Loadings on a tidal stream turbine during installation using CFD modelling

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Abstract **— Deploying a tidal stream turbine is a process which must be made more economic if tidal stream energy is to become a competitive and viable option. Significant costs arise from the installation process itself along with subsequent removal as part of the maintenance cycle. Currently the marine renewable industry largely relies on the use of offshore construction vessels from the oil & gas sector which can cost in the region of £125k per day. Downtime cost is also significant whilst waiting for favourable conditions in which to carry out the removal and/or installation process.**

This work uses CFD modelling to assess the loadings on the nacelle of a horizontal axis tidal stream turbine associated with its installation at the slack period of a neap tide. The loadings were found to be significantly higher at a flow stream velocity of 0.75 m/s compared with at 0.5 m/s. This will better inform installation procedures. The orientation of the nacelle relative to the flow stream was also found to be significant due to the hydrodynamic profile of the blades with certain orientations reducing the complexity of the loadings.

Keywords **– Tidal Stream Turbine, Installation, Deployment, CFD modelling.**

I. INTRODUCTION

There is an increasing interest in renewable energy as a means of providing a clean source of energy. Policy to reduce climate change focusses largely on the reduction of CO_2 emissions as their significant impact is now widely accepted [1]. Data indicates that in 2014, 31% of the UK's total greenhouse gas emissions came from 'energy supply' which is defined as 'fuel combustion for electricity generation and other energy production sources' [2]. The largest contributor within this sector was the combustion of coal and natural gas for electricity production in power stations. It can be argued that decarbonising the UK's electricity supply has the potential to create a significant impact on climate change.

Whilst reducing the level of CO_2 could be also achieved by the increased use of nuclear energy this option is not popular with many due to concerns over safety and environmental issues involving waste disposal. A more acceptable way to achieve this may therefore be to increase the proportion of marine renewable energy.

Tidal stream energy resources are almost entirely predictable. This makes balancing the electricity supply with the load more straightforward as the contribution required from non-renewable sources in order to meet the demand can be anticipated [3]. However to ensure the reliable provision of this energy effort is needed to underpin turbine deployment and removal for necessary maintenance. This paper considers the deployment of a turbine nacelle under varying flow conditions to assess how to best support such a process.

II. TYPES OF TIDAL STREAM TURBINE DEPLOYMENT

There are several different types of configuration for tidal stream turbines currently being explored with no generally accepted single 'best' solution. Figure 1 shows some of the different variations for the support structure for a horizontal axis tidal stream turbine. All the examples shown are surface piercing, however all but the floating tethered platform could also be deployed as a fully submerged structure. Examples of devices using these techniques are:

Mono-pile: the first deployment of a commercial scale tidal stream turbine was the SeaGen S turbine by Marine Current Turbines rated at 1.2 MW and located in Strangford Lough. This system used a mono-piled support structure [4].

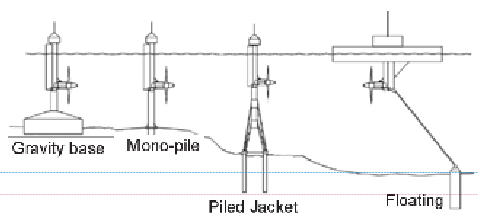

Figure 1 - Types of support structure for a horizontal axis tidal stream turbine

Floating: two devices; Nautricitiy's COrMaT [5] and Minesto's Deep Green [6] are tethered devices. COrMaT is

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tethered between a gravity base and a float and utilises contra rotating rotors to neutralise the torque experienced by the nacelle [7]. Deep Green is tethered to a gravity and allowed to 'fly' in a figure of eight pattern.

Gravity Base: the design of the DeltaStream device by Tidal Energy Limited used 3 turbines mounted onto a triangular gravity base support structure. The support structure had patented 'rockfeet' located at each vertex of the triangular base which essentially dug in to the seabed to resist the thrust of the turbines [8].

Possibly the biggest project to date, the MeyGen project, has a planned array of tidal stream turbines located at the Inner Sound, Pentland Firth. The project aims to have 398 MW of installed capacity by the early 2020s. Initially 4 demonstration turbines have been installed as proof of concept and to gain an understanding of how the turbines perform in an array as opposed to in isolation. The turbines to be used in the array are the Atlantis AR1500 and the Andritz Hydro Hammerfest [9].

The Atlantis AR1500 turbine uses a support structure which can be either a gravity base or a pile depending on the site requirements [10]. The nacelle is removable and is installed onto the support structure which will have been pre-installed on the seabed. The nacelle is installed via a 'gravity stab' mechanism; the nacelle has the male part of the mating interface and the support structure has the female part. As the two parts are brought together under the action of gravity the nacelle 'progressively aligns' itself onto the base. The nacelle remains fixed to the support structure under the action of gravity only.

The Andritz Hydro Hammerfest is designed with a 25 year lifetime and 5 year service intervals [11]. The structure is also secured via gravity, pins or pilings, again depending on the site requirements.

III. Installation of tidal stream turbines

The inaccessible nature of tidal stream energy devices presents a key challenge. Their removal for maintenance and service has the potential to be both problematic and costly. A significant portion of this cost is due to the fact that the marine energy industry largely relies on the use of Offshore Construction Vessels (OCVs) from the oil and gas sector. The cost of these vessels can be in the region of £125,000 per day. Another issue is that the daily rate for the vessels is applicable during downtime whilst waiting for favourable conditions. Tidal stream energy converters will by nature be deployed at sites which experience high flow stream velocities. Due to dynamic positioning limitations it is likely that OCVs must typically operate during a 30 minute window aligned with the slack period of a neap tide where the flow stream velocity is less than 0.5 m/s [12].

There is the need for construction vessels which are specifically tailored to meet the needs of marine energy operations. A consortium of companies led by Mojo Maritime Ltd received a grant from the technology strategy board to develop a vessel which specifically meets the needs for the installation and removal of tidal stream turbines. The concept design for the vessel (the High Flow Installer) has been outlined [12] with the aim to have a daily rate of £30,000. The vessel is a catamaran configuration which helps to maximise stability as well as deck space and the length of the ship has been kept as short as possible (60m) to reduce cost. The vessel has 4 Voith Schneider Propellers (VSPs) thrusters on the end of each hull used for both propulsion and dynamic positioning. The VSPs as well as providing superior dynamic positioning are also quieter and minimise harm inflicted on marine mammals. The vessel is able to operate in flow streams of up to 5.14 m/s which can significantly reduce downtime.

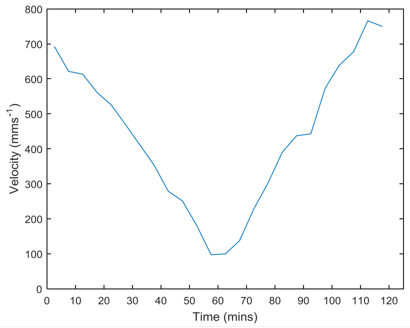
The design for the SeaGen turbine appears to address the potentially costly issue of removing the turbine for maintenance as the turbine can be lifted out of the water without the use of a construction vessel. This arrangement however surely must add to the capital cost of the device, it would also not be possible where a surface piercing support structure was not possible either in deep waters (current technology not does allow piling technology to be used in waters deeper than 40 metres [7]) or at a location where a surface piercing structure would interfere with shipping lanes. Favourable weather conditions may still be required to work on the device when the nacelles are lifted out of the water on the monopole.

The issue of installation and removal for maintenance remains a challenge for all of the different types of tidal stream energy converters being developed and is one which must be addressed before tidal stream energy can become fully commercialised.

IV. Scope of this work

This work considers the loadings acting on a removable nacelle of a horizontal axis turbine during the installation onto a pre-installed support structure. Computational Fluid Dynamics (CFD) modelling has been used to determine the forces and moments acting on the nacelle for flow stream velocities of varying magnitude and direction. The angular position of the rotor has also been considered. Knowing the criticality of any changes to these conditions can provide valuable insight for the installation process. Details of the flow conditions were obtained using an Acoustic Doppler Current Profiler ADCP to take measurements of the flow velocity during the neap tide slack period at Ramsey Sound [13].

Figure 2a shows the tidal stream velocity (which has been averaged across the depth) during the slack period for a neap tide. Figure 2b shows the direction for different flow stream velocities, the red dot corresponds to when time equals zero. The proposed lifting arrangement to be assessed is to have two ropes/cables as shown in Figure 3 with the flow being in the Y direction, the two ropes thus restraining the nacelle in the direction of the flow. Positioning the nacelle in this orientation relative to the flow stream reduces the frontal or projected area of the nacelle and so should reduce the drag force which the nacelle experiences.



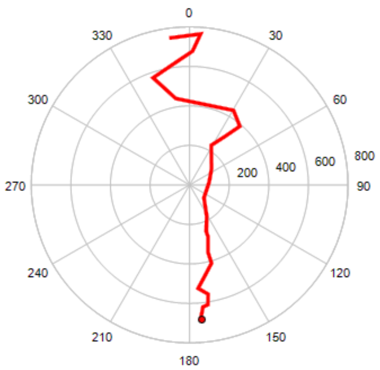


Figure 2 – a) Velocity averaged across the bins against time in neap slack; b) Tidal rose for neap slack indicating both direction relative to North (0) and south (180) [13]. Radial distances show velocity in mms^{-1}

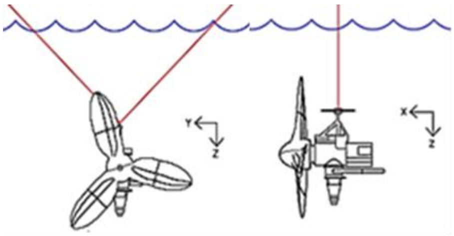


Figure 3– Proposed lifting arrangement

The nacelle considered has a 12m diameter rotor and is approximately 8m long. The body of the nacelle not including the rotor or lifting frame is approximately 5m from the top of the section containing the gearbox to the bottom of the male part which interfaces with the support structure. The lifting point is vertically in-line with the centre of gravity of the nacelle including the lifting frame, this takes into account the buoyancy of the rotor when it is fully submerged in the water.

A. CFD Modelling

The forces and moments on the nacelle have been determined by the use of a steady state CFD model using ANSYS Fluent. The fluid domain was split up into 9 sections as shown in Figure 4 with the turbine surfaces located in a cylinder in the central region of the domain.

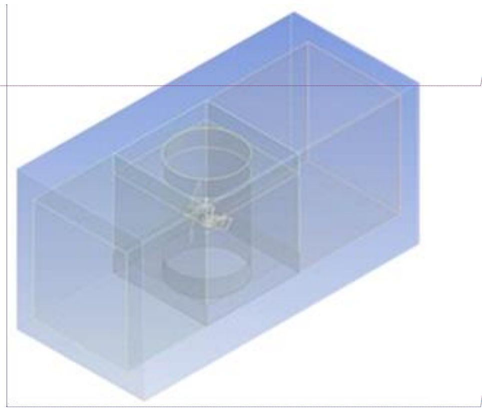


Figure 4 CFD domain sections

The outer 8 sections were meshed using the sweep method which used hexahedral elements. An unstructured mesh using tetrahedral elements was used to mesh the cylinder which contained the surfaces of the turbine. The mesh size was reduced on the surface, and in the local vicinity of the turbine. The size of the mesh elements on the outer surface of the cylinder was matched to that of the hexahedral elements used in the sweep mesh.

The turbulence model used was the Reynolds Averaged Navier-Stokes (RANS) *k*-ω Shear Stress Transport (SST) model. The surfaces of the turbine blades were set as no-slip walls, the surface roughness constant and roughness height were left at the default values of 0.5 and 0 m respectively. The cylinder containing the surfaces of the turbine was rotated about its axis to model the effect of flow stream approaching from different directions relative to the turbine.

After completing a mesh independency study a meshing scheme was chosen with 11.8 million elements and a growth rate of 1.150. For the mesh size in the far field 0.5m was used. Figure 5 shows the force in the X and Y direction against the number of iterations. The analyses were left to run for 4000 iterations; this still resulted in a reasonable time for each model. This model was then deployed as the basis for the further investigations.

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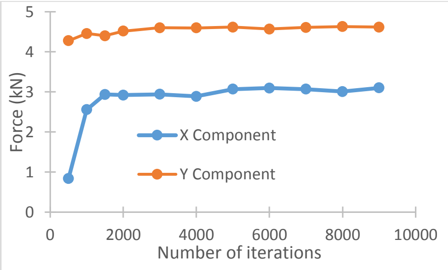

Figure 5 - Drag vs Number of Iterations

B. Reliability of results

The reliability of the results was assessed by estimating the drag coefficient of the turbine.The drag coefficient of the turbine was estimated by considering the projected area of the nacelle and was computed to be 24 m^2. The maximum theoretical drag force available was calculated as being 6.75kN and the calculated drag from the CFD model was, in the direction of the flow 4.5kN. Hence the drag coefficient was estimated as 0.66. This represents a reasonable approximation which lies within the region of what may be expected from other studies.

V. Results and Discussion

A. Loadings on the nacelle for varying magnitudes of tidal stream velocity

The effect of changes to the tidal stream velocity on the forces and moments acting on the nacelle was investigated. Three representative magnitudes for the tidal stream velocity were used; 0.25 m/s, 0.5 m/s, 0.75 m/s, these were taken from the study of the flow at Ramsey Sound by [13] which found that during the slack period the flow range varied from around 0.1m/s to 0.75 m/s as shown in Figure 2a. Flow stream velocities less than 0.25 m/s were not considered as flow of this magnitude only occurred for a short time period; the loadings on the nacelle were also found to already be very small at a flow of 0.25 m/s.

The origin was taken as the main lifting point on the lifting frame as shown in Figure 6. Moments were taken about the X, Y and Z axes, the force acting on the nacelle in the X and Y direction has also been considered. The direction of the incident flow stream is in the positive Y direction with reference to the coordinate system in Figure 6.

It can be seen in Figure 7a that the angle of the resultant force changes very little with flow stream velocity. The magnitude of the resultant force however changes considerably from around 0.5 kN at a flow of 0.25 m/s to just under 5.5 kN at a flow of 0.75 m/s. The X and Y components of the force acting on the nacelle for different flow stream velocities are shown in Figure 7b. It can be seen that as the flow increases from 0.25 m/s to 0.75 m/s there is an increase in both the X and Y components of force of about an order of magnitude as it increases from approximately 0.5 kN to 3.0 and 4.5kN, respectively.

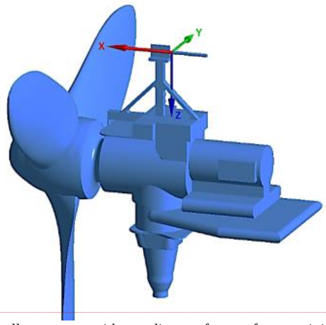

Figure 6 - Nacelle geometry with coordinate reference frame, origin is the main lifting point.

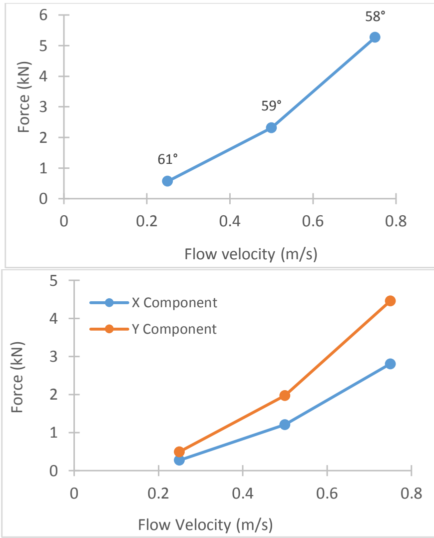

Figure 7 – a) Resultant force in the XY plane for increasing flow stream velocities. Data labels show angle of resultant force in the XY plane;
b) X & Y Components of force acting on nacelle against flow stream velocity

The main reason for the magnitude of the X component of force acting on the nacelle is that there are regions of negative pressure created on the front of the blades as well as on the nose cone/rotor hub. The flow also strikes the rear of the blades which causes a positive pressure on this opposing surface. As the flow velocity increases there is also an increase in the X component of force on the rotor. This resultant X component is mitigated by the forces acting in the opposite direction due to the flow striking other parts of the turbine reducing the total force in the X direction. The resultant X component therefore is due to the flow acting on the blades and rotor hub.

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B. *Moments*

Figure 8 shows how the positive moments about the X, Y and Z axis are defined.

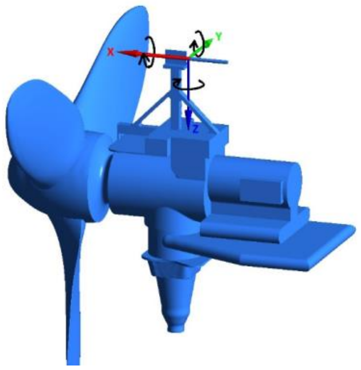

Figure 8 – Definition of positive moments about the lifting point

Figure 9 indicates that there is a large increase in the magnitude of the moments acting on the nacelle as the flow stream velocity increases from 0.25 to 0.75 m/s. The magnitude of the moment about the X axis increases from just under -2 kNm to around -15.5 kNm. The moment about the Y axis increases from around 1 kNm to around 9 kNm. The moment about the Z axis increases from around 1 kNm to just under 7 kNm. The forces and moments acting on the nacelle are therefore highly dependent on the magnitude of the flow stream velocity and as such it would be advantageous to perform the installation when the flow stream is 0.25 m/s or less, for which there is roughly a 30 minute window.

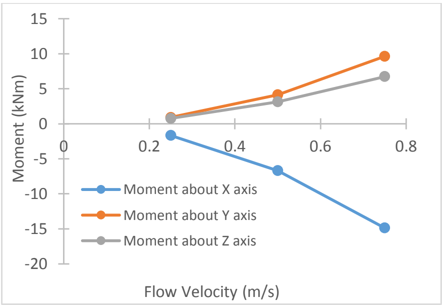

Figure 9 - Moments acting on Nacelle about X, Y and Z axes for increasing flow velocities. Origin is defined as the lifting point on the lifting frame

C. *Displacement and rotation of the nacelle under loading*

The rotation of the nacelle about the lifting point and the displacement have been calculated for steady state conditions using the results from the CFD model. The values for the moments and forces acting on the nacelle have been taken for a number of cases of particular interest. Steady state conditions have been assumed where the forces and moments are both constant and in equilibrium. The rotation or displacement of the nacelle required to produce an opposing moment or force which equals that created by the drag of the tidal stream has been calculated. For example the drag force causes a moment acting on the turbine about the lifting point, this causes the turbine to rotate so that the centre of gravity no longer lies vertically in-line with the lifting point. The perpendicular distance between the weight vector passing through the centre of gravity and the lifting point creates an opposing moment. The nacelle will rotate until this opposing moment equals that caused by the drag and this is the position that the nacelle will 'sit' in equilibrium in the fluid stream under steady state conditions.

A similar approach has been taken which looks at the angle of the lifting rope required so that the tension has a component which is equal and opposite to the drag force created by the fluid stream. This study assumes steady state conditions which in reality are unlikely to occur. The incoming flow stream is likely to contain fluctuations in velocity as well as turbulence. This means the nacelle could experience constant changes in the forces acting upon it and hence changes in its position. It is also possible that oscillations of increasing amplitude could occur.

This study only assesses moments causing the nacelle to pitch and roll, it does not assess moments (about the Z axis) that will cause the turbine yaw, with recommendations made with regards to the lifting arrangement so as to minimise the yawing moment. However should the turbine yaw into a different angular position relative to the fluid stream then the moments causing pitch and roll are subject to change from those generated by the CFD model. This is also true if the angular position at which the turbine 'sits' in the water due to pitch and roll is sufficiently large enough to cause the drag and lift forces to alter as a result.

In all cases the resultant weight of nacelle (including lifting frame) in water is 276.31 kN (this accounts for buoyancy effects in water).

- Moments about the X axis

The moments about the X and Y axis are considered separately. The lifting arrangement is shown in Figure 10. The origin about which moments are taken is coincident with the lifting point on the lifting frame of the nacelle which is assumed to be fixed in the Y direction due the two cables being used, this is shown in Figure 10. The X axis, about which moments are taken is 'coming out of' the figure. The deflection L of the bottom of the pintle adapter (or the male part of the connector) as shown in Figure 11 has been considered as knowledge of the displacement of this part is critical if it is to mate with the support structure

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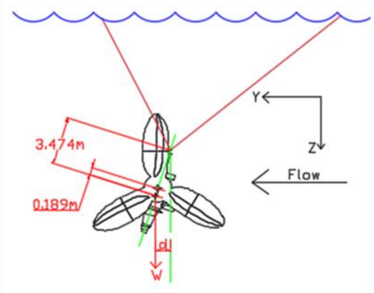

Figure 10 – Nacelle constraints and rotation about the X axis

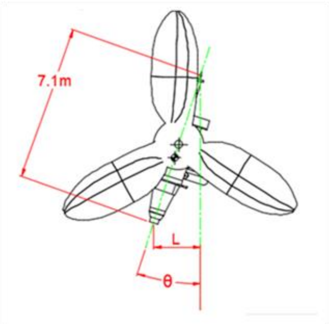

Figure 11 –Pintle adapter deflection along the Y axis

- Moments about the Y axis.

As well as the rotation of the nacelle about the X axis, caused by the drag in the direction of the fluid stream, there is also a component of the drag force at 90° to the direction of the fluid stream (along the X axis) and a moment about the Y axis. The lifting point on the nacelle was considered to be fixed in the first case, the situation is different here as there are not two ropes restraining the lifting point in the XZ plane. As such there can be rotation about the crane (pivot point 2) as well as about the lifting point on the nacelle (pivot point 1) as shown in Figure 12. The rope will be considered to be perfectly straight with free rotation about both ends (any significant curvature in the rope will be extremely unlikely due to the weight of the nacelle). As there is no rotational constraint applied where the rope is fixed to the nacelle, moments which are applied to the nacelle will not be transferred to the rope. There will merely be a vertical and horizontal component of force which, in equilibrium will equal the weight of the nacelle in water and the X component of the drag force respectively

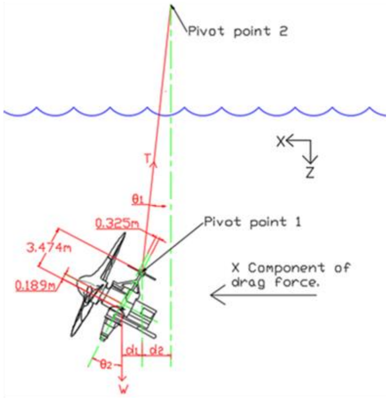

Figure 12 - Nacelle constraints and rotation about the crane and the lifting point on the lifting frame (reaction forces at the crane are not shown)

D. *Forces acting on the rope*

The forces acting on the rope will be considered first and are shown in Figure 13. The calculations considered the scenario where the flow is in the Y direction, the velocity is 0.75 m/s and the rotor is at position 0° or top dead centre. The X component of drag, determined from the CFD model was 2.8 kN. The bottom of the nacelle is to be lowered onto the support structure 20m below the surface of the water. The height of the crane could, for example, be 15m above the surface of the water. The turbine is around 7m in length from the lifting point to the bottom of the pintle adapter. The rope length will therefore be taken as 28m. The displacement d1 of the end of the rope at the lifting point on the nacelle from its original position for these conditions is 0.293 m from the vertical.

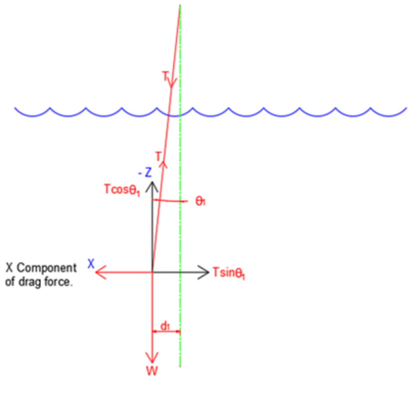

Figure 13– Forces acting on the rope due to weight and the X component (90° to flow) of force on the nacelle

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E. Moments acting on the nacelle

The lifting point on the nacelle is considered to be fixed once the initial displacement d1 has occurred, the forces acting on it due to the weight of the nacelle, the drag forces and the rope tension are assumed to be in equilibrium for a steady state condition, as shown in Figure 14. The rotation required to cause a shift in the centre of gravity necessary to create an equal opposing moment to that created by the drag force is calculated in a similar manner as for the initial scenario. The moment about the Y axis from the CFD model, Myy, is 9500 Nm (clockwise with reference to Figure 14).

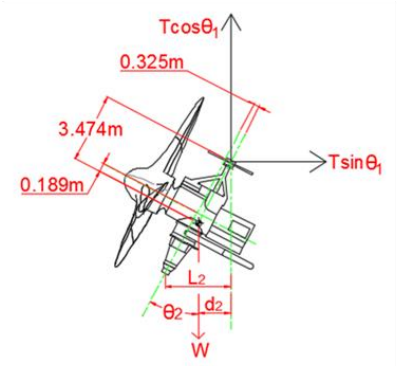

Figure 14 - Rotation of nacelle at the lifting point on the lifting frame due to the X component (90° to flow) of drag force.

F. Displacement of the bottom of the pintle adapter

The displacement of the bottom of the pintle adapter (Figure 15) has been calculated as for the rotation about the X axis.

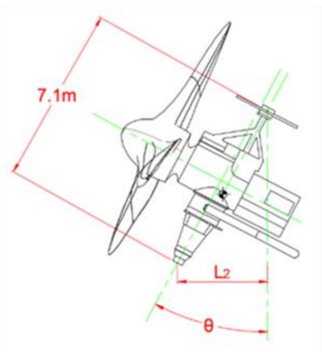

Figure 15 Displacement of the base of the pintle adapter due to rotation about the Y axis.

The results for the above scenarios can be found in Table 1. Calculations have also been repeated for the case of a flow direction at 90°. The calculation has also been repeated using a flow of 0. 5 m/s at 90° so that the effect of the flow velocity on the deflections and rotations can be clearly seen and compared with the other scenarios in the table.

Setting 1 in Table 1 use the lifting arrangement as shown in Figure 10. Settings 2 and 3 are applied to the alternative lifting arrangement, shown in Figure 16, where the flow is at 90° (aligned with the X axis).

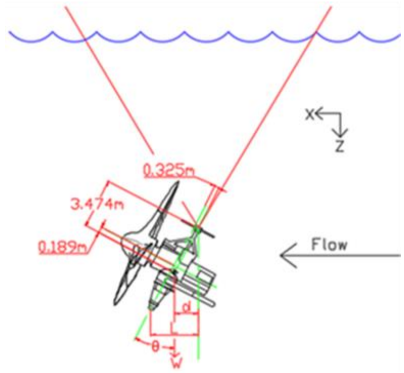

Figure 16 – Alternative lifting arrangement to be used when flow stream direction is at 90° relative to the nacelle.

The reason for this is that were the nacelle intentionally orientated at 90° to the flow stream it would be beneficial to have two ropes restraining the nacelle in the XZ plane as shown in Figure 16. As there are no components of force at 90° to the flow stream then there will be no movement at 90° to the flow despite the nacelle not being restrained in the YZ plane. For Settings 2 and 3 θ, d and L refer to the angle of rotation of the nacelle, the distance through which the centre of gravity moves and the distance through which the bottom of the pintle adapter moves respectively (as defined in Figure 16). For setting 1 θ, d, L, θ1, d1, θ2, L2, d1 + L2 are as defined above.

As can be seen from the values in Table 1, setting 1 has a maximum deflection in the direction of the flow stream, however the deflection at 90° to the flow stream is zero. Whilst the deflection is a maximum in the direction of the flow stream it is less than the total deflection at 90° to the flow stream (d1 + L2). The arrangement shown in Figure 16 therefore minimises the overall deflection, the angle of the nacelle however is greatest using this arrangement being 1.8° for a flow velocity of 0.75 m/s.

This study largely considers the flow conditions during the slack period of a neap tide at Ramsey Sound. However one more condition has been considered which is for a flow stream velocity of 5 m/s and a flow direction of 90°. A flow stream velocity of approximately 5 m/s has been chosen as the tidal energy specific construction vessel detailed in [12] will have

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Commented [i25]: It already says this?? Tim dynamic positioning capabilities in flow streams up to this velocity. It is therefore important to understand the loadings that the turbine will be subjected to along with the corresponding displacement and rotation.

The results for the case using a flow stream velocity of 5 m/s are shown in shown in Table 2. It can be seen that at this flow velocity the component of force perpendicular to the flow stream (Y component) is no longer zero, however it is two orders of magnitude smaller than in the direction of the flow stream. The same can be said for the moments about the X and Z axes, which are 3 orders of magnitude smaller than the moment about the Y axis.

The distance, d, required to produce a moment which opposes that about the Y axis would be 4.75 m which is larger than the distance between the lifting point and the centre of gravity so even if the nacelle were to rotate 90° an opposing moment would not be created. In reality the nacelle will rotate about the lifting point and unlike the case for flow stream velocities typical during the slack period, the angle of rotation would be significant enough so that the loadings on the nacelle change as it rotates. As the nacelle rotates about the Y axis the projected area of the blades will reduce thus reducing the drag on the nacelle until equilibrium is reached. To gain this information a further series of steady state CFD models would be required at increasing angles of rotation of the nacelle about the y axis. The rotation about the X axis and the displacement of the nacelle in the Y direction have not been calculated as the values obtained for the force and moment would be subject to change due to the significant rotation of the nacelle about the Y axis.

What can be gleaned from these results is that at larger flow velocities the displacement and rotation of the nacelle become particularly significant compared to the minimal values obtained for the flow conditions present during the slack period. This highlights the fact that despite having a vessel capable of keeping position in flow stream velocities of up to approximately 5 m/s, the operation of installing a removable nacelle onto its support structure would be problematic at high flow velocities.

Table 1 – Moments and forces with corresponding deflection and rotation

		Setting 1	Setting 2	Setting 3
Metric	Unit	Rotor Position 0° Flow = 0.75 m/s Flow direction = 0° (Y direction)	Rotor Position 0° Flow = 0.5 m/s Flow direction = 90° (X direction)	Rotor Position 0° Flow = 0.75 m/s Flow direction = 90° (X direction)
θ	°	0.9	0.8°	1.8°
θ_1	°	0.6°	0	0
θ_2	°	0.5°	0	0
d	m	0.056 m	0.048 m	0.107 m
d_1	m	0.293 m	0	0
L	m	0.112 m	0.099 m	0.223 m
L_2	m	0.074 m	0	0
$d_1 + L_2$	m	0.367 m	0	0

Table 2 – Loadings on the nacelle for a flow velocity of 5 m/s, flow direction = 90°, rotor position = 0°

X component of force (kN)	Y component of force (kN)	Moment about X axis (kNm)	Moment about Y axis (kNm)	Moment about X axis (kNm)
389.86	-6,86	-2,44	1311.45	-9.33

VI. CONCLUSIONS

This work has considered the CFD-based modelling of the installation of a tidal stream turbine nacelle onto a support structure fixed to the sea bed. The installation and removal of the nacelle may form part of the maintenance cycle, which is a key challenge of tidal stream energy devices as they are by nature located in inaccessible environments. Chartering and operating a suitable vessel for lifting/lowering the nacelle is costly and the operation may only be carried out when sea conditions are favourable.

This work has demonstrated the use of CFD to investigate the loadings on the nacelle during installation for a variety of different conditions. This modelling was informed by real life data for the flow stream velocities which was acquired during the slack period for a neap tide at a location suitable for the deployment of a tidal stream turbine. Whilst the flow stream velocity is minimal during the slack period this is true only for a specific time period before more significant flow stream velocities occur; the site for a tidal stream turbine by nature will be subjected to high flow stream velocities.

The nacelle assembly has a complicated shape particularly due to the hydrodynamic profile of the blades which were modelled as being in position, attached to the nacelle. This leads to a variety of different loadings which can act to cause the nacelle assembly to rotate and translate as it is either lifted or placed by the use of lifting cables. This is particularly important when installing the nacelle as it must be aligned with the support structure on the sea bed.

The case considered uses an arrangement of two cables connected to the nacelle, one which would be attached to the crane and would be the main lifting point and the other attached to another winch on the ship to enable orientation and yawing control of the nacelle assembly.

The intended aim of this process was to better define the range of sea conditions during which maintenance operations could be successfully enacted. This in turn would provide guidance as to the time between tides during which such operations could be attempted. The work described in the paper has shown that it is possible to design a gravity based tidal generator where the turbine/nacelle can be removed from the structure with no guidelines between the mating parts. The orientation of the turbine relative to the flow is also important in order to minimise any deflections or rotational displacement of the turbine.

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