Prediction of the stability of a floating tidal turbine platform under towing conditions

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Abstract— **Floating tidal turbine systems are seen as being preferred to fixed bottom and mid-column systems due to cheaper deployment and maintenance costs. As such, the stability of the floating system under varying flow and surface conditions is as important as the performance of the tidal turbine. The stability of a floating tidal turbine system at various velocities in a tow test was predicted using ProteusDS, and compared against the physical tow test results of the same floating tidal turbine system. The model was calibrated against the static case of the floating tidal turbine system floating in water, and was found to work well with the other cases. The position of the centre of gravity of the platform and the position of the turbine was found to affect the platform stability, with the centre of gravity having a larger influence. The model was also tested under different wave conditions, and an operating envelope was developed. The ability to perform quick and accurate predictions of the stability of the floating tidal turbine system would allow technology developers to optimise the design to fit the site conditions easily, thus saving time and cost.**

Keywords— **Tidal turbine, Floating platform, ProteusDS, Stability**

I. INTRODUCTION

Ocean Energy is having an increased interest in South East Asia (SEA), where most of the population do not have access to a reliable source of electricity. SEA is also made up of many small islands, which might be off the main grid. Electricity cost might be relatively high on these islands due to the need to import oil for their energy generation. As such, ocean energy is seen as one of the possible means of providing affordable electricity to these communities [1, 2].

Due to the less affluent nature of most SEA countries, a low cost and reliable system is desirable in order to accelerate the uptake of ocean energy technologies. As such, floating systems are being regarded more favourably due to the ease of installation of such systems and the lack of expensive foundations [3].

Based on this preference, OceanPixel Pte Ltd aided in the development of such a floating tidal power platform. Besides the generation of power, the stability of a floating tidal power platform is also important in various metocean conditions. As such, it is important to develop a working dynamic model of the floating platform to predict its performance in various conditions. Having a working dynamic model is also useful in predicting how best to improve future iterations of the floating platform.

This paper describes the effort undertaken by OceanPixel to develop such a model and to assess the practicality of using the model in the design and optimisation process.

II. DESCRIPTION OF THE FLOATING TIDAL POWER PLATFORM

The development of the floating tidal power platform was a project led by the Energy Research Institute @ Nanyang Technological University, Singapore (ERI@N), with Envirotek Pte Ltd joining as a collaborator. OceanPixel Pte Ltd provided consultancy and management services for the project [4]. Following the successful development of the floating platform, Envirotek has developed plans to commercialise the floating platform in SEA.

The floating tidal power platform is of a catamaran design and employs the SIT250 made by SCHOTTEL HYDRO, which has a rotor diameter of 4m and a rated power of 67kW. The turbine is mounted on to an A-frame, and the whole structure is lifted into and out of the water using an electrical winch and pulleys. A diesel generator is on board to supply electrical power. Draft markings were painted at the bow and stern of the platform at intervals of 0.1m, allowing the draft of the platform to be read.

A picture of the floating tidal power platform is shown in figure 1, and the planform of the platform is shown in figure 2.

Figure 1 The floating tidal power platform berthed at the shipyard

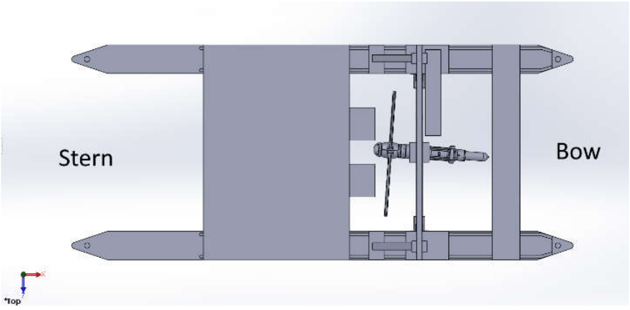

Figure 2 Planform of the floating tidal power platform

Tow tests were carried out as part of the development process to simulate and validate the behaviour of the floating platform under expected operating conditions before deployment.

The development of the dynamic model of the floating platform is based on the results of one such tow test that was carried out prior to deployment of the platform.

III. METHODOLOGY

The dynamics simulation software ProteusDS was used to evaluate the stability of the floating tidal turbine platform. All forces are represented by coefficients, and the final loadings on each object is calculated using the Morison's approach.

With the exception of the hull, the model of the floating platform was built within the software using regular geometric objects. The hull was imported as a custom object that was made in Rhinoceros, a 3D modelling software. The turbine is represented by a disk, to which a drag coefficient equal to the thrust coefficient of the actual turbine is applied. The features above the water line are ignored as the wind speeds were deemed to not be significant in this study.

To simulate towing, one end of the tow line was fixed in space, with the other end of line being fixed to the floating platform. The water was then given a velocity to simulate the towing of the floating platform. This is illustrated in figure 3.

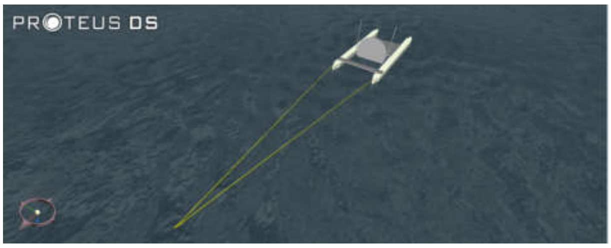

Figure 3 Illustration of the tow setup in ProteusDS

The tow test saw the floating platform being towed with the turbine raised from the bow, and in both directions with the turbine lowered. Draft readings were taken at speeds of 2, 4 and 6 knots, and the trim of the platform calculated. The trim of the platform is defined as the difference in draft at the bow and stern of the platform. A positive trim is defined in this paper as the platform pitching towards the direction of motion.

The two main parameters being calibrated are the longitudinal position of the centre of gravity (CG) and the drag coefficient of the hulls.

The position of the CG was calibrated by comparing the trim of the model platform against the actual platform for the static case, while the drag coefficient of the hull was calibrated against the tow cases.

Due to certain sensitivities regarding the floating platform, results presented will be non-dimensionalised where possible, and a fudge factor will be applied otherwise.

IV. RESULTS AND DISCUSSION

A. Model calibration

Figure 4 shows the comparison of the trim of the model platform against the actual platform at static condition for various CG positions. The position of the CG is measured with respect to the stern of the platform.

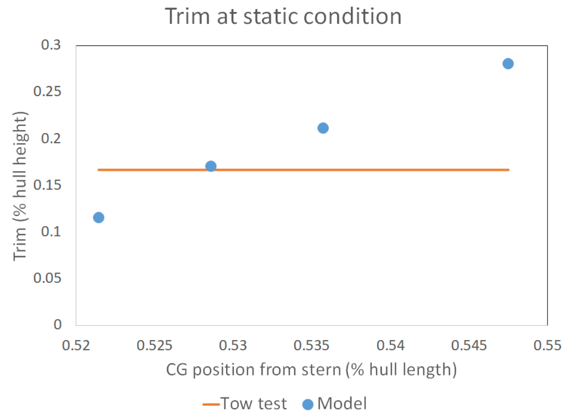

Figure 4 Trim of the model floating platform with various CG positions against tow test results

It is seen that the CG position of approximately 53% of the hull length from the stern produces the best match against the actual platform. This is CG position is closer to the stern than that calculated by the naval architect. Reasons for this could be due to the weight of the diesel in the diesel generator was not taken into account by the naval architect. Another reason could be that the amount of ballast added to the platform was more than what the naval architect provided for. Minor structural modifications were also made after the naval architect's calculations, which likely shifted the position of the CG closer to the stern.

The drag coefficient was next calibrated against the case with the platform being towed with the turbine raised. Figure 5 shows the results of two drag coefficients tested, Cd-1 and Cd-2. Cd-2 is approximately 60% higher than Cd-1.

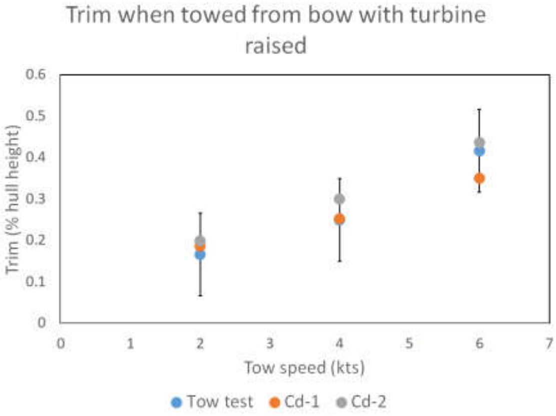

Figure 5 Trim of the model platform compared to tow test results for the case with turbine raised

Both drag coefficients are seen to produce good agreement with the results from the tow test. Cd-1 produced better agreement at tow speeds of 2 and 4 knots, while the Cd-2 produced better agreement at 6 knots.

The two drag coefficients were next tested against the case with the turbine being lowered and towed from both sides. Figures 6 and 7 shows the results for the platform being towed from the bow and stern respectively.

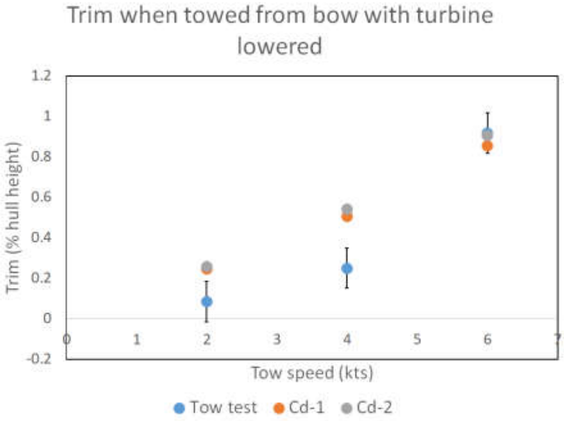

Figure 6 Trim of the model platform compared to tow test results for the case where the platform is towed from the bow with the turbine lowered

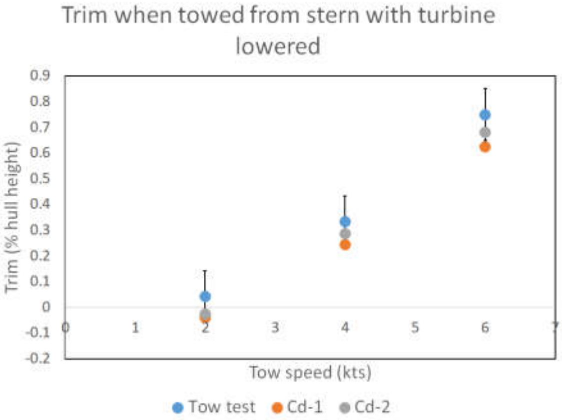

Figure 7 Trim of the model platform compared to tow test results for the case where the platform is towed from the stern with the turbine lowered

Figure 7 showed that the model with Cd-2 had a closer match with the tow test results across all the tow speeds. Cd-2 is also seen to produce a better match with the tow test result at 6 knots in figure 6. It is also seen that the model overestimates the tow test results at 2 and 4 knots. However, given the good agreement between the model and the rest of the tow test results, it is suspected that the overestimation could be the result of human errors in the measurements of the trim during the tow test. Hence, Cd-2 is used in subsequent studies.

Studies performed thus far has been based on the existing floating tidal power platform. Studies presented in the following sections do not involve modifying or further testing of the platform.

B. *Influence of CG and turbine position on stability*

Comparing figure 6 with figure 7, it is seen that the platform is more stable when towed from the stern than from the bow, as evidenced by smaller trim values. This might be acceptable if the flow in one direction is stronger than the other direction. However, it might be advisable to balance out the platform when facing flows which are almost equally strong in both directions.

Figure 8 shows the effect of shifting the position of the CG to stabilise the floating platform, with the study being performed at a flow speed of 6 knots. The additional mass needed to shift the position of the CG is not considered here.

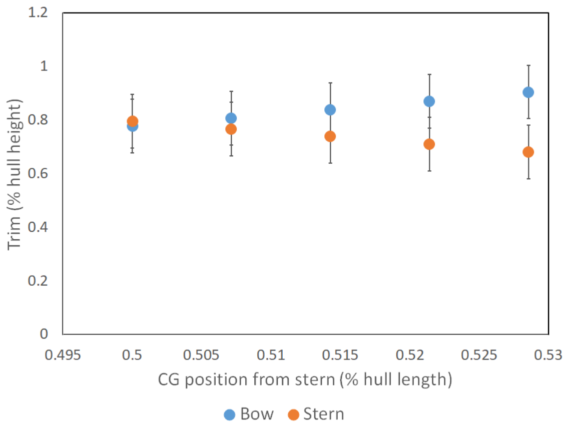

Figure 8 Trim of the floating platform at 6 knots with the CG at various positions

It is seen that the optimal position of the CG is between 50% and 51% of the hull length from the stern for the best stability in currents from both direction. This is noted to be close to the middle of the platform. This is to be expected as the pitching moment arm created by the CG position would be almost equal for flows arriving from both directions. This also indicates that the current longitudinal position of the turbine does not seem to have a huge influence on the stability of the platform.

A study was next performed to determine if the longitudinal position of the turbine would have an effect on the bi-directional stability of the platform. The study was performed at a flow speed of 6 knots, and the position of the CG at 50% hull length from the stern.

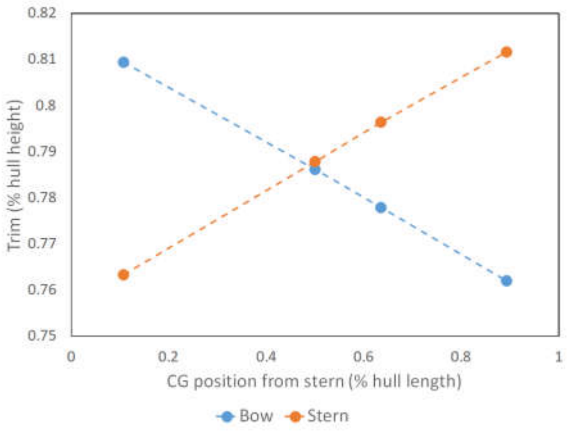

Figure 9 Trim of the floating platform when towed in both directions for different positions of the turbine plane on the floating platform

It is seen that shifting the turbine plane upstream of the of the water flow direction results in a slightly smaller trim compared to when it is furthest from the tow point. This is due to the fact that the turbine plane is ahead of the centre of buoyancy, leading to the vertical component of the turbine's thrust helping to produce some moment to counter that produced by the horizontal component of the turbine's thrust. This is illustrated in figure 10. Placing the turbine plane downstream of the centre of buoyancy would lead to the vertical component of the turbine's thrust adding to the pitching moment created by the horizontal component of the turbine's thrust, as illustrated in figure 11.

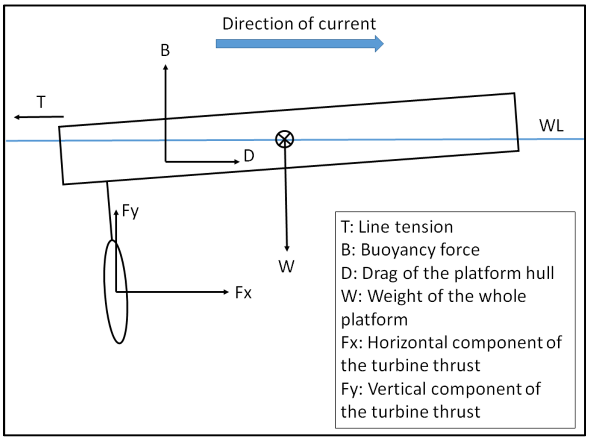

Figure 10 Force diagram of the floating platform with the turbine near the bow

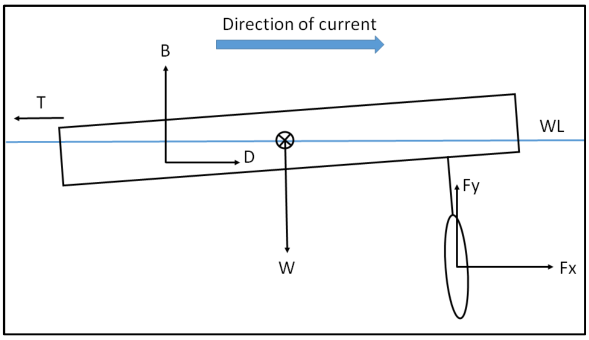

Figure 11 Force diagram of the floating platform with the turbine near the stern

From the above findings, it can be deduced that should a platform be designed for use in a single flow direction, the turbine should be placed further upstream, while the CG be placed further downstream of the platform for the best stability during operations. The turbine and the CG should be placed at the middle of the platform if the platform is designed for use in bi-directional currents.

C. Testing under wave conditions

The model can also be used to determine the maximum allowable wave height and period during towing operations. The model with the turbine raised was tested with 0.25m and 0.5m wave heights and for wave periods of up till 15s for flow speeds of 4 and 6 knots. This corresponds to the annual mean significant wave height and the 99% significant wave height found in Singapore. The model was also tested with waves in the longitudinal and transverse direction with respect to the model. The 2nd order Stokes wave model was used.

The minimum allowable wave period of each wave height was determined with the requirement that significant portions of the hull is not lifted out of the water at any time. The results are shown in tables 1 and 2.

Table 1 Minimum allowable wave period for the various tested wave parameters at a flow speed of 4 knots

4 knots		Wave direction	
		Transverse	Longitudinal
Wave height	0.25m	> 3s	> 3s
	0.5m	> 6s	> 8s

Table 2 Minimum allowable wave period for the various tested wave parameters at a flow speed of 6 knots

6 knots		Wave direction	
		Transverse	Longitudinal
Wave height	0.25m	> 3s	> 3s
	0.5m	> 6s	> 9s

The results show that the minimum allowable wave period is generally shorter in the transverse direction than in the longitudinal direction. This is because the platform is shorter in the transverse direction, leading to a shorter minimum allowable wavelength and hence smaller minimum allowable wave period.

The minimum wave period is marginally shorter with slower flow speeds. The reason is likely because the shallower trim of the platform at lower flow speeds allows for higher additional pitching movements of the platform due to the wave action. The effect is expected to be more pronounced with higher tow speeds and larger wave heights.

Although this study was performed for towed conditions, the availability of a calibrated model would be advantageous in developing an accurate mooring model in the future.

V. CONCLUSION

A series of studies studying the stability of a floating tidal power platform have been performed using ProteusDS. The performance of the model was calibrated against tow test results by varying the CG position and the hull drag of the floating platform. It was found that the model managed to show reasonable agreement with actual tow test results.

It was also noted that the model is effective in the use to assess optimal positioning of equipment on the platform. The model also allowed for more cost-effective way of determining effects of environment on the platform than a tow test.

The results in this study can be used to inform future design iterations for the floating tidal power platform, and to determine safe operational envelopes. The calibrated model can also be used for future studies on mooring systems.

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