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# The optimization of podded propeller and its azimuthing hydrodynamic performance

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**ABSTRACT**

The pull podded propeller and its azimuthing hydrodynamic performance are investigated with CFD method in this paper. First, the optimizations are got to this pod. It is found that the pressure resistance of strut has accounted to 20% of propeller thrust at high advance coefficient. The modified NACA profile is designed to replace the original ellipse cross-section of strut and the final podded thrust efficiency is about 55% which increased by 5 percentage points. Then the podded azimuthing hydrodynamic performance is simulated by unsteady CFD method. The hydrodynamics performances of pod cell from zero to 360 degree azimuthing angle per 10 degree are discussed. The optimization podded propeller experiments is carried out in the tunnel. The simulations show good agreement with test results. The pod cell open water simulation accuracy is about 3% and azimuthing hydrodynamic performance simulation accuracy at large azimuthing angle is about 7%. The results in this paper will support the full podded propeller design and especially the CFD method provide a credible way to evaluated the pod cell performance.

**Keywords**

Podded propeller, CFD, Optimization, Azimuthing hydrodynamic performance,

## 1 INTRODUCTION

The podded propeller is a most important kind of marine thruster. With the growing power of the electrical motor while getting smaller geometry scale, more and larger tonnage merchant ships chose podded propeller. There are many advantages of podded propeller compare with normal propeller, such as superior maneuverability, convenient arrangement and so on. Therefore more and more attentions were focused on podded propeller.

Hassan et al (2014) used a potential method to predict the hydrodynamics performance of the athimuthing podded drive systems. The computational method could calculate the thrust and torque quickly to examine the performance of thruster in design process. Reza et al (2014) used viscous method to simulate the flow field around the puller podded. The RANS solver with sliding mesh is applied to study the interaction between the propeller, the pod, and the strut in the case of straight condition. He also uses this method to simulate the performance of podded drive in azimuthing conditions, but the yaw angles of the podded drives are only set to vary from -30° to +30° with 5° increment. Maciei et al (2007) test the manoeuvring forces on zaimuthing podded propulsor model in the cavitation tunnel. The hydrodynamics performances of the podded propulsor are measured in the range of deflection angles from -45° to +45°. Pengfei Liu et al (2009) simulated the unsteady hydromechanics of a steering podded propeller unit. The unsteady forces, torques and bending moments of pod in off-design conditions are predicted and compared with test results, which show good agreement. Sakir et al(2009) combines the boundary element method （BEM） and vortex lattice method (VLM) to analyses the performance of podded propeller. The original numerical method is improved by using axial and tangential induced velocities on the propeller disc plane as well.

In this study, the optimization of the strut profile of podded propeller is applied and the performance characteristics in azimuthing conditions with the range of azimuth angles from 0° to 360° are analysed. The predictions are compared with the time averaged experimental data. The simulations provide some useful data for podded thruster design.

## 2 METHOD

### 2.1 Model

The podded propeller has three parts such as propeller, pod packs and pillar, which are shown in figure 1, the diameter of pod hub is 1040mm, length is 4700mm, strut height (distance to propeller rotation axis) is 1950mm. The strut section is a elliptic with long axis 1780mm and short axis 500mm. The strut top is the pod installation disk, the diameter of which is 1780mm. The propeller has

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4 blades, diameter of which is 2200mm，average pitch ratio is 1.025, and model scale ratio is 1:10.

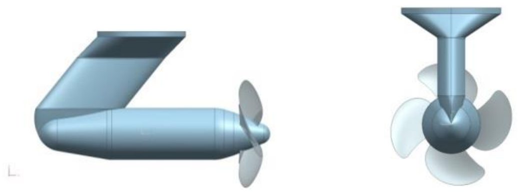

**Figure 1 The original podded model**

## 2.2 Numerical Method

The computational domain is a column with diameter 20D (D is the propeller diameter) and length 50D, the distance from entrance to pod is 20D, as shown in Figure 2. Because of complicated geometry of POD surface, hybrid mesh type has been chosen to generate the mesh of pod model by using ICEM commercial software. The 'O' and 'H' mesh topology type is used in radial and axial direction respectively, as shown in Figure 2. The tetrahedral mesh is used in the flow region around POD by Octree grid generation method. This smaller region is a column with diameter 2.5D and length 3D. In order to simulate the pod surface flow better and meet $y^+$ value on the surface wall required by the turbulence model. The boundary layer grid with 5 layers is generated on pod surface, as shown in Figure 2, and final $y^+$ is about 30.

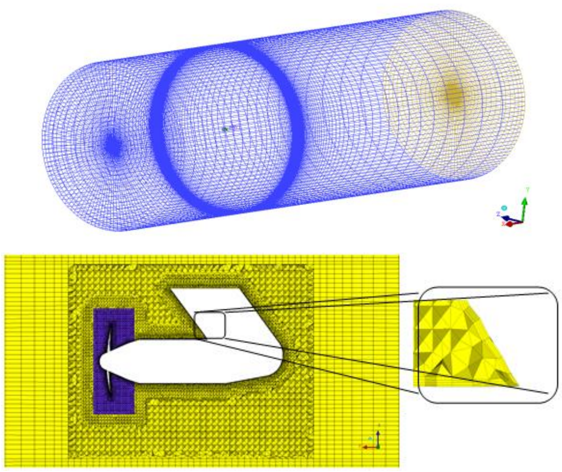

**Figure 2 Calculation region and mesh**

The governing equations used in this paper are RANS equation as follows:

$$\frac{\partial u_i}{\partial x_i} = 0 \quad (1)$$

$$\rho \frac{\partial u_i}{\partial t} + \rho u_j \frac{\partial u_i}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\mu \frac{\partial u_i}{\partial x_j} - \rho \overline{u_i' u_j'}\right) \quad (2)$$

Where: $u_i$ is the average velocity ($u_1 = u, u_2 = v, u_3 = w$), $\rho$ is the fluid density, $p$ is average pressure, $\mu$ is the fluid viscosity coefficient, $-\rho\overline{u_i' u_j'}$ is the stress for Reynolds. (1) and （2） is the so-called Reynolds averaged Navier-Stokes equation (RANS). The SST $k-\omega$ turbulent model is used in this report, which is suitable for the propeller rotating component after a lot of studies.

## 3 RESULTS

The 0 degree azimuthing angle of pod is defined as the bow direction, which is also the X axis direction. The intersection of the pod rotating shaft and propeller rotation axis is the origin point of coordinates. The definition of positive angle is the POD turning to starboard and negative angle as reverse, as shown in figure 3. Z axis is vertical downward, and goes through the pod rotation center.

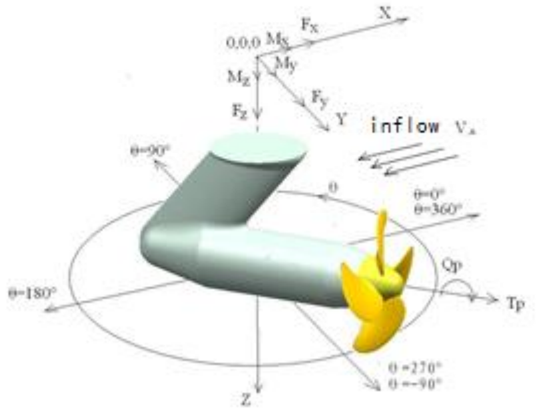


**Figure 3 Schematic diagram of coordinate system**

The dimensionless coefficient of propeller thrust and torque is defined, as well as the pod thrust, efficiency and other parameters. Each coefficient is defined as follows:

$$K_T = \frac{T}{\rho n^2 D^4} \quad (3)$$

$$K_Q = \frac{Q}{\rho n^2 D^5} \quad (4)$$

$$\eta = \frac{J}{2\pi}\frac{K_T}{K_Q} \quad (5)$$

Where: $T$ is the force of propeller or the pod department (N); $Q$ is the propeller torque (N • m); $\rho$ is the water density 998.2kg/m3, $n$ is the rotation speed (r/s); $D$ is propeller diameter (m);$J$ is the advance coefficient; $K_T$ is the thrust coefficient; $K_Q$ is the propeller torque coefficient; $\eta$ is the efficiency of podded propeller.

### 3.1 Hydrodynamic Performance of the Original Podded

Figure 4 is the hydrodynamic performance of podded thruster. With the increase of the advance coefficient, the torque and thrust coefficient of the podded decreases, and the efficiency increases, and the maximum efficiency is about 50.6% at $J$=0.75, which does not meet the design requirements that the efficiency must be higher than 55%.

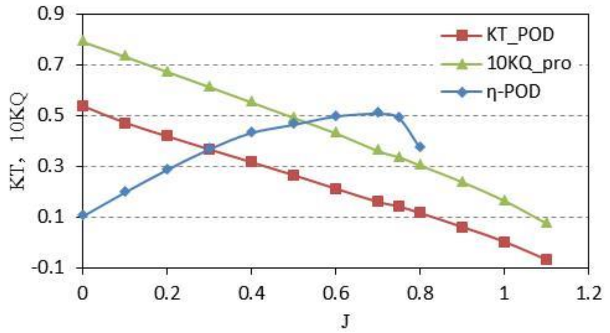


**Figure 4 The performance of the original podded thruster**

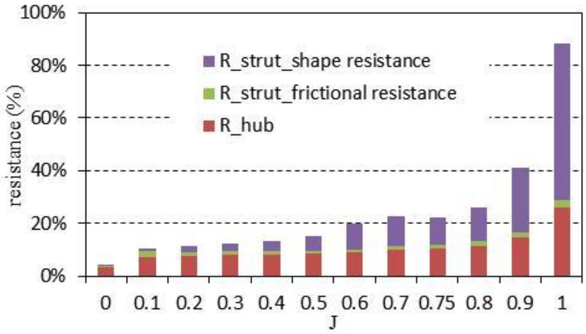


**Figure 5 The pod hub and strut resistance accounted for the propeller thrust**

Figure 5 is the pod hub and strut resistance accounted for the propeller thrust. When J=0.75, the resistance of pod hub and strut is about 20% of propeller thrust. Because of the size constraints of electric motor, it is hard to change the hub geometry. So the optimization of strut should be done, and the profile of strut could be changed, because of its high shape resistance. With the increasing of advance coefficient, the shape resistance of strut increases more.

### 3.2 Optimization Results

The original profile of strut is an ellipse with poor streamline, which resulting higher shape resistance. A new strut profile is designed based on NACA0024 hydrofoil with length and thickness modified, and final foil section is 170mm long, the maximum thickness is 40mm. This plane is optimization model 1. The model 2 has changed the shape of mounting plate on the top of strut based on model 1 as shown in figure 6. We reduce the meeting flow cross-sectional area of the mounting plate to reduce its resistance.

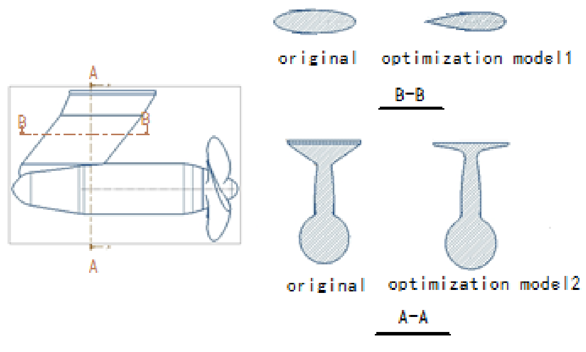


**Figure 6 Cross-section of strut of optimization model 1 and cross-section of the mounting plate of optimization model 2**

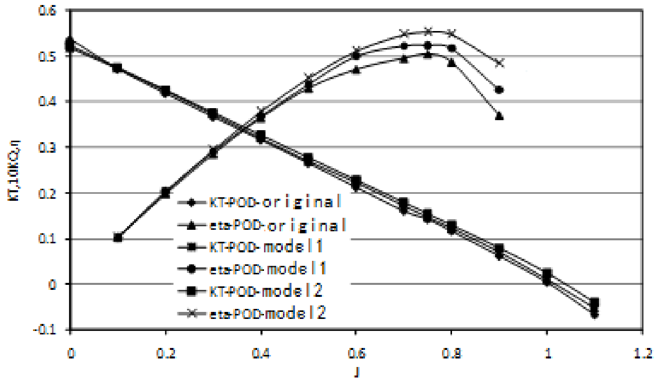


**Figure 7 Hydrodynamic performance of optimization model**

The hydrodynamic performances of optimization model compared with original are shown in figure 7. It can be seen that after optimization the pod efficiency is improved. At advance coefficient *J*= 0.75, the efficiency is improved to 52.3% of model 1 and 55.4% of model 2, which is about 5 points higher than the original model. The final model 2 is tested in the tunnel and the simulations, which makes good agreement with the test results as shown in figure 8.

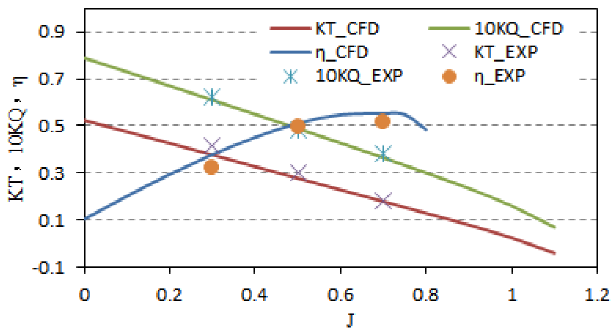


**Figure 8 Calculations compared with experiments of optimization model**

### 3.3 Results of Azimuthing Conditions

The hydrodynamics forces of the podded propeller are simulated under the azimuthing conditions every 10 degrees by using unsteady sliding mesh method. The calculating time history is about five propeller rotation circles and last circle results are chosen to calculate the average forces and moments of the podded propeller. The advance coefficient is *J*=0.73.

Figure 8 is the $K_{TX}$ of podded propeller. The coefficient $K_{TX}$ decreases over zero thrust point and then the podded propeller generates resistance increased with azimuthing angles. The $K_{TX}$ line is symmetry with maximum force at about 130°or 250°. Figure 9 is the side force of podded propeller with the azimuthing angle range from 0° to 360°. The line shows an ant symmetry character. The $K_{TY}$ is about zero at straight condition, then the $K_{TY}$ amplitude increases until at about 90°, at this time, the strut is perpendicular to the flow direction.

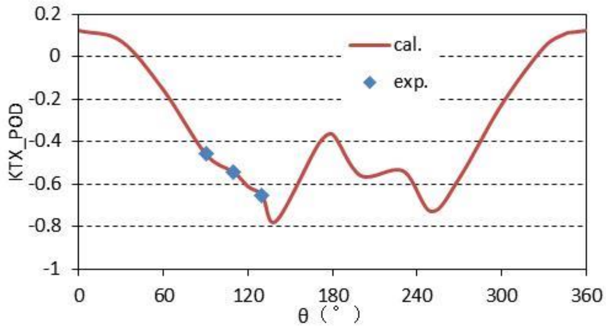


**Figure 8 The pod unit thrust coefficient of different azimuthing angles (X direction)**

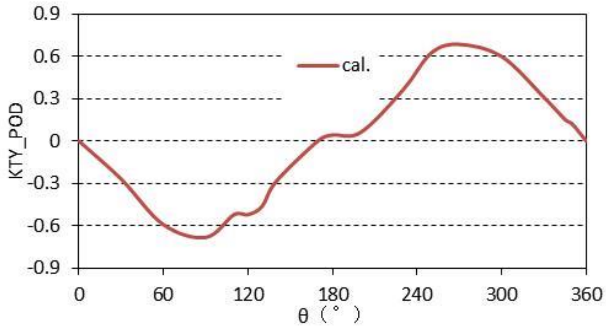


**Figure 9 The pod unit thrust coefficient of different azimuthing angles (Y direction)**

Figure 10 shows the pod rotation moment with the azimuthing angle. The torque coefficient has maximum value at the azimuthing angle of 90 degrees and 270 degrees. The character of moment curve is similar to $K_{TY}$ curve. When the azimuthing angle goes beyond 180°, the incoming flow acts on other side of the pod and the force on pod will change its direction in the coordinate system fixed on podded propeller.

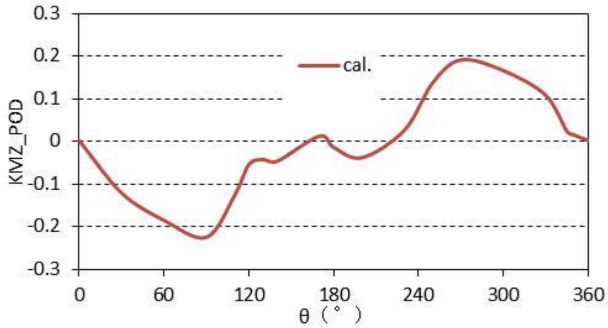


**Figure 10 the torque coefficient of turning podded propeller**

## 4 CONCLUSION

The CFD method is used to simulate the hydrodynamic performance of podded propeller in this paper. We optimize the strut of podded propulsor and increase the efficiency up to design target. The advance coefficient of working is *J*=0.73, which is carried out to analyse the hydrodynamic performance of podded propeller at azimuthing conditions. The pod unit thrust coefficient, side force coefficient and rotary torque the parameters of the pod are analysed. We get the following conclusions:

1) The hydrodynamic coefficients of each part of the pod are analysed by CFD method, and it is found that the pod strut pressure resistance accounted for a larger proportion, so the strut profile is optimized and the final optimization model efficiency increases about 5 percentage points. The open water hydrodynamic performances are test and the simulations are verified.

2) The thrust and torque coefficient of podded propulsor of different azimuthing angles are analysed, and the thrust coefficient in X direction are compared with experiments at large azimuthing angle, which shows good agreement.

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## DISCUSSION

### Question from Hannu Jukola

Were the CFD calculations made in model or full scale?

### Author's closure

The CFD calculations were made in model scale. We plane to calculate the full scale and find the scale effect of hydrodynamic in the further works.