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Study on Hydrodynamic Performance of Podded Propulsor at Steering Conditions

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ABSTRACT

The hydrodynamic performance prediction of a podded propulsor at steering conditions has been presented. Firstly, a numerical simulation method for podded propulsor with steering angle has been established, and the calculations were carried out with the steering angles range from port 30° to starboard 30°. Simultaneously, a experimental setup was designed for the study of podded propulsor characteristic at different steering angle conditions, and the test was performed in towing tank. The comparison was made between numerical simulation results and measurement data, the thrust, torque and transverse force agreed well with each other. Further more, some performance characteristic of podded propulsor at steering conditions are presented, and some flow details from numerical simulation are introduced.

Keywords

podded propulsor, steering condition, CFD, test, transverse force

1 INTRODUCTION

In the last two decades, the podded propulsor has been widely used in marine market, Podded propulsors are rapidly becoming more and more attractive as main propulsive unit for a wide class of vessels, including navy and commercial ships. One significant characteristic of podded propulsor is the combined propulsion function and steering function together, and replaces the conventional propeller added rudder configuration. Except the characteristic of propelling, the performance of podded propusor at steering conditions is very important when they are applied for course keeping and other manoeuvring operation. Additionally the podded loading at different steering conditions is very important for structure fatigue analyse and bearing design.

In this field many work have been carried out. The earliest experimental study focused on the hydrodynamic performance of podded propulsor with static azimuth angles is about in 2001(Szantyr 2001). In their work, the axial and transverse force were measured and the azimuth angle range was from -15° to 15°, but the effect of azimuth angle on propeller torque was not analysed. Friesch(2004) conducted cavitation test on a puller podded propulsor with static azimuth angles between ±6°. He found that the cavitation behavior changed significantly under steering conditions, and the effect of steering angle on the pressure fluctuations was remarkable. At some degrees of azimuth angles, the drop pressure at the suction side of strut might cause erosive cavitation. It was also found the performance was sensitive to the direction of propeller rotation. Heinke(2004) made systemic experimental research on podded driver in pull and push configuration under different static steering angles conditions, he found that the effects of steering angle on the characteristics of podded drives in pull- or push-mode were different. The trends of longitudinal force and transverse force of pull or push podded were very complex with the changing azimuth angles. The steering moment coefficients of pushing podded were distinctly lower than pulling one . Another experimental research also focused on the hydrodynamic performance of podded for a range of advance coefficient combined with the range of steering angles from 30 to -30 degrees(Grygorowicz M., et al,2004) , they found that the thrusts of both pull and push podded were strongly dependent on the steering angles, and the dependences were quite different for pulling and pushing version. They noted that the propeller loading and external flow velocity played an important role on transverse force, and the zero transverse force was not corresponded to zero steering angle, and about 5 degrees steering angle was required to produce zero transverse force. Pustoshny and Kaprantsev (2001) observed the cavitation of the twin puller podded for a cruise vessel at various steering conditions. They noted that the cavitation increased in severity with changing of steering angles. Wang et al.(2003) analysed experimentally the cavitation of the puller type podded propulsor for a supply vessel. They studied the effect of static azimuth angles between ±30° on the propeller loading and cavitation behavior, the cavitation intensity and pattern were changed significantly with the increasing azimuth angle, the cavitation patterns and intensities at port and starboard were different. The deformed trajectory of propeller tip vortices at extreme azimuth angle has also been found. The comprehensive cavitation tunnel test for cavitation patterns observation, and fluctuation pressures measuring, and propeller noise measuring at static pod azimuth angles were conducted(Johannsen and Koop 2006). The effect of steering angle on pressure fluctuation was obvious, and the trends of pressure magnitude and distribution were different depending upon the direction of the steering. The study on influence of dynamic azimuth condition was conducted(Heinke 2004, Stettler 2004, Islam et al. 2007a, 2007b) . The comparison was done for propeller force and moment at different steering angles for static and dynamic azimuth ranges, it is showed that the load values measured under static azimuth angle were very close to mean values measured under dynamic azimuth conditions.

This paper aims to enhance the understanding of the podded propulsor performance at steering conditions. The performance predictions of podded propulsor at static steering angles based on model test and CFD simulation are presented. The results from test and numerical simulation are introduced and compired. The brief descriptions of CFD computation and model test are also introduced.

2 Podded Propulsor Model

The object podded model applied for this research was a pulling-type podded propulsor, with 5 blades, hub, hub cap, strut, pod housing, tail fin and right-handed propeller. Figure 1 shows the sketch of the podded propulsor. Table 1 gives the main parameters of the podded propulsor.

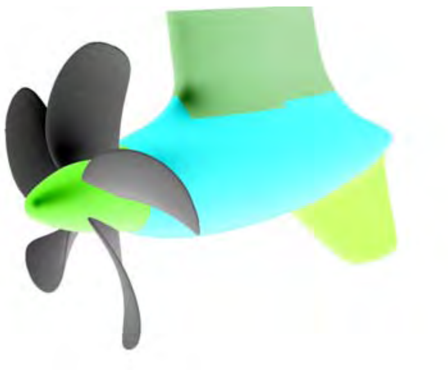

Figure 1. Sketch of the podded propulsor

Table 1 Main Parameters of Podded Propulsor (Model Scale)

	Symbol	Unit	Data
Number of blades	N	[-]	5
Diameter	D	[m]	0.200
Mean pitch ratio	$Pmean/D$	[-]	1.0412
Area ratio	A_E/A_O	[-]	0.614
Skew angle	θ_S	[°]	22.09
Hub diameter ratio	dh/D	[-]	0.24
Length of pod housing	Lp	[m]	0.2759
Diameter of pod housing	dp	[m]	0.0867

The definition of the forces and moments and co-ordinates are given in Figure 2. The azimuth angle turning to port side refers negative steering angle. The positive X-axis is the forward direction of towing carriage.

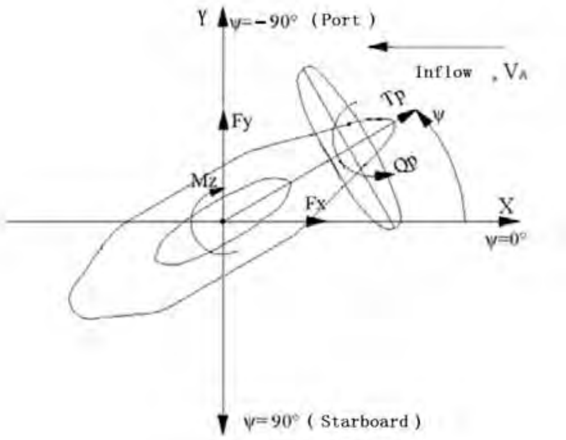

Figure 2. Definitions of forces, moments and co-ordinates of pulling podded propulsor

In the present paper, the unit force, transverse force and moments are non-dimensional by traditional way, and the defined performance coefficients are listed in Table2.

Table 2 List of coefficients for Podded Propulsor

Advance coefficient	$J = V_A / nD$
Propeller thrust coefficient	$K_{TP}= T_P / \rho n^2 D^4$
Propeller torque coefficient	$K_Q=Q / \rho n^2 D^5$
Unit thrust coefficient	$K_{TX} (K_{TUint}) = F_X / \rho n^2 D^4$
Unit efficiency	$\eta_{Unit} = J K_{TUint} /(2\pi Kq)$
Transverse force coefficient	$K_{FY} = F_Y / \rho n^2 D^4$
Steering moment coefficient	$K_{MZ} = M_Z / \rho n^2 D^5$

Note: V_A and unit thrust F_X in the direction of carriage motion.

3 CFD Simulation

The commercial CFD software Fluent was used to solve RANS in the flow field around the podded propulsor at static steering angle, and the grid generating was done by Gambit.

3.1 Computational Domain and Grid Generation

The coordinate system origin locates at the point where the propeller reference line intersected with the rotation axis of propeller. The x-axis is pointing towards bow, y-axis towards port side, and z-axis upward. Computational domain was defined with dimensions -2.5Lp<x<1.5Lp in x-axis direction, -2.5Lp<y<2.5Lp in lateral direction and -1.5Lp<z<1.8D in vertical direction. The dimension range of this computational domain and other numerical parameters used in this case were decided based on the experience from some other series study in this area(Xingrong, Shen, et al 2009). The steering angles were changed by varying the components of inflow.

The moving mesh was applied to simulate the rotating effect of the actual geometric propeller. To obtain the accurate flowing field solution and stable convergence, a good mesh quality is required and unsteady time-step iterations are performed. The rotating part of the mesh is in a cylindrical block, just big as entirely enclosing the propeller blades. Sliding surface was set between the rotating part and the fixed part. Based on the early study on sensitivity of mesh size, the strategy of mesh generation is decided. The cell number of rotating part is about 0.7 million, and the number of fixed part is about 1.0 million. So the total cell number is about 1.7 million. The grid of rotating part and fixed part are shown in Figure 3.

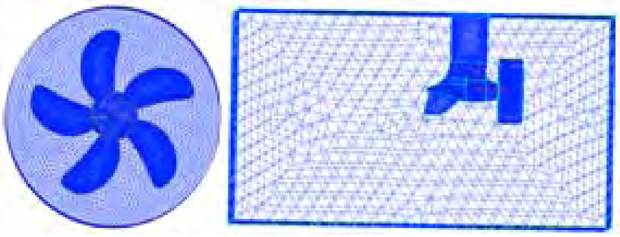

Figure 3. Grid of the computing domain(Left is rotating part, Right is fixed part)

3.2 Solve Strategy

A 3D unsteady time-step iterations, pressure based and segregated implicit solver were applied. The viscous solvers are very sensitive to turbulence model and discretization scheme. In this work, the realizable k- ε turbulence model was used; PISO algorithm was selected for pressure-velocity coupling and PRESTO was used as pressure discretization scheme; second-order upwind was used for the discretization scheme of momentum, turbulence kinetic energy and turbulence dissipation rate. In this case, the result shows that the convergence, reliability and stability of this solve strategy are quite satisfactory.

3.3 Results

Unsteady flow simulation of podded propulsor was carried out for a range of advance coefficients combined with the steering angles between -30° and 30° with 2.5° and 5° and 10° increments. The variation in podded performance with change of steering angles and advance speed was analysed, the results of forces and moments were presented as changes with advance coefficients and steering angles, and some details of flow around steering podded were postprocessing.

3.3.1 Performance at Steering Conditions

The calculated podded propulsor unit efficiency curves are show in Figure 4. In this figure the curves are showed as isoline of advance coefficient with the varying of steering angles(legend J06 means J=0.6). The varying of unit efficiency depends strongly on the propeller loading conditions. On the heavy loading condition, the unit efficiency is almost not changed with the steering angle varying, while on the light loading conditions, the efficiency changes strongly with the steering angle varying. Figure 5 shows the results comparison of transverse force coefficient at different steering angle. It can be seen that the zero transverse force does not correspond to zero degree steering angle. The characteristic curves are not symmetry to the corresponding angles for port and starboard. The asymmetrical characters are also found at steering moment curves in figure 6. The steering moments are close to zero at zero degree steering angle.

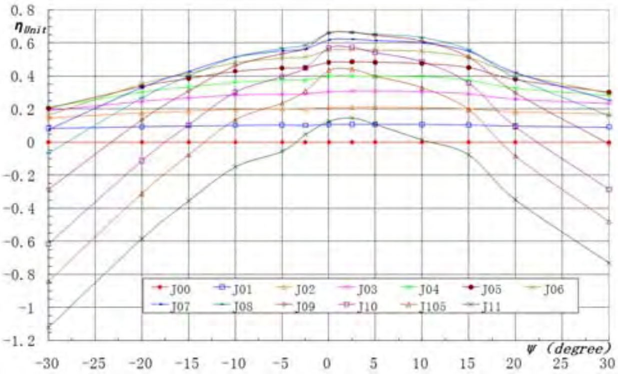

Figure 4. Unit Efficiency of Podded Propulsor from CFD at Different Steering angles

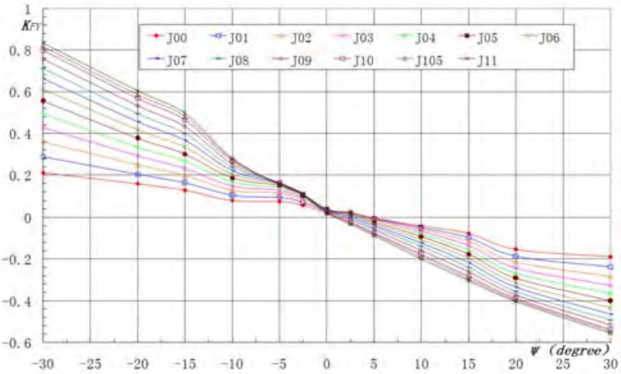

Figure 5. Transverse Force Coefficient of Podded Propulsor from CFD at Different Steering angles

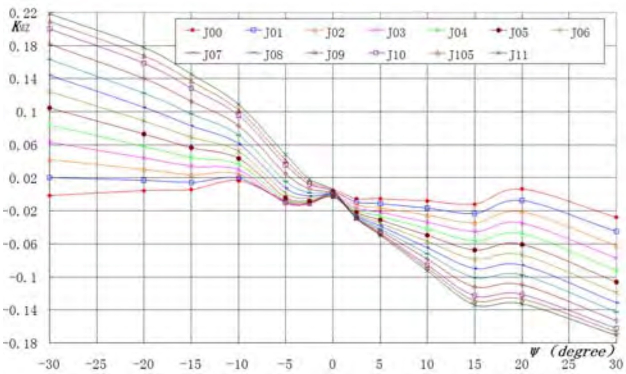

Figure 6. Steering Moment Coefficient of Podded Propulsor from CFD at Different Steering angles

3.3.2 Flow Field around Podded Propulsor

Podded propulsor hydrodynamic performance at steering conditions is largely characterized by the interaction between the rotating propeller and fixed components(pod housing, strut, fin). The forces acting on the fixed components play an important role on the total force, especially for transverse force and steering moment. The transverse forces acting on strut and fin are the dominant role in the total transverse force, as shown in figure 7. Meanwhile the longitudinal force (thrust) is dominated by the propeller generating thrust, and the forces acting on the fixed components are relatively small. The distribution information on different components is very useful to podded propulsor design and optimization.

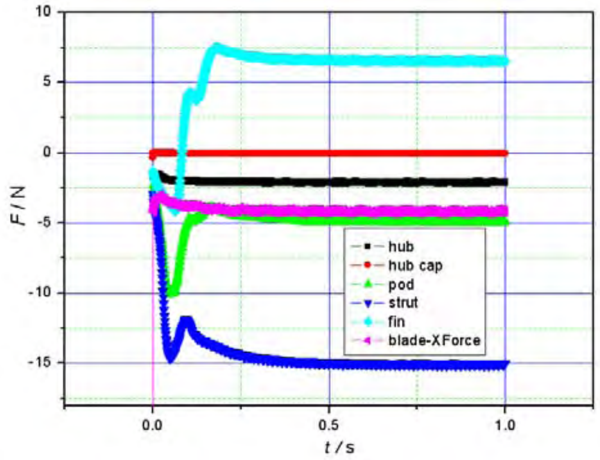

Figure 7. Transverse Force Acting on The Components from CFD at Starboard 5 Degree (J=0.7)

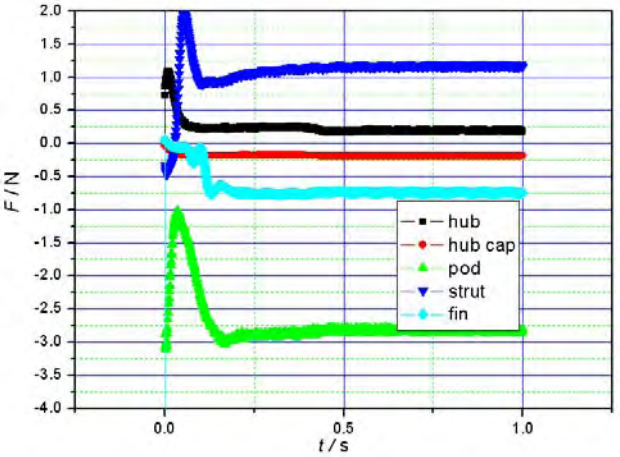

Figure 8. Longitudinal Force Acting on The Components from CFD at Starboard 5 Degree (J=0.7)

Figure 9 shows the pressure distribution on every component of podded propulsor at port 30 degrees in advance coefficient J=0.7. The steering conditions have significant effects on the flow field around the podded propulsor. The propeller working conditions and the inflow attack angle of strut and fin are changed significantly comparing with zero degree steering conditions. The podded pressure distributions at steering conditions are very different from that at zero steering angle. The streamlines around the podded propulsor at port 30 degrees are presented in figure 10. It is apparent that the flow separation occurs at the strut port side. The trailing vortex may be found at the end of the podded housing and strut and fin. The trailing vortex manners are different from that at zero steering angle condition. The trailing vortex only appears at the end of podded housing at zero azimuthing angle.

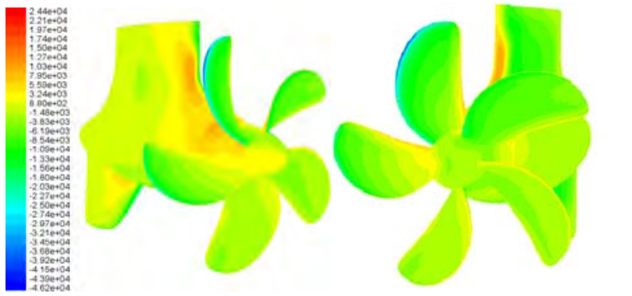

Figure 9. Pressure Distribution on the Podded Propulsor (Left: starboard view;Right: port view . J=0.7)

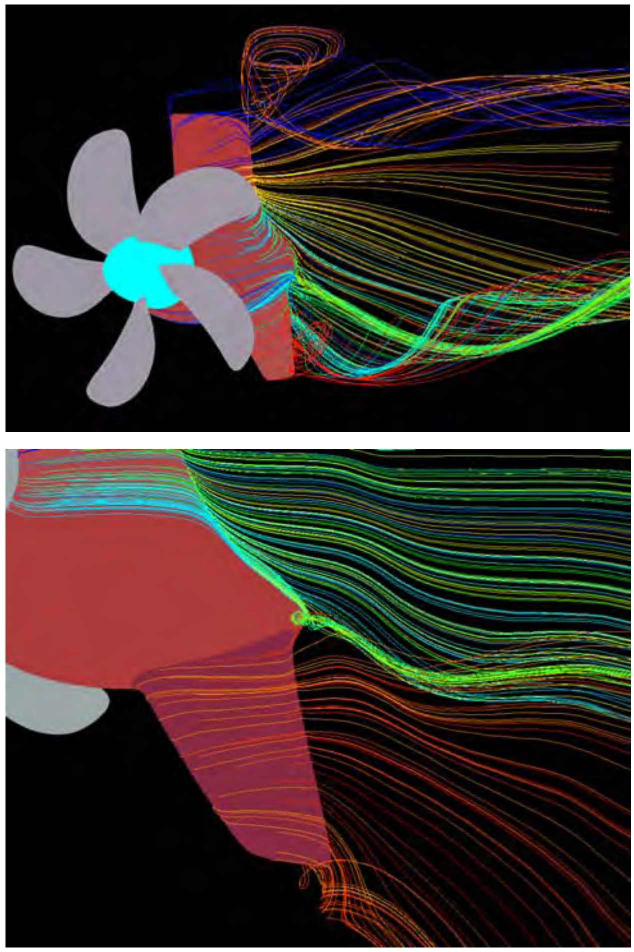

Figure 10. Streamlines on the Surface of podded propulsor (J=0.7)

4 Experimental Study

4.1 Test Device and Experimental Approach

Differing from conventional propeller test, besides propeller thrust and moment measuring, it is necessary to measure the unit forces and moments for podded propulsor. A new developed test devices including a propeller dynamometer and a three components balance were used in this research, and several test setups for experiment on podded at steering conditions were designed(ITTC2002,2005,2008). The dynamometer wrapped in podded housing was used to measure propeller thrust and moment, and the three components balance located between free motion part and fixed part was applied for longitudinal force, transverse force and steering moment measurement. The test devices were designed in accordance with ITTC recommended procedure, and the sketch of experimental device is shown in Figure 11.

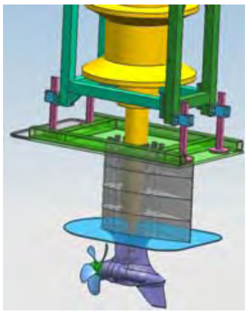

Figure 11. Sketch of experimental device for podded propulsor

The distance between propeller shaft and water surface was 1.8D in test, the whole podded unit can be turned to any azimuth angles, and the dynamometer for propeller thrust and moment measurement was located inside the podded housing, the three components balance was fixed on the top support plate of the carriage. The test was carried out in towing tank, and the object podded propulsor was tested at constant numbers of revolutions in the advance coefficient range J=0 to J=1.1 at 13 different static steering angles between -30° and 30° . This test device and experimental approach applying in open water test were validated (Shen. et al. 2011) .

4.2 Test Results

The variations in hydrodynamics performance of podded propulsor with the change of advance coefficient and steering angle are presented in figure 12~15.

Figure 12 shows that the unit thrust coefficient decreases with the increase of advance coefficient. When the steering angles increase in both directions (port or starboard), the unit thrust coefficients are decreasing. The decreasing amplitude of K_{tunit} for steering to port is bigger than that to starboard, and this reveals that the turning direction of propeller plays an important role on podded propulsor performance.

The change of propeller torque coefficient with advance coefficient and steering angle is shown in figure 13. It can see that the trend of torque coefficient with the steering angle changing is different from that of unit thrust coefficient. The torque coefficient increases with the increase of steering angle. The magnitude and the trend of torque coefficient are approximately same for the two opposite angle (e.g. ±20°) at all advance coefficient range.

The comparison of unit open water efficiency at different steering conditions is illustrated in figure 14. The lowest unit efficiency is occurred at port 30° , the efficiency at starboard 2.5° is nearly the highest value for whole research advance coefficient. The efficiency at starboard 2.5° is close to that at straight open water condition. The unit efficiency decreases with the increase of steering angle, but there are some different characters between steering to port and starboard.

Figure 15 shows the characteristic curves of transverse force coefficient versus the steering angle and advance coefficient. The transverse forces in the range of steering angle from 0° to starboard 5° are close to zero. The steering angles corresponding to zero transverse force are varying with the propeller loading change.

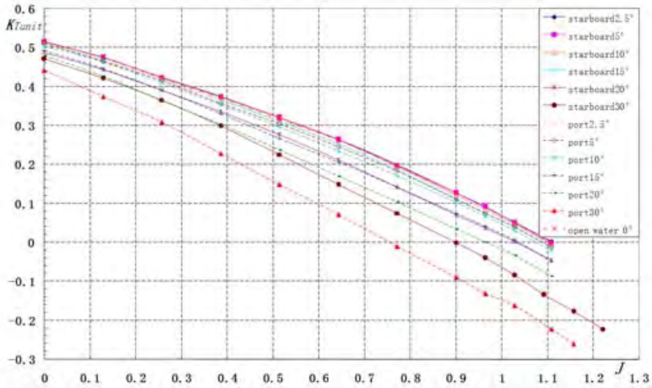

Figure 12 . Unit Thrust Coefficient of Podded Propulsor at Different Steering angles

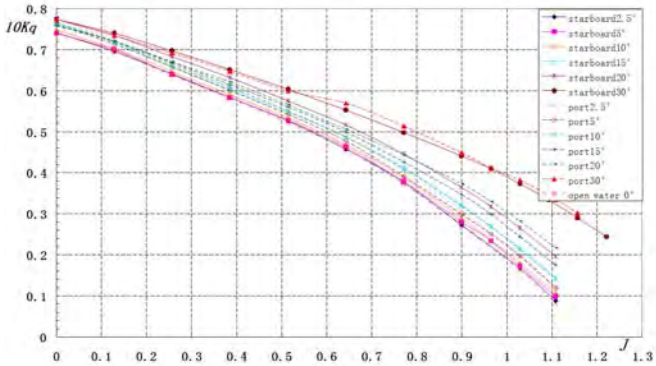

Figure 13 . Torque Coefficient of Podded Propulsor at Different Steering angles

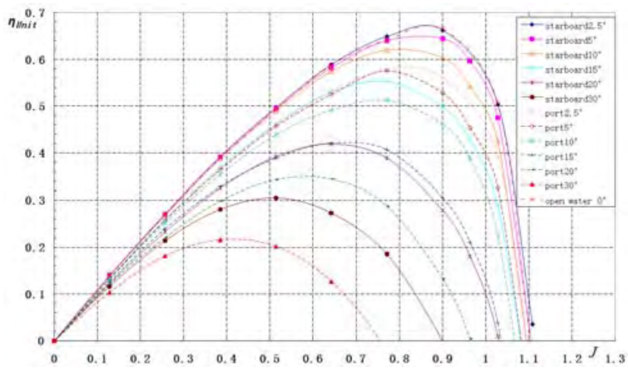

Figure 14 . Unit Efficiency of Podded Propulsor at Different Steering angles

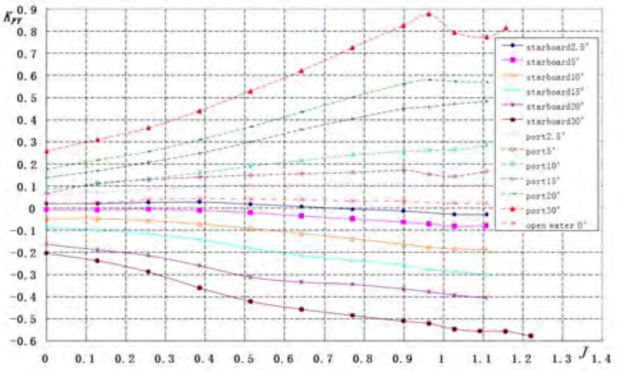

Figure 15 . Transverse Force coefficient of Podded Propulsor at Different Steering angles

4.3 Comparison Between Test and CFD

The characteristics of podded propulsor at steering conditions from test results and CFD results are in good agreement with each other. The hydrodynamics performance trends with the steering angle varying from model tests and CFD calculations are similar. The results from both approaches show that the unit thrust, transverse force, steering moment and propeller torque of podded propulsor are varied complicatedly with steering angle and propeller loading. It is important to identify the hydrodynamics performance of podded propulsor at steering conditions for ship operation and podded propulsor design.

5 Conclusions

The characteristics of podded propulsor at steering conditions are studied by test in towing tank and by CFD method, the results from both approaches are well agreement each other.

The unit thrusts (longitudinal force) of podded propulsor are decreasing for both steering directions. The decrease of unit thrust at steering to port side is bigger than that to starboard due to the effect of propeller rotation direction.

The thrust and torque of propeller increase with the increase of steering angle. The characteristics curves at the two opposite steering angles are quasi-symmetry. The unit efficiency decreases with the steering angle increasing.

At the steering conditions, the flow separation and trailing vortex occur easily around the podded. The performances of podded propulsor at steering condition are affected by steering angle and propeller loading and propeller rotation direction.

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