the side channels was evaluated. Increasing numbers of TF's were moved into the neutral attitude in the side channel with the in-line foils set at zero. The force transferred into the drive belt was, therefore, due to the downstream drag created by the flow on the side channel arrays.

The dynamic system was then used to investigate the dynamic angle of attack relative to the apparent velocity. In the free-to-rotate state, all 10 hydrofoil pairs were deployed. A friction brake was fitted into the drive train such that a variable retardation force could be imposed on the system. At a set water flow velocity (V) and braking effort, the angle of the foil pairs traversing the flume were noted (U) and photographed from vertically above each line. The system damping was then changed such that the rotational velocity was also adjusted to suit. The hydrofoil angle was again noted. The vector diagram, as shown in Figure 10, of the two velocities would then verify if the self-trimming tail was operating correctly relative to the apparent velocity (W) by comparing the estimated angle with that measured off the photographs.

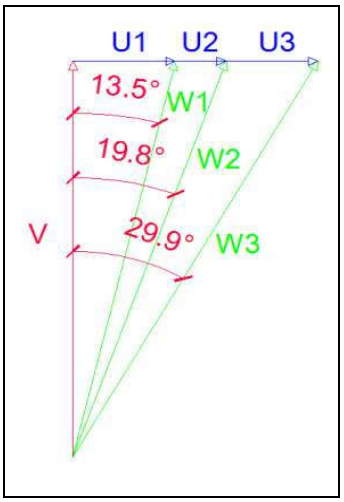


Fig. 10 Apparent Velocity Diagram for 3 System Speeds

It should be noted that the downstream foil angle would be the combination of the AoA and the upstream downwash angle.

3) Tail Location: Problems obtaining foil rotational stability and predicable AoA had resulted in the self-trimming tails being located above and below the end plates of the power hydrofoils. This design meant the tails remained in the advective flow and were not, therefore, influenced by either the downwash angle or the turbulence created by the foils. However, this resulted in a relatively long assembly requiring deep submersion for total immersion of all components. Also, careful selection of the control angle on the downstream foils was required, since the angle would vary relative to the system rotational speed. Knowledge gained in previous tests regarding the requirements for an operational tail had resulted in a new design that would again be checked when placed directly astern of the power foils and at the same elevation. An example of each configuration is shown in Figure 11.

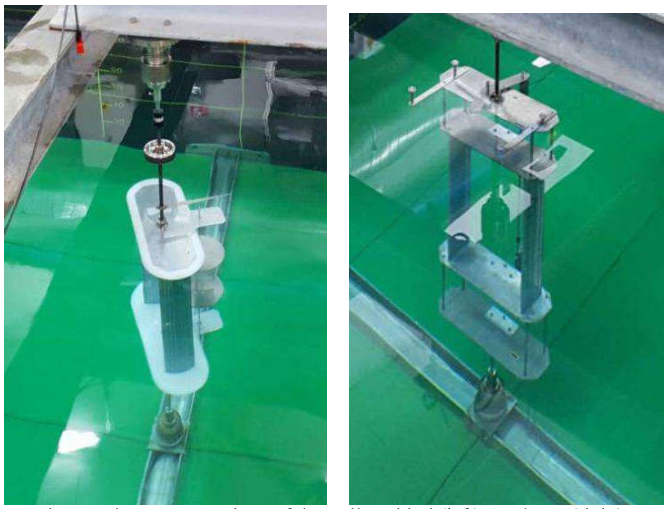


Fig. 11 The Two Locations of the Tail, Behind (left) & Above (right)

For the single tail a specially modified foil pair was jury rigged into the existing 6DoF sensor configuration. The visual projector scale and pointer were attached so the AoA could be measured and noted. The standard water flow of 0.3 to 1.0 m/s in steps of 0.1m/s was run and data monitoring undertaken.

This was only a preliminary test set to evaluate if the new tail worked such that a complete investigation package could be assemble for testing in the second campaign.

4) Wave Forces: During a previous test programme at the IFREMER flume, a solo Tidal Flyer array was exposed to waves to measure the additional loading imposed on the foils and frame components and the instability they may create when in motion. However, it was discovered that the deployment of the wave paddles created high turbulence in the flow such that the main component of the increased forces was the flow instability. When attempting to extract the wave influence from the data of 1) flow only and 2) wave and flow, the result was a small number extracted from two large numbers such that the uncertainty was high. It was decided to run an extra set of tests with just the wave present to check the initial calculations.

As previous, a solo foil pair was fitted to the upper and lower load cell and monochromatic waves were generated to impinge on the Tidal Flyer. A full set of 20 wave periods at a set height were run. This set-up did not produce sufficient force on the self-trimming tail to control the Tidal Flyer so a light current of 0.2 m/s was also run to hold the TF steady at the correct A0A. There was little additional flow turbulence at this low velocity. During the wave runs approximately 20 wave cycles were measured. The wave-set used in the previous test programme was re-run.

A second set of increased wave height was also run to enable all wave forces to be extrapolated.

5) End Plates: Although the Tidal Flyer end plates aided the assembly of the hydrofoil pair, they also could produce unwanted vertical lift forces when the system is operating at speed. For the proposed higher λ device this could become problematic so a set of tests without the end plates was conducted. The assembly is shown in Figure 12.



Fig. 12 A Tidal Flyer without End Plates

These tests had two objectives:

- To obtain the lift and drag characteristics, including vertical forces;
- To check the operational AoA and TF stability.

A key equipment improvement introduced for these trials was the attachment of an encoder to the main drive shaft, as shown in Figure 13. The encoder was a Rotacod SMRA-GG2-08-L10 offering a resolution of 16384 steps per revolution (i.e. 0.02degree).

As can be seen from Figure 11 the frame holding the foils still offered some endplate functionality to the foils but not the tail. The first set of flow runs resulted in the AoA being too high for sensible evaluation of lift and drag so the Tidal Flyer was locked into the upper load cell at the correct AoA and a second set of current run conducted.



Fig. 13 Rotational Angle Encoder

6) Foil Profile: As stated previously, this test campaign was assembled to investigate specific aspects of the Tidal Flyer system with the aim of informing the design for a fully functional dynamic model that would verify a higher λ operation. One of the recommendations for the dynamic model was to employ solid, two dimensional foils rather than the flexible type used to date. The suggested profile was a NACA 0014. This test package was designed to obtain the coefficients of LIFT and DRAG for this new foil.

The same fixing rig and monitoring equipment was utilised for these trials, including the encoder. The instillation is shown in Figure 14. Water speeds were now produced from 0.3 to 0.8m/s with steps of 0.1m/s. The angle of attack was adjusted manually from 0 to 20 degrees in steps of 2 degrees, using the encoder to measure that angle. The drive shaft was fixed in the load cell for each angle flow rate setting and the matrix of lift and drag readings produced.



Fig. 14 Thick NACA 14 foils under test, no tail was required since the array was locked in the upper load cell.

7) Tail Profile & System Control: The set angle on the tail to obtain the correct angle of attack on the hydrofoils varies according to the tail characteristics. The tail profile options and system control trials were, therefore, combined. A stepper motor was used to progressively adjust the tail angle during current runs which produced the tail-foil relationship and verified the power control potential. The motor can be seen in Figure 15. The stepper motor is a Stógra SM 87.1.18M5 with a rotation resolution of approximately 1.8°. A gearbox was also fitted which improved this step to 0.2°, if desired.

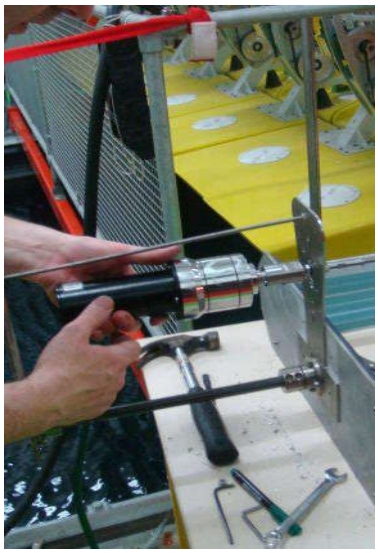


Fig. 15 Fitting the Stepper Motor

A second, important equipment modification was the incorporation of a two axis bearing in the upper connection to the load cell. This had not been previously possible since test with the drive shaft locked to the sensor were interspersed with the freely rotating runs.

For the profile trials, the tail was positioned around the horizontal centreline of the power foils, that is, behind and at

the same height as the foils. Four tail profiles were tested equivalent to:

- The previously proven tail dimensions in span and cord (10% foil area);
- Twice the area at the same cord, equivalent to the upper and lower tails of previous tests (20% foil area);
- Twice the area at the same span as the foils and a cord to suit (20% foil area);
- A high aspect ratio tail at 1.5 times the area of the original tail and the same cord as above. The span was adjusted as required

Initial trials were not very successful when the system was unstable with all tails. A pair of end plates was jury rigged for the 20% standard cord tail and the trials repeated, this time successfully. The deployed set-up, including the stepper motor, is shown in Figure 16.



Fig. 16 Tail Control with the End Plates Fitted

Further runs were made to establish the required tail set angle since it now lay in the downwash from the power foils. The stepper motor was controlled from the data acquisition computer via a dedicated proprietary program. A screen shot of the display is shown in Figure 17.

Once established as 7 degrees the full experimental runs, using the stepper motor to rotate the tail from that maximum angle to -1 degree, were undertaken. The step between angles was 1 degree and data was gathered from the encoder to monitor the subsequent angle of attack of the power foils and rotational stability of the system.

The system control aspect of the tests came from the simultaneous lift and drag measurements made by the 6 axis load cell pair of sensors.

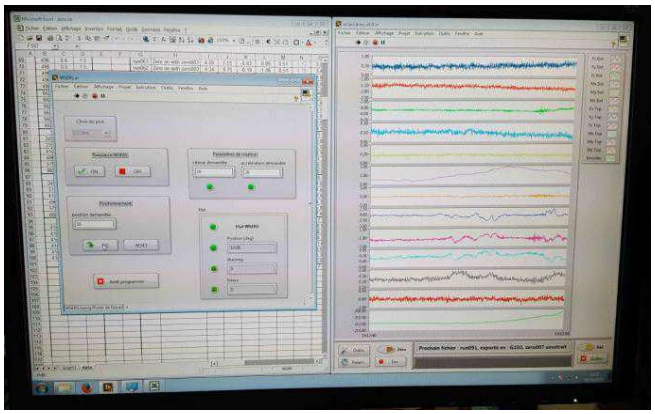


Fig. 17 The Stepper Motor Active Control Display

III. Physical Results

The data acquisition equipment used at IFREMER is a National Instruments based system linked directly into a monitoring control computer. Real time history traces of all the sensor outputs are displayed on the computer screen, as can be seen in the right-hand window in Figure 16. Acquisition commences with a zero off-set reading on each sensor input which is manually incorporated in all record time series before acquisition initiation. All channels are monitored at 100Hz and the duration is usually 6000 data points but can be software adjusted if required for any particular test runs, such as when waves were incorporated.

In addition to this visual data validation process a quasi real time EXCEL summary data sheet of all sensor traces is displayed. Any test set problems are immediately identified and runs can be repeated, if required.

The post processing data analysis began with an automated MathCad validation routine to ensure no errors in the raw data time series had been imported. The summary data was organised as individual Tidal Flyer configurations per water velocity changes i.e. configuration 1 for water flow 0.3 to 0.8m/s, step 0.1m/s. Initially, all sensor channels from each 6DoF load cell were displayed on a single time history graph for inspection.

Test programme packages, as shown in the flow chart, Figure 2 and described in Section II, Physical Testing could then be summarised and compared as described below.

N.B 1; It should be noted that since two load cells were used the physical parameter is the combination of the two independent sensor channel measurements. Also, since one load cell was inverted the property value sign must be taken into account.

N.B. 2; When the Tidal Flyer was free to rotate the moment measurements are invalid.

N.B. 3; Only a sample of the summary results are presented here.

N.B. 4; Fx is the force in the flume longitudinal direction, therefore equivalent to the system DRAG;

Fy is the force in the flume transverse direction, therefore equivalent to the component of LIFT.

1) Wake Tests: Each and all combinations of the line and foil spacing were analysed and compared. The full matrix is as shown in Figure 18.

Foil Space	Line Space	Long (B&V)		Medium (HMRC)		Short (River)	
Wide (B&V)		2 tails	1 tail	2 tails	1 tail		
Medium (HMRC)				2 tails	1 tail * 3	2 tails	
Close (River)							

Fig. 18 Test Matrix for the Wake Tests

TAIL LOCATION: The advantage of converting to the single tail arrangement is shown in Figure 19. The blue graph line is the two tail configuration and the red the single tail. There is only a slight reduction in lift (Fy) but a considerable reduction in the drag (Fx) for a single tail.

The line and foil spacing is common in both test sets.

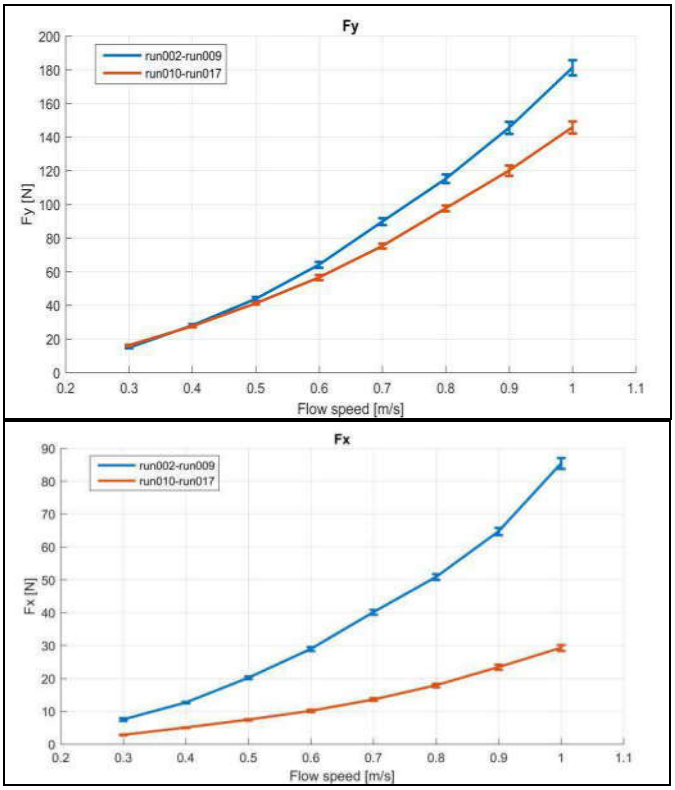


Fig. 19 Tail Location: Red = solo tail, Blue = twin tails

It can also be noted, but not shown here, that the lift values measured when the Tidal Flyer is in the wake are the same as when the Tidal Flyer is in open water.

LINE SPACING; the results from the extreme line spacing are shown in Figure 20.

For this configuration there was a slight loss of lift component across the mid water flow velocities but little reduction in the drag.

The results are based on the two tail set-up which explains the high drag component in both cases.

The line spacing difference is a factor of 4 so some lift reduction may be warranted to compress the overall foot print of the Tidal Flyer system.

Also, there will be a reduced number of idle foils in the side channels which will decrease the parasitic losses they create.

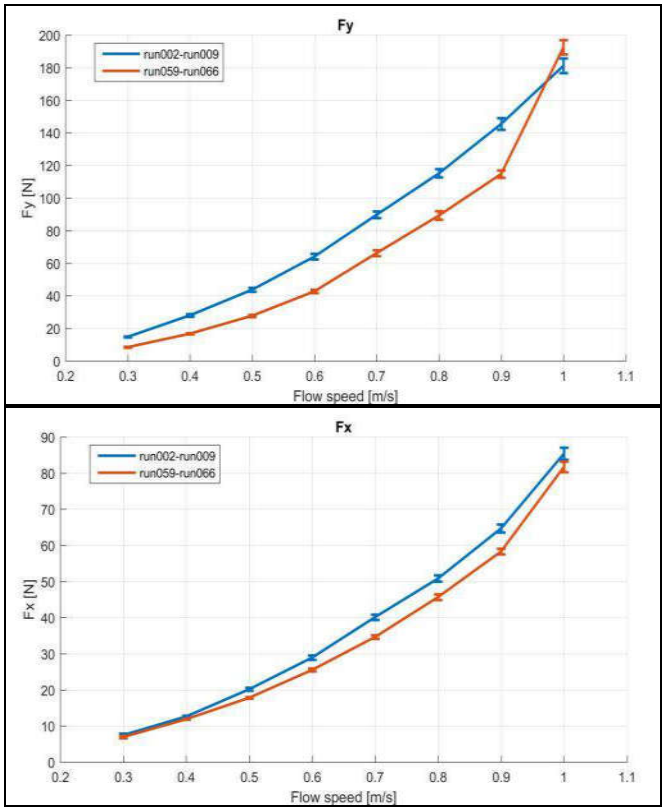


Fig. 20 Line spacing; Red = short, Blue = long,

For the mid line spacing setting there was insignificant difference with the long setting.

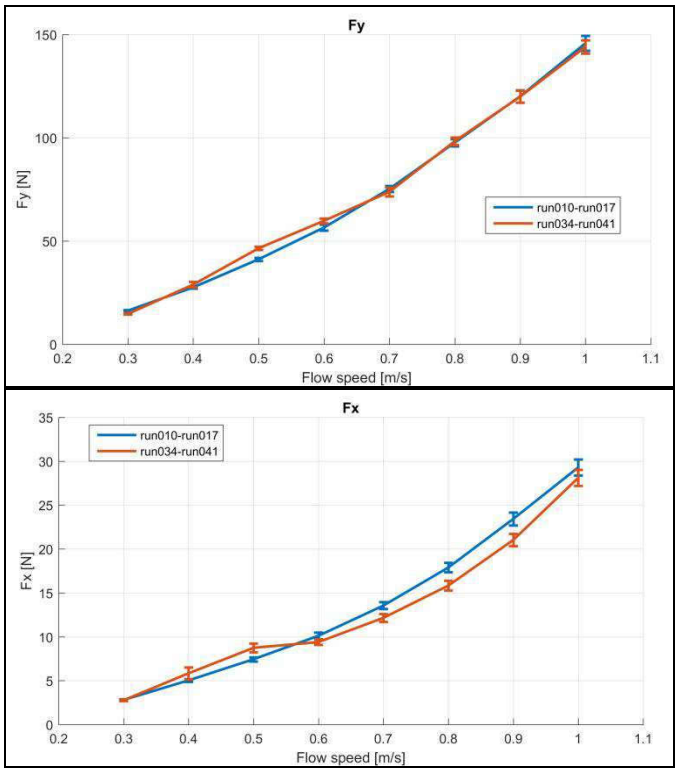


Fig. 21 Foil Separation; Red = Narrow, Blue = wide

FOIL SEPERATION; An example of the lift and drag sensitivity for different foil separations is shown in Figure 21.

Again the system shows little sensitivity to the up-stream device induced wake, within experimental error.

Not shown in this graph set are the results when both parameters (line spacing and foil separation) were varied. However, as predictable from the individual parameter comparisons, the differences are minimal, except in the extreme configuration.

It is acknowledged that these results represent only the downwash and wake effects and not the power reduction caused by the up-stream line of Tidal Flyers. Unfortunately, arranging an experiment that could investigate this situation would be extremely difficult to arrange.

2) Full System Rig; as outlined in section C) Test Setup and Equipment, two types of results are available from this test set, the STATIC and DYNAMIC mode.

STATIC; several different comparisons can be extracted from the data when the Tidal Flyer system was locked by the load cell. The side channel drag data is still under review so is not included in this paper.

The results that support the wake trials are presented in Figure 22.

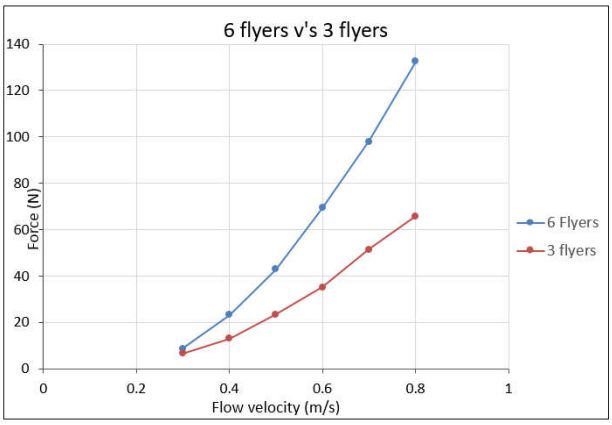


Fig. 22 Comparison of 6 and 3 Foil

As can be seen from the graph lines the drive belt tension when there are 3 upstream and 3 downstream foils the tension in the drive belt is twice that when there are only 3 upstream foils. This again infers a minimal influence between the two lines of foils.

DYNAMIC; the primary results from the dynamic runs were obtained by comparing the angle the foils traversed the IFREMER flow flume under different drive belt retardation force for a given water flow. These results advised how well the self-trimming tails were operating in a dynamic environment.

The data was obtained from the known water flow velocity and measurements of the system speed obtained from a hand held rev counter. The angles were then measured from vertical photographs, an example is shown in Figure 23. A vector diagram of the measured velocities is superimposed on the corresponding photograph.

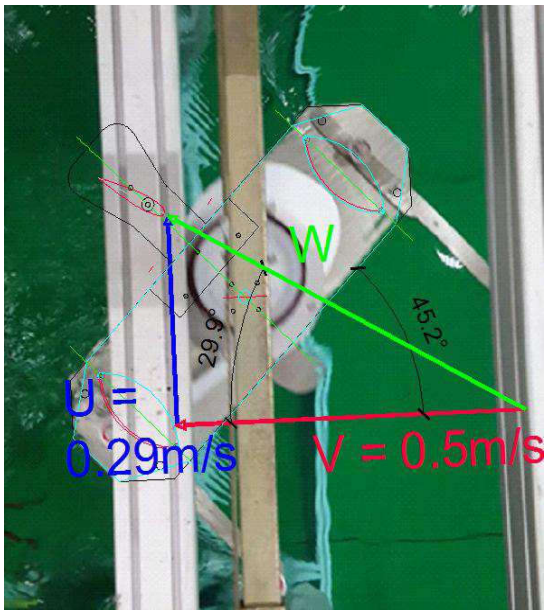


Fig. 23. Checking the Tail Operation

3) Tail Location; Initial tail location trials visually measured the power foil angle obtained from a particular tail setting. The observations verified the full tests should be undertaken but no results need to be presented here.

4) Wave Forces; as above the data from the wave tests are still under review.

5) End Plates; The lift and drag forces measured for the foils when there was no end plate are shown in Figure 23.

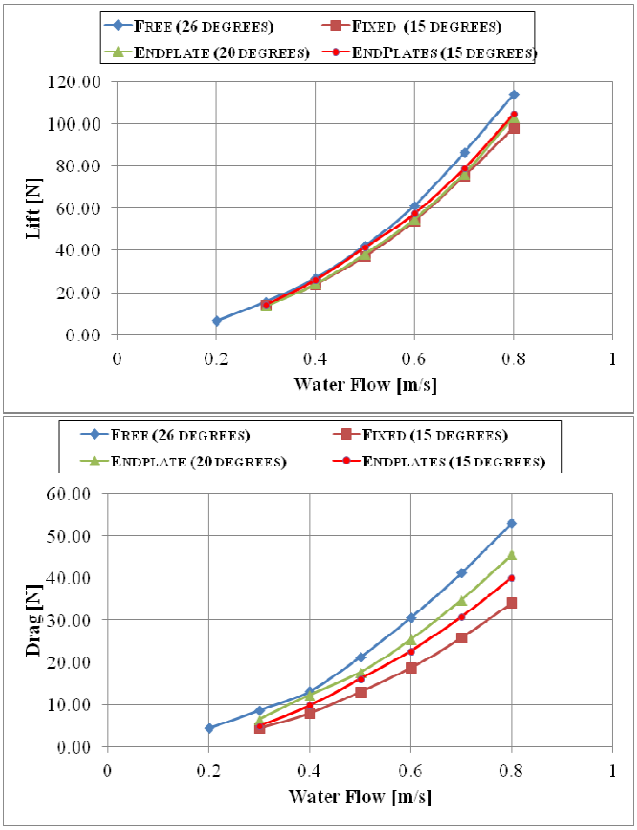


Fig. 23. Lift & Drag with & without End Plates v Water Flow

The results compare the 4 cases of;

- No end plates, free rotating;
- No end plates; fixed;
- End plates; free rotating;
- End plates; fixed

The two fixed set-ups were undertaken because the selected tail did not achieve the correct AoA in each free case.

As anticipated, for foils with such a reasonably large aspect radio, there is only a small decrease in the lift characteristics in all test cases. Also, as expected, there is a slight increase in the drag forces since there will be some tip vortex shedding when there are no end plates fitted.

6) Foil Profile; the NACA0014 had been selected as the likely foil for testing in the Phase 2 system so a pair of NACA0014 foils were manufactured (to the same scale) and testing in the tank.

Also, interesting foil shapes had been identified from the software foil design package XFLR5.2. The opportunity was taken during this test campaign to verify the software by comparing the numerical prediction for a NACA0014 with the empirical results for the same foil profile produced during these tests. These results for theory and practice are shown in Figure 24.

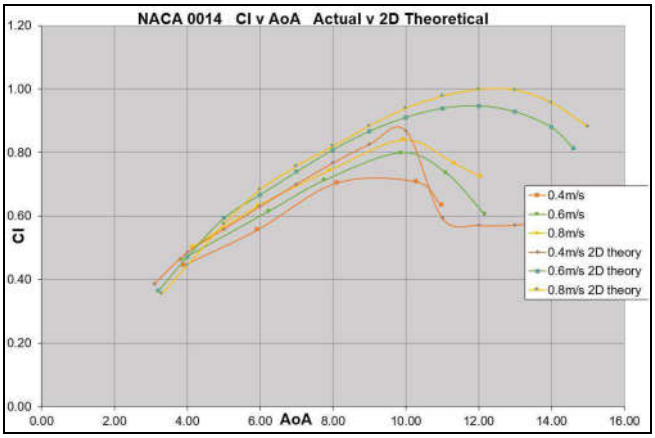


Fig. 24. Coefficient of Lift for NACA0014 from XFLR5 2D software

As the graphs show, there is good correlation between the 2D idealised software and the physical models measured in the tank. It is considered that the highest Lift coefficient of approximately 1.0 for the 2D results is comparable to the maximum Lift coefficient of approx. 0.84 for the actual model. It is considered that the differences expected between 2D modelling and physical testing within the 16% difference along with the accuracy and smoothness of the built model. It is expected to make a small improvement on these results with 3D printed foils (which is the plan for the Phase 2 tests).

7) Tail Profile & Control; once the correct tail and end plate configurations had been identified the primary result concerned the lift forces produced as the tail was rotated from the operating angle to -1 degree. Figure 25 shows the results for one particular set-up across two water flow velocities.

The results show that there is a close response between the two related angles but that there is also a relatively large hysteresis depending on the direction of tail rotation (i.e. increasing or decreasing). As expected the relationship is repeated for the lift forces.

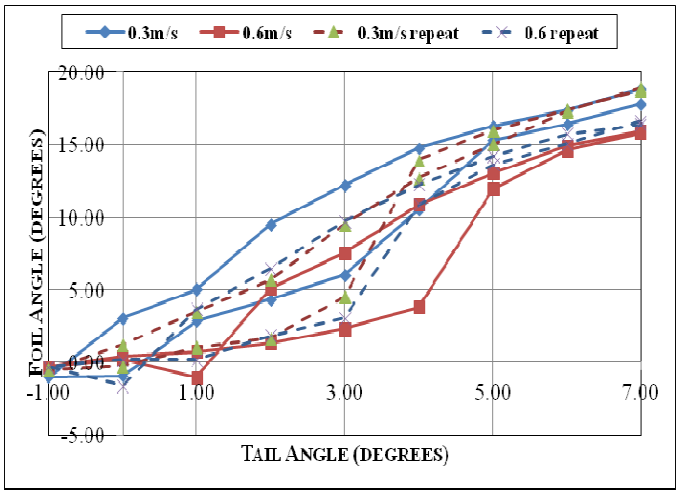


Fig. 25. Change of AoA due to Change of Self-Trimming Tail Angle

IV. Conclusions

From the physical tests, it is observed that it may be possible to have the upstream line and downstream line in close proximity to each other. However as these results were static, as opposed to dynamic, tests both options (long and short separation distances) will be designed and tested in FloWave campaign. In addition, the tails will be located directly behind the foils (at the same elevation) so they are in the downwash of the foils. Further, reduced size endplates will be used on both foils and tail and the NACA0014 foil has sufficient force generated for the system to achieve 1.5 x λ in regard to system velocity.

Prior to the Phase 2 Flowave tests, it is likely that more detailed trials will be conducted with a tail setup directly behind the NACA0014 foils with the stepper motor.

In summary this test campaign indicated;

- Wake has minimal influence on motion or forces on downstream foils (for static tests);
- Self-trimming tail offers a control mechanism for power capping which would be additional control, separate to the PTO;
- Self-trimming tail can be positioned at the same altitude as the power foils but may require end-plates;
- There is a slight performance loss if no end plates are fitted to the power foils.

Acknowledgment

The physical test programme was supported by the Sustainable Energy Authority of Ireland (SEAI) under the Ocean Energy Prototype Research and Development Programme.

References

[1] B. Holmes & T. Devaney *Investigation of the Fundamental Operation of a Novel Tidal Energy Device at Circa 1:16 Scale Tidal Flyer Junior,* EWTEC proceedings, Southampton 2011.

[2] *B. G. Newman and G. I. Fekete, Analysis and Preliminary Design of a Sail Boat with a Self-Trimming Wing Sail, Marine Technology, Vol. 20, No. 4, Oct. 1983, pp. 370-376.*