CFD-3D ANALYSIS OF WAVE'S EFFECT ON A SUBMERGED FLOAT

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INTRODUCTION

For extracting energy from the sea flow one of the best devices is the horizontal axis tidal turbine (HATT). In the best sites wind-generated waves are strong and can penetrate deep by introducing oscillatory effects on the local flow [1]. For this reason it's necessary to install the turbine at a depth where the influence of the waves is not too strong[2]. For high depths the turbine can be anchored at the sea bottom using a rope, and it's kept in place using a float. In this study, using the commercial code CFD Ansys Fluent and Ansys ICEM, is evaluated the best form of a submerged support float for a marine turbine. Afterwards, the effect produced by the surface waves on the best shape of the float previously identified is analysed. It's assumed that the float is anchored, with two cables on the front end and two cables on the rear end, to the turbine. It has been assumed that the turbine has a yaw system. The float has no mass and is constrained to the turbine, so when the turbine moves, as a result of the yaw, the float also moves following the turbine. For this reason, is considered only the direction of the flow perpendicular to the turbine axis.

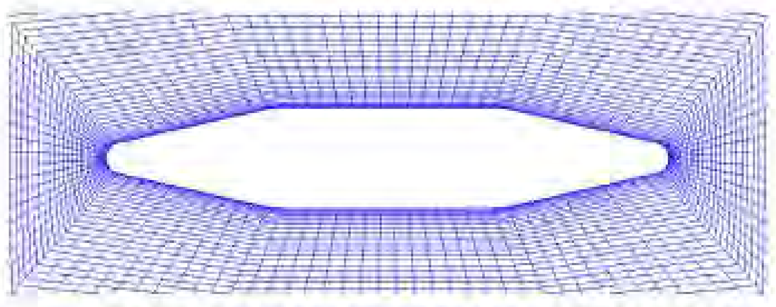
METHOD

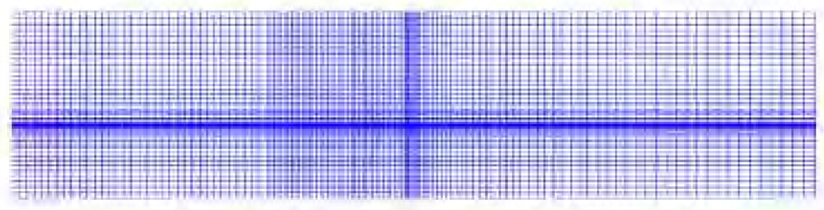
In this study it's supposed to support a 5000 kg turbine with the float, consequently the volume of air that must be contained inside the float is 5 m^3. Four different types have been assumed for the shape of the float: sphere (diameter 2.12 m); torpedo (length 6.7 m, diameter 1 m); modified torpedo (length 6.7 m, max diameter 1.2 m, min diameter 0.36 m); drop (diameter 1.5 m, length 7.625 m). A single-phase simulation has been used to see which shape has a lower drag coefficient.

The three-dimensional computational domain was created using Ansys ICEM software. The computational domain is a parallelepiped of dimensions $42\ m\ x\ 18\ m\ x\ 21\ m$. The center of the float is positioned a 6 m from the bottom and a 6 m from the separation surface between water and air. The geometry of the domain is simple, which is why a multi-block structured mesh consisting of hexahedral cells is used. An O-grid was built around the float area. The grid has been thickened close to the free surface and the float in order to use the turbulence model k-w SST and have more accurate results in these areas of interest.

For the simulation of the two-phase flow, the "Volum of Fluid" (VoF) model is used, implemented in Ansys Fluent, in which air is defined as the primary phase and water represents the secondary phase [3].

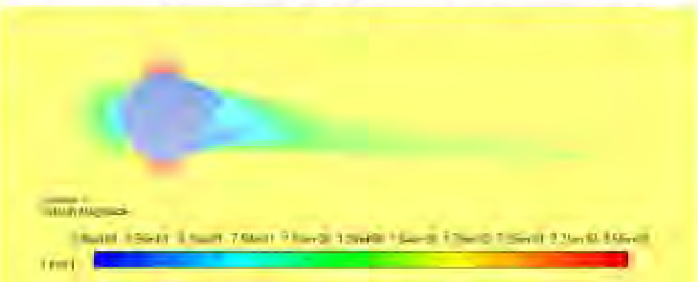
All simulations were performed using water's speed 1.75 m/s. This speed is chosen because the average speed range at sea is $1.75 - 2\ m/s$ [4].

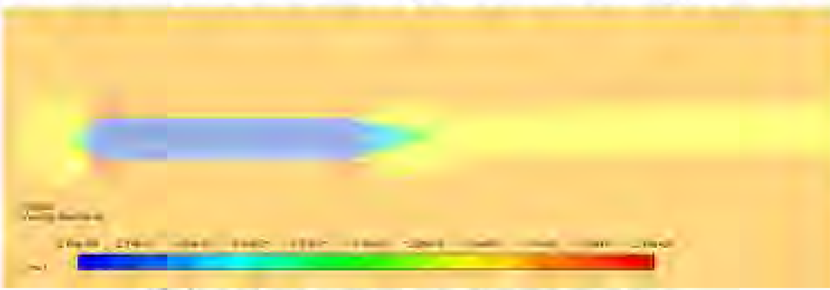

Detail of the surface mesh: modified torpedo


Detail of the surface mesh: free surface

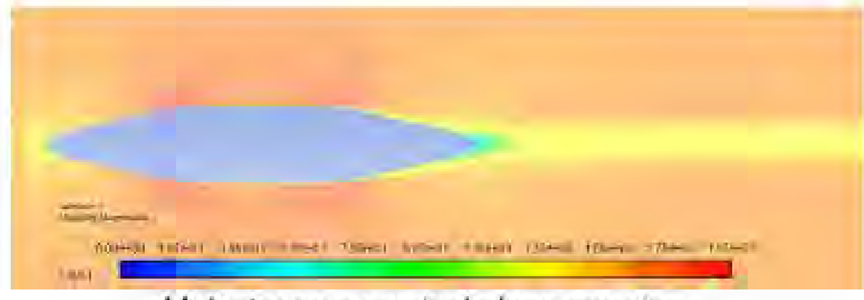
RESULTS

The single-phase simulation showed that the modified torpedo is the shape that minimizes the drag coefficient (Cd=0.0095).

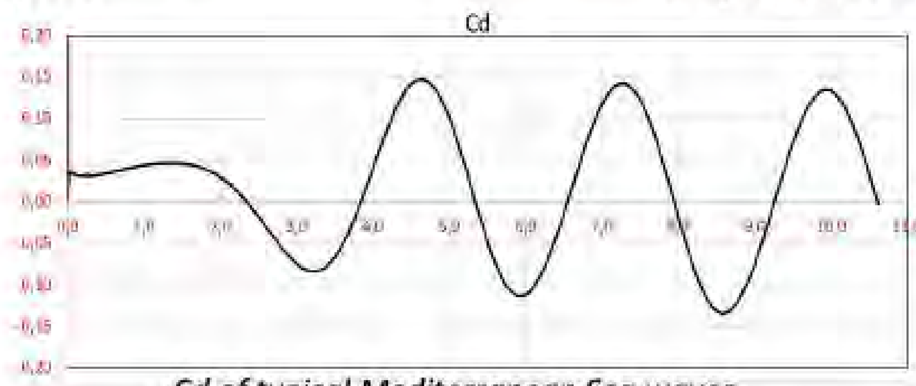

Velocity on a vertical plane crossing the float axis: sphere


Velocity on a vertical plane crossing the float axis: torpedo

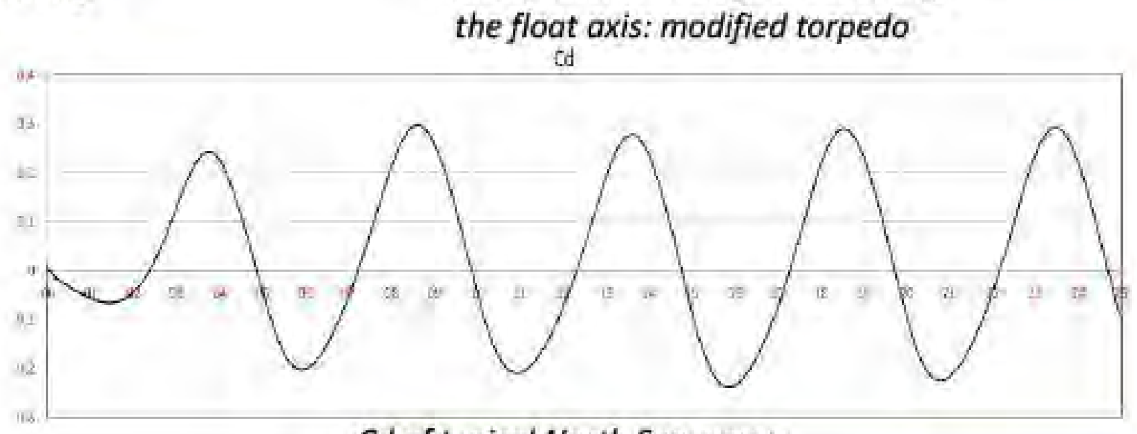

Velocity on a vertical plane crossing the float axis: drop


Velocity on a vertical plane crossing the float axis: modified torpedo

In the two-phase simulation, two different scenarios are considered: typical Mediterranean Sea waves (H=1.5 m; L=20 m), typical North Sea waves (H=2.5 m; L=55m).The trend of the drag coefficients are shown in the side figures.



Cd of typical Mediterranean Sea waves

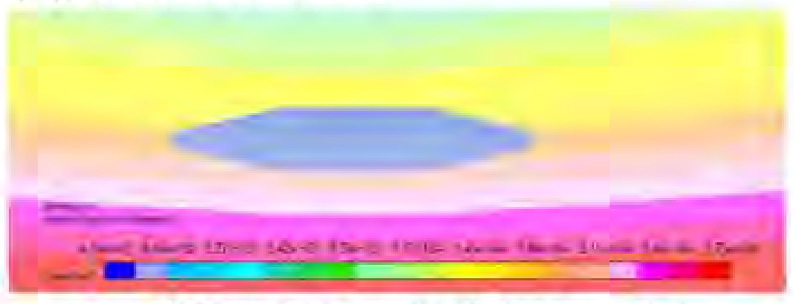


Cd of typical North Sea waves

The resistance coefficient value fluctuates between a positive and negative value. These values are higher than the C_d value obtained in the absence of waves. This suggests that the waves, in addition to causing a periodic trend of the resistance coefficient as a function of the wave period, also cause an increase in the value of the resistance coefficient. The periodic trend of C_d agrees with the results present in the literature [5] [6]. The C_d of North sea fluctuates in a wider range compared to the case of Mediterranean sea waves. This is due to the waves of greater height which induce greater speed variations in the uniform motion field.

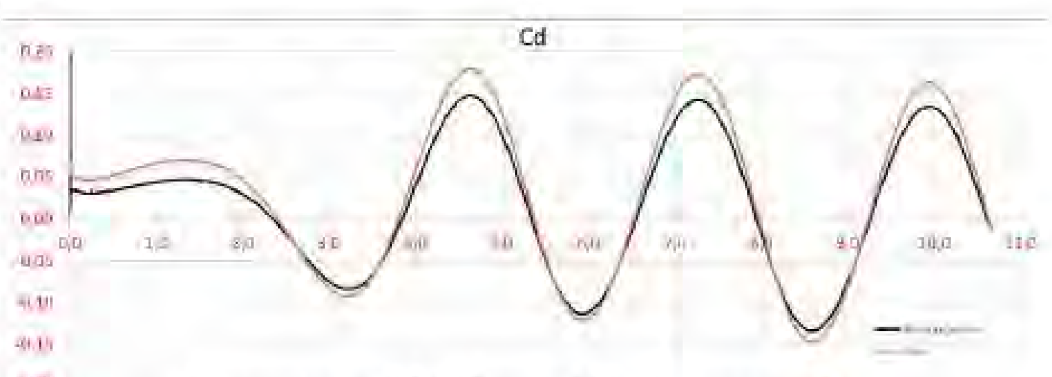
The periodic trend of the drag coefficient can be explained by the interaction between two effects: detachment of a vortex at the trailing edge (phenomenon of Von Kàrmàn vortex shedding), difference of pressure and speed between the leading edge and trailing edge of the float due to waves. When $C_d = 0$ the float is placed completely under a wave trough (or a wave crest); when $C_d > 0$ front part of the float is subjected to a wave crest while the rear part is subjected to a wave trough; when $C_d < 0$ the front part of the float is subjected to the wave trough while the back is subjected to the wave crest. The oscillating trend of the C_d can be explained by analysing the pressure's distribution.

Subsequentially, the same two types of waves are also simulated for torpedo and the results are compared with those of the modified torpedo. The wake in the case of the torpedo is larger than in the case of the pointed torpedo, this means that the friction resistance is greater. In addition, the pressure difference between the front end and the rear end is greater in the case of the torpedo. This implies higher pressure resistance than the case of the modified torpedo.

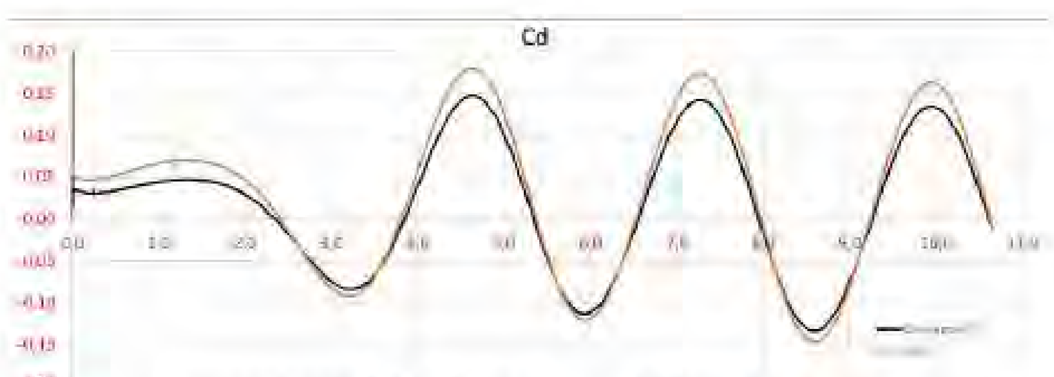

Pressure on a vertical plane crossing the float axis: $C_d = 0$


Pressure on a vertical plane crossing the float axis: $C_d > 0$


Pressure on a vertical plane crossing the float axis: $C_d < 0$



Comparison of Cd of typical Mediterranean Sea: torpedo and modified torpedo



Comparison of Cd of typical North Sea: torpedo and modified torpedo

CONCLUSIONS

From the analysis of the simulations carried out for the modified torpedo-shaped float, it can be stated that the presence of waves involves a worsening of the drag coefficient compared to the case without waves, which is explained by analysing the pressure and speed range. Moreover, it is also observed that the drag coefficient has a periodic trend as a function of the wave period, due to the variation of the pressure distribution as a function of the wave. From the comparison between the simulations carried out for different waves for the modified torpedo, it can be stated that as the height of the waves increases the effects induced by the waves weigh more and more on the float, producing an increase in resistance. Conversely, the increase in wavelength involves an attenuation of the effects caused by the waves on the float. Furthermore, it has been observed that a small modification to a simple geometric shape, such as that of the torpedo, to obtain a more hydrodynamics geometric shape, such as that of the modified torpedo, entails greater benefits on resistance especially in the presence of waves with high height. So in the case of seas characterized by waves with not too high heights, such as the Mediterranean Sea, the shape of the modified torpedo could be a good compromise between economy and resistance.

In these simulations, the RANS equations are used to estimate the resistance acting on the float. Despite this, to have a more complete view of the effects due to waves, especially as regards the vortices, it would be useful to use, instead of the RANS equations, the LES formulation or the DES formulation which can also simulate the vortices related to vortex shedding (it would be enough also use the LES formulation given the lower computational cost it has compared to the DES formulation). This would allow us to more accurately analyse the effects that the vortex shedding phenomenon induces on the drag coefficient trend.

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References:
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