TIGER TIDAL STREAM INDUSTRY ENERGISER

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Test Procedure 3 – Recommendations for non-conventional tidal energy converters: resource measurement for power performance

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Disclaimer

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Executive Summary

This report is part of the deliverable T1.7.3 – Accredited turbine performance test procedures – under the TIGER project.

The purpose of this deliverable will be to assess any areas of improvement in the IEC/TS 62600-200: Electricity producing tidal energy converters – Power performance assessment technical specification [1] when applied to non-conventional tidal energy converters, particularly tidal kites, and specifically to the incident resource measurement required.

Recommendations have been made as how the performance of a non-conventional tidal energy converter might be measured and where further research may be required in order to develop a standardised test methodology.

Abbreviations

Acronym	Meaning
ADCP	Acoustic Doppler Current Profiler
BSI	British Standards Institute
EMEC	European Marine Energy Centre
IEC	International Electrotechnical Commission
PPA	Power Performance Assessment
TIGER	Tidal Stream Industry Energiser
TEC	Tidal Energy Converter
TS	Technical Specification

1 Introduction

The purpose of this report is to assess the effectiveness of applying the IEC/TS 62600-200: Electricity producing tidal energy converters – Power performance assessment (PPA) technical specification (TS) to non-conventional devices, particularly tidal kites, and specifically the incident resource measurement required.

The aim is to then act as feedback to the IEC/TS 62600-200 maintenance team so that the comments can be considered as a second edition is developed. It will also be informative in how the European Marine Energy Centre (EMEC) approaches and reports on future performance tests.

This activity falls under the scope of the Interreg Channel Manche – TIGER project, intended to develop a go-to pan-European energy supply chain resource in the channel region.

2 Non-conventional devices

2.1 Tidal PPA Technical Specification when applied to non-conventional TECs

The current technical specification (IEC/TS 62600-200: Electricity producing tidal energy converters – Power performance assessment technical specification) (TS) has well defined requirements for carrying out a PPA. The standard plays an important role in building investor confidence in the sector and helping to accelerate commercialisation. The PPA relies on the measurement of the incident current resource. Upstream seabed mounted Acoustic Doppler Current Profiler (ADCP) are viewed as the most reliable measurement method. It is however, an expensive and operationally complex method for developers, especially so for those whose designs aim to reduce seabed operations [2].

At the time of publication of the current TS (2013), the industry was generally dominated by horizontal-axis, seabed-mounted turbine devices. Over the ten years since its publication, many other types of devices have been developed. This variety is demonstrated amongst the four developers under the TIGER project where there is a range in concept types, as can be seen in Table 1.

Developer	TEC type
HydroQuest	Seabed mounted, vertical axis – reasonably covered by the current TS [1]
Orbital Marine Power	Floating, horizontal axis – somewhat covered by the current TS [1]. Apply recommendations made in [3] and [4].
Sabella	Seabed mounted, horizontal axis – well covered by the current TS [1]
Minesto	Tidal kite – not covered in the current TS [1]
SIMEC-Atlantis	Seabed mounted, horizontal axis – well covered by the current TS [1]
QED Naval	Seabed mounted, horizontal axis – well covered by the current TS [1]

Table 1 | Device types of developers in the TIGER project

There are a range of 'non-conventional' concepts for which the TS [1] is not as relevant and standardised methodologies should be developed where and when there is sufficient industry need/demand. These include:

- Undulating Membrane
- Enclosed Tips
- Tidal Kite

There are a few methods that could be used to apply the general TS approach to the above concepts; however, this report will focus on the methods presented below.

1.1.1 Undulating membrane

Undulating membranes are a flexible hydrofoil attached to an oscillating arm, like the example shown in Figure 2.1. The device is actuated by the flow of water across its surface causing the flexible membrane to undulate like a flag in the wind. An example of this device includes EEL's prototype [5]. This system is not covered in the current TS [1] and some deviations may be necessary for it to be compliant.

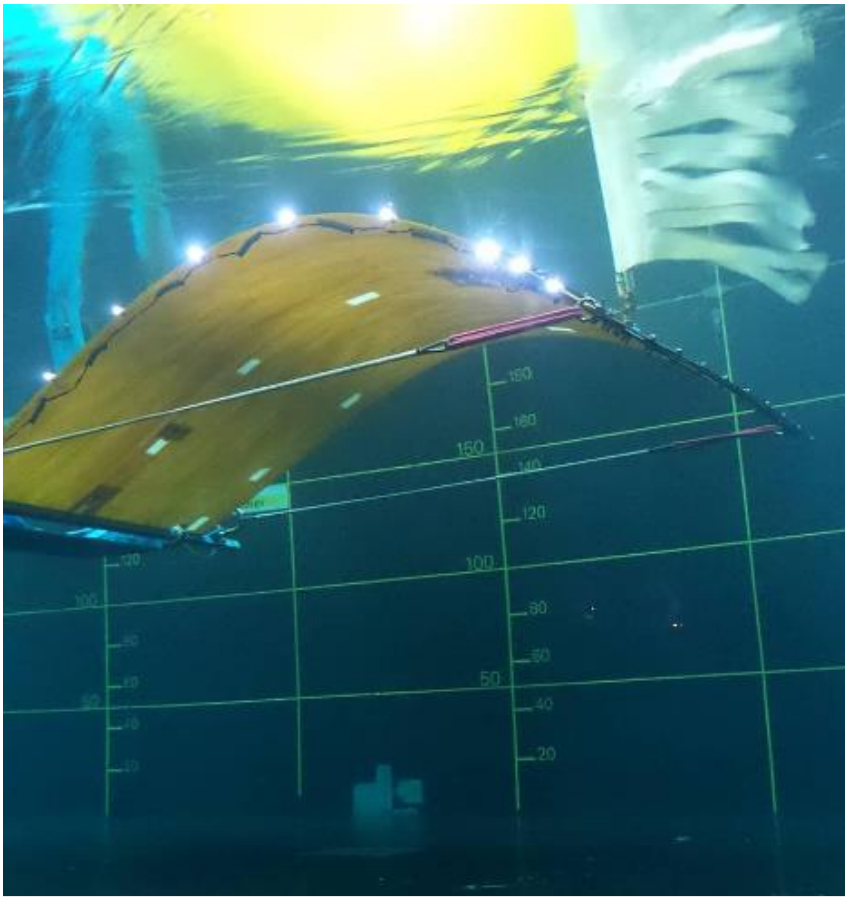

Figure 2.1 | EEL Energy's undulating membrane device

2.1.1 Enclosed Tip

Enclosed tip devices are usually using a vertical or horizontal axis turbine enclosed in a duct of some description, as shown in Figure 2.2. The water velocity is increased, due to the Venturi effect, as it is funnelled through the enclosure. The resultant flow can drive a turbine directly or the induced pressure differential in the system can drive an air turbine.

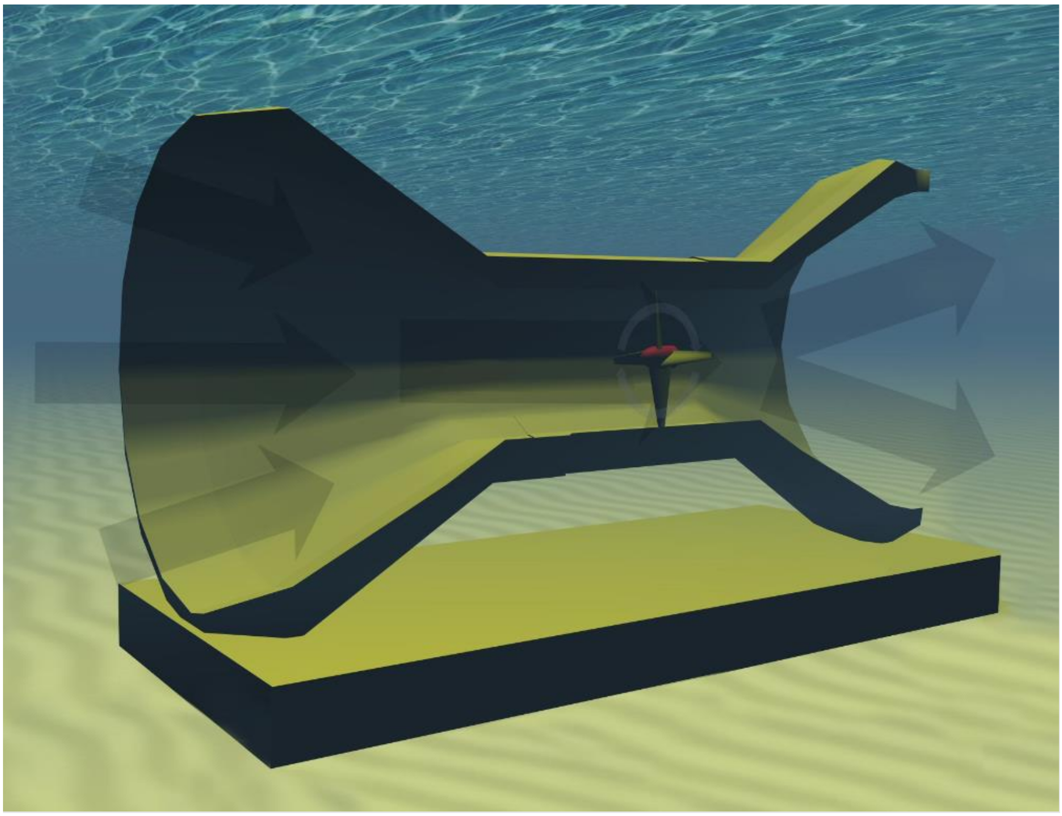

Figure 2.2 | Enclosed tip TEC device [3] [4] (© 2008 AQUARET)

This concept is mostly covered in the current TS [1], except for an example calculation for calculating the capture area and equivalent diameter for a ducted design.

3.1.1 Tidal Kites

A tidal kite flies in the tidal stream, tethered to the seabed. A turbine is on-board the kite which swoops in a figure-of-eight path perpendicular to the tidal flow direction, as can be seen in Figure 2.3. This flight path allows the tidal kite to fly fast with a higher relative velocity flowing through the turbine [4] compared with if the turbine was statically mounted in the tidal stream. Figure 2.3 shows front and side views of a tidal kite in operation.

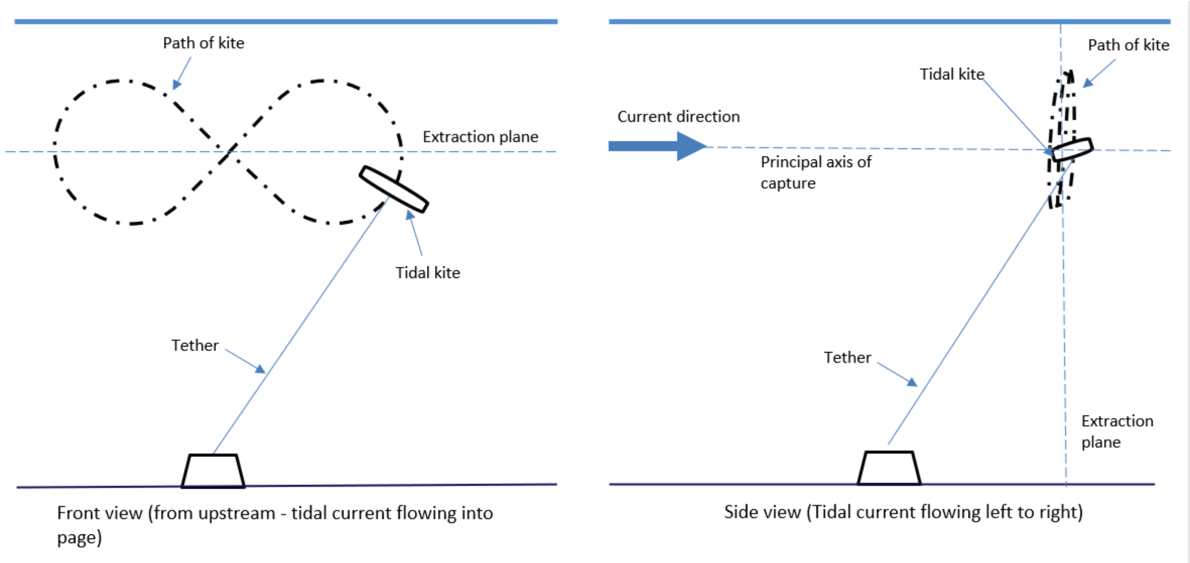

Figure 2.3 | Tidal Kite

The tidal kite is beyond the scope of the current early-stage TEC TS [5] and the full-scale TS [1]. The power performance needs to be in relation to the incident tidal stream velocity. It will be of interest to the TEC developer to understand the relationship between the incident resource velocity and the kite's velocity through the water but, although this will be an important relationship for optimising the performance of the TEC, this will not necessarily be critical for assessing the performance. Investigating these dynamics and relationships for a conventional TEC would normally be covered during the early-stage development of the TEC by following the TS62600-202 [5]; however, the tidal kite is beyond the scope of that TS.

3 Considerations when measuring the incident resource for the PPA of non-conventional TECs

A few of the key considerations have been broken down as an attempt to simplify the problem.

Device control

An accredited PPA for a static, seabed mounted horizontal-axis turbine TEC does not allow any alteration to control algorithms during the test. The test should be ‘autonomous’ from a control perspective. It may be impractical to run a PPA in the traditional ‘hands off’ way when it comes to ‘non-conventional’ TECs. For a fully developed prototype, performance testing with autonomous control with no intervention should be the goal, but for earlier stage devices some deviation on the control will likely be required.

Kite path

In the case of the tidal kite, which moves relative to the tidal stream, special thought needs to be considered for the test methodology. The kite’s optimal path across the water column will likely change as the current velocity changes and will also be affected by the control plan. It is possible that this could be modelled numerically, forecasted using harmonic analysis, or measured during operation.

Shear profile

Understanding the natural shear profile in the resource (upstream of any influence of the TEC) in all three dimensions is important because if there is negligible variance then there could be justification for simplifying the measurement method.

For a tidal kite, the kite’s path features large sweeps which will cover large areas and may vary in all three dimensions. The baseline vertical shear profile could be significant across the kite’s path footprint. The lateral shear over the kite path width may be more pronounced than the relatively narrow vertical shear.

Defining the Projected Capture area

The projected capture area is an important input into the power performance calculation. The current TS [1] allows comparability between PPAs of conventional TECs at similar fidelities. Achieving comparable fidelity for non-conventional TECs may be more challenging. The current TS [1] defines capture area for ducted, or enclosed, TECs, which is reasonable. However, there is no clear definition for tidal kites.

The undulating membrane hydrofoil capture area could be defined by the maximum footprint of one oscillation, as illustrated in Figure 3.1.

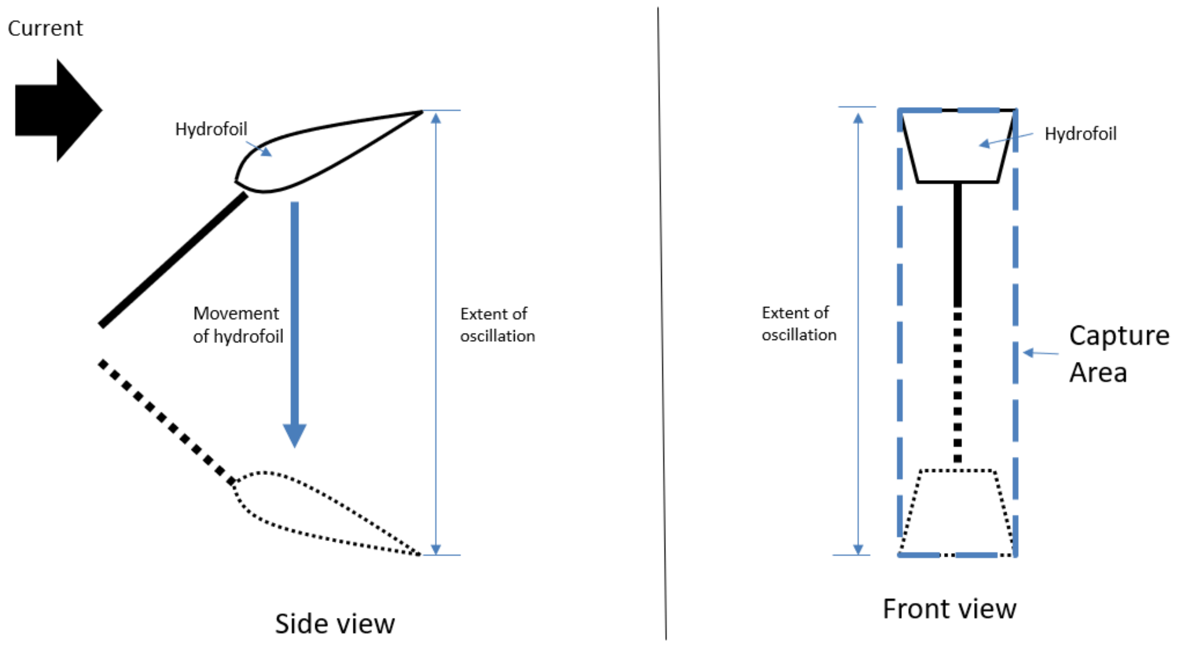

Figure 3.1 | Possible capture areas for an undulating membrane hydrofoil

In the case of a tidal kite, in the simplest case, the projected capture area can be considered a box which has the width and height equal to the width and height of the figure of eight, as illustrated in Figure 3.2. This is likely to be a large area and only valid if there is limited variance in the vertical and horizontal shear profiles, however, it can be split into sections in the same way that is used for a horizontal axis rotor. In a site where there is variance in shear, the area could be defined by the area covered by the kite's wingspan as it completes a sweep, meaning it would be equal to kite wingspan x kite path length. This is shown on the right of Figure 3.2.

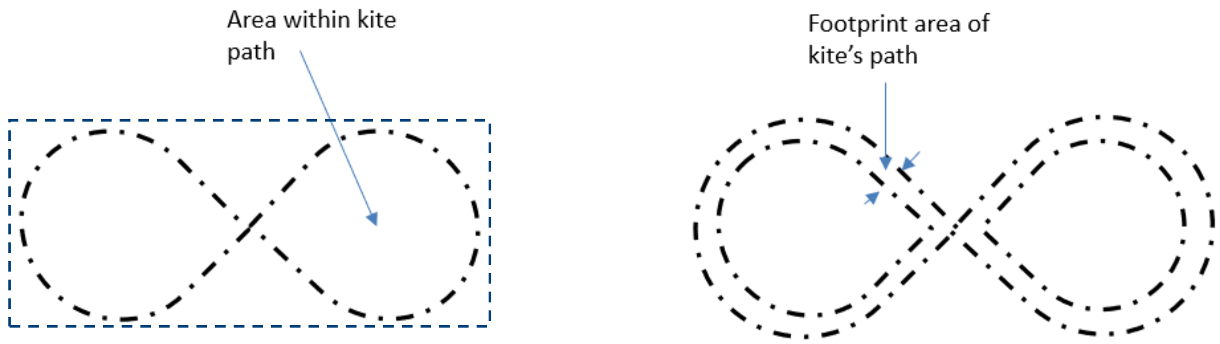

Figure 3.2 | Tidal Kite Projected Capture Area

Both may be difficult to calculate accurately without real operational position data or modelling of the system and would still likely be vulnerable to horizontal shear variance, especially at points when the kite is at the extreme sides of the figure of eight. The main impact of this variance is deciding the placement of any current profiler. Depending on the horizontal range of the tidal kite's path, two current profilers might be required.

Beam Spread and sidelobe contamination

Due to the beam angle of a current profiler, the beam spread increases with distance from the instrument. In the case of a bottom-mounted instrument measuring capture areas close to the surface, the beams can be separated by some distance. Several of the non-conventional concepts, such as the tidal kite and the undulating membrane, could have capture areas that are not adequately covered by the beam spread.

In the case of the tidal kite, capturing the entire sweep of the kite's path may not be possible for a vertically orientated current profiler due to its beam spread. In the instance that the horizontal shear across the kit's path has already been proven to have limited variance, the current may be considered equivalent across the kit's path. Other orientations could be employed which may be able to capture the entire spread, for example, using forward-facing horizontally orientated ADCPs mounted at the tether point of the tidal kite, or using multiple seabed mounted instruments. It will likely be more practical to use a sea-bed mounted ADCP and attempt to quantify the uncertainty due to the projected capture area being wider than the beam spread. Velocity measurements from onboard the kite could aid this activity.

Sidelobe contamination, which occurs when acoustic leakage to the side of the main beam is reflected from a strong scatterer such as the water surface, is also a necessary consideration. For any instrument beam that reaches the surface, like in the case of bottom mounted instruments, approximately the top 10% of the water column is lost to interference. This could apply to any non-conventional concept for which the capture area is in this region, if floating on the surface or midwater, or moving in the tidal stream such as the tidal kite.

3.1 Summary of considerations

It is clear that there are some non-conventional concepts for which the current specification [1] can be applied with little adaption, while others will need significant deviations.

Ultimately, the power curve, which constitutes a plot of the power production (y-axis) against the incident tidal current resource (x-axis), allows the power performance to be compared between different TECs and applied to estimate energy generation at tidal sites in conjunction with long-term resource estimates. This is reasonably achievable with minor deviations to the TS [1] for the enclosed tip and, depending on the exact orientation, the undulating membrane/hydrofoil. The tidal kite concept is very different and will require some more significant deviations.

4 Proposed Methodology

The PPA tests that are carried out at this stage should aim to collect a significant amount of supporting data.

4.1 Incident resource measurement

Where there is no infrastructure to support a floating ADCP for the incident resource measurement, a seabed mounted ADCP, upstream of the device, should be used. If possible, the orientations of the instrument positioning should be compliant with the requirements of the IEC/TS62600-200 [1] (2-5D_E upstream or 1-2D_E to the side).

In the case of the undulating membrane/hydrofoil, the placement of current profilers should be based on the capture area which should be defined as the footprint of the hydrofoil through one oscillation, as described in Section 3. As a minimum, the requirements of the TS [1] for the number of bins and maximum bin size across the capture area should be met. The position of any seabed mounted instrument should be in a position close enough to be representative of the global flow at the TEC's position without any impact due to the proximity of the TEC itself. In most cases, the Equivalent Diameter (D_E) should be defined as the widest dimension of the undulating membrane/hydrofoil's path as detailed in [1].

In principle, the enclosed tip TEC should not need too much alteration from the current specification. The measurement position should be upstream enough to not be impacted by the local flow field of the TEC. The guidance and requirements in the current TS [1] for calculating the equivalent diameter and positioning the current profiler should be adequate for this concept. It is recommended that fluid velocities inside the duct are measured using pitot tubes or single point velocity meters. In the case that the device is misaligned to the principal flow, or for any of the tidal cycle whilst the device is generating, there could be appreciable impacts on the power curve. In that case, it is suggested that secondary power curves using the component of tidal current velocity which align with the principal axis of capture, are added to the appendices of the test report.

In the case of the tidal kite, the placement of the instrument could be based on modelling, or position data of the kite in operation. Evidence that the position is reasonable for measuring the projected capture area should be presented or supporting evidence to any alternative. If possible, it is recommended that incident resource data is gathered at both a reference point that is representative of the flow and from the kite device itself. Gathering these two data points will allow a relationship to be defined between the tidal resource and the apparent turbine-axial-flow at the kite. The equivalent diameter (D_E) used for defining the instrument placement should be defined as the diameter of the kite's path at its widest extreme. This is likely a conservative requirement, and so deviations with justifications can be made. Alternative measurement methods could include downward facing current profilers on a buoy or vessel moored upstream.

For the definition of the capture area, the projected capture area should be defined as the entire area within the most extreme path of the kite, or the capture area should be refined to the area that the kite travels through (kite wingspan x length of figure of eight). The method should be justified by demonstration of limited variance in the shear profile. If there is great variance in the kite path between tides, or throughout the tide, this approach should be refined with supporting evidence. The current specification requirements for number of bins across the capture area may not be appropriate and so may be a deviation until such time as the specification considers alterative capture areas.

As the methodology on tidal kites is likely to improve as more devices are tested, it is important to collect onboard velocity data where possible to understand the apparent flow. However, from the perspective of the PPA, it is the incident flow that is of interest.

5 Conclusion

In conclusion, there are concepts that do not fit into the conventional TEC category and for which the current PPA technical specifications require some adjustment in order to carry out a PPA. The broad principles in test methodology which are covered in both the IEC TS62600-200: Electricity producing tidal energy converters – Power performance assessment, and the IEC TS62600-202: Early-stage development of tidal energy converters are still relevant.

The following considerations are suggested when measuring the power performance:

- For the undulating membrane/hydrofoil and enclosed tip concepts, comparing the performance with more conventional systems is possible if comparable methodologies (mostly related to swept area and incident resource measurement requirements) have been applied.
- For the tidal kite:
    - The swept area of the kite and its impact on measuring the incident flow needs to be considered. Extra measurements may be required to demonstrate the validity of the test methodology in terms of instrument type, orientation and placement. This should include consideration of the beam spread of any current profilers used. The approach should be documented with figures that show the expected (or recorded, if possible) kite path relative to the measurements taken by any ADCP beams.
    - As a minimum, the requirements of the TS [1] for the number of bins and maximum bin size across the capture area should be met as far as possible to reduce deviations vs the TS, though this may require additional monitoring. Where the bins lie within the water column, i.e. their position relative to the kite's path, should be documented in the test report through figures.
    - Understanding the relationship between the incident tidal stream velocity and the axial-flow in the turbine's reference frame will be helpful in assessing and improving device performance but it is not required for the PPA.
    - The equivalent diameter (D_E) used for defining the instrument placement should be defined by using the widest width of the kite's path through the water column.
    - Non-autonomous control should only be used if it is absolutely necessary for the basic operation of the device and it should not be done to optimise the performance during the test. Where control intervention is needed, a complete record should be made and presented as evidence in the test report.

At present, there may not be sufficient development of any of the concepts discussed in this report to make any major alterations to the current TS [1] necessary. Using this report alongside the current TS [1] will allow for methodical testing and measurement of the power performance for the undulating membrane/hydrofoil, enclosed tip, or tidal kite concepts.

6 References

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