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On the Model Tests for POD Propulsion Ships

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Abstract

The procedures of model test and performance prediction for the CRP-POD propulsion ships, are studied. At the CRP-POD system, which are highly applicable to ultra large container carriers, RPM ratio of two propellers is not fixed, unlike conventional CRP system, and hence the power of each propeller must be predicted respectively. In this paper, a CRP-POD system is designed for 10,000 TEU class ultra large container carriers, and the characteristics of the CRP-POD system are experimentally studied. Finally, based on this study, the procedure of powering performance evaluation for CRP-POD propulsion ships is suggested. However, further studies on quantitative correction of the present procedure are required.

Keywords: CRP-POD, powering performance, ultra large container carrier, open water test, self-propulsion test

1 Podded drives as electric propulsion system

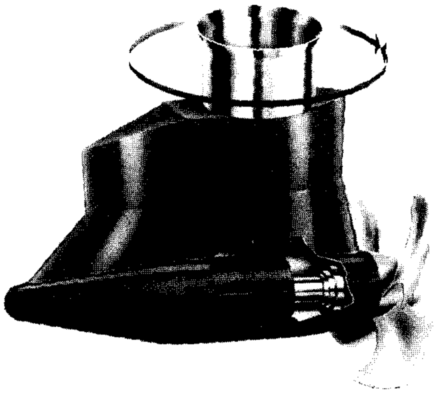
Electric propulsion is a new trend of ship propulsion system nowadays, and the use is continuously increasing for various types of vessels, for which has many advantages over conventional propulsion system – good maneuverability, low level of noise and vibration, space saving design and improved hydrodynamic efficiency.

Podded drives, which are one of the electric propulsion system, has the definition as below and figure 1.

- Electric motor is located inside a POD
- The total unit is azimuthing

Single podded drive can be used as main propulsion system for small size vessels, and if twin podded drives, for medium and large size vessels such as tanker, LNG carrier. Recently, due to continuous growth in world trade, container transport is expected to grow more faster, so development of bigger and faster container carriers is required. Due to higher propulsion power demand of this kind of vessels, alternative propulsion systems have been studied, and CRP-POD propulsion system is presented by ABB.

The CRP-POD propulsion system is composed of well-proven diesel engine and pulling type POD unit, and the two propeller is rotated in opposite direction. They are located on the same axis, but without direct connection, i.e., the propeller of the pulling type podded drive unit will contra-rotate in relation to the shaft driven main propeller. There is no need for conventional rudder due to azimuthing podded drive unit. The two propellers are driven by independent power supply system each other, which is another advantage of the CRP-POD system in view of redundancy.



The Azipod unit incorporates an electric AC motor, located inside the pod.

Figure 1: Definition of podded drive unit

Test procedure and hydrodynamic analysis of CRP-POD propulsion ship are difficult and incomplete yet because of some points as below : Firstly, in spite of powering performance prediction method of conventional CRP propulsion system has been presented by many researchers, the validation of the method has not arrived at perfection and what is more, for CRP-POD drives have the two propellers which are driven by independent power supply system, the degree of freedom in power and rpm ratio is more complex in contrast to conventional CRP propulsion system. Secondly, the treatment of POD housing/strut drag which has strong interaction with propeller is very difficult and scale effect of the drag should be also considered with more care.

In this paper, model test setup and procedures for CRP-POD propulsion ship is presented in focus with power and rpm ratio of the two propellers, and powering prediction has been tried out with modification of traditional ITTC'78 method in common prudence.

2 Model tests setup & procedures

In conventional CRP propulsion system, two propellers which contra-rotate on the same shaft driven by main diesel engine, has gear box, so rpm ratio is fixed by appropriate propeller design. In contrast with conventional CRP, as CRP-POD propulsion system has independent power supply system which drives contra-rotating two propellers each other, rpm ratio is not fixed and two propellers are operated independently. However, the independent power supply systems (main diesel engine for forward propeller and diesel generator-electric motor for aft propeller) have limited capacity each other, then rpm ratio is restricted by power ratio of two independent power supply systems if proper design of two propellers is carried out.

Table 1: Capacity and type of main engine and POD propulsion system

CRP-POD	Main	M/E	9K98MC-C
		MCR	69840 x 104
		NCR	58800 x 100.4(70 % of total propulsion power)
		Propeller	8.8 m dia. x 4 blades
	POD	M/E	AZIPOD(Type 25)
		MCR	28020 x
		NCR	25520 x 110~120 (30 % of total propulsion power)
		Propeller	6.4 m dia. x 5 blades

A CRP-POD propulsion system is designed for ultra large container carrier in this research project, and capacity and type of main engine which drives forward main propeller (hereafter, called "main propeller") and POD propulsion system which drives aft pod propeller(hereafter, called "pod propeller") were selected on the basic design stage as table 1.

2.1 Tests procedures for CRP-POD propulsion ships

In the first place, some assumptions should be made for thrust of POD propeller. As figure 1, pod propeller has housing of spheroid geometry which covers electric AC motor and strut which covers control and power cables connected to housing. Drag of POD housing and strut in the aft flow field of ship is a negative thrust of POD propeller, therefore POD propulsion system can be considered as normal propeller which generates net thrust (propeller thrust subtracted by drag of housing/strut). Throughout model tests, net thrust is used for POD propeller.

From the basic design stage, power ratio of two power supply system which drives two propellers independently is 70%:30%, therefore rpm ratio should be decided to absorb each power for two propeller designed properly, and we must check whether the rpm ratio is unique for the power ratio through self-propulsion test.

Test procedures for CRP-POD propulsion ships is presented in this research project, some modification is made to traditional powering method.

To begin with, the drag of POD housing/strut is included in net thrust of pod propeller, resistance test for bare hull(without POD) was carried out. And then, self-propulsion test to decide the rpm ratio corresponding to pre-determined power ratio should be carried out. In the self-propulsion test to determine rpm ratio, rpm variation was made by matrix method for main & pod propeller. When the rpm ratio is determined, self-propulsion test for speed variation was carried out where the rpm ratio is fixed.

For POW(propeller open water) characteristics, POW tests were carried out with 4 conditions. In hydrodynamic analysis of CRP-POD propulsion ships, two methods were devised. In method 1, two propellers are considered as a whole one propeller, i.e., thrust and torque of two propeller is added to effective thrust and torque and we could get powering performance as a whole propulsor unit (power and rpm). On the contrary, method 2 consider two propellers as separate propulsion system, and powering performance for each system could be available, then delivered horse power are sum up. To this reason, POW tests with 4 conditions are needed, normal POW of main propeller and pod propeller for method 2, and POW test of total unit(reverse main propeller and pod altogether) for method 1. Reverse POW of main propeller only is also needed for method 1 to check the effect of open boat to performance of propeller when POW test is carried out in reverse direction.

Test procedures for CRP-POD propulsion ships are summarized in figure 2.

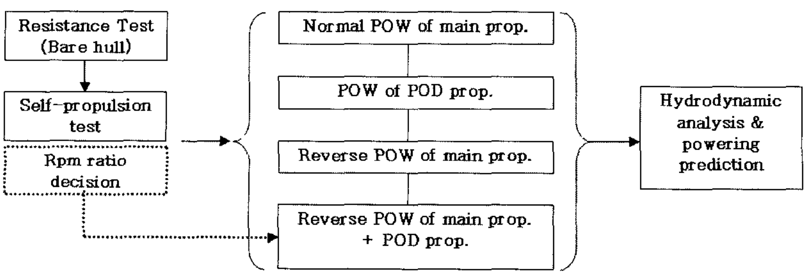


Figure 2: Test procedures for CRP-POD propulsion ships

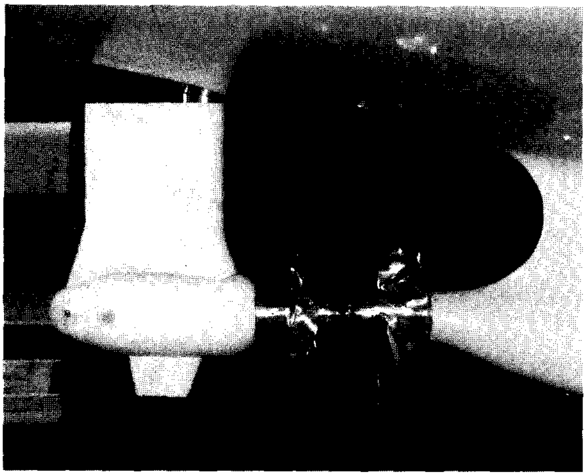


Figure 3: Scaled model ship, propellers and POD housing/strut

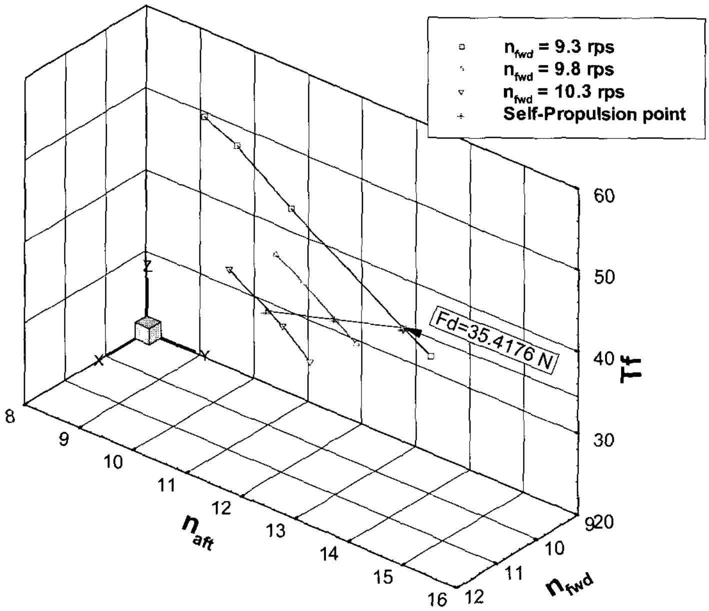


Figure 4: Self-propulsion test with rpm matrix of main & pod propeller

2.2 Model tests setup and hydrodynamic analysis

For self-propulsion tests of CRP-POD propulsion ships, scaled model ship, propeller, and POD housing/strut were manufactured and propeller driving & dynamometer system were installed on model ship as figure 3.

As mentioned above, net thrust is used to hydrodynamic analysis. To this, 2-component dynamometer is installed in the connection part of POD unit and model ship, and can measure net thrust. And also, propeller dynamometer located in POD housing can measure thrust and torque of pod propeller, so we could get the information of drag component in net thrust.

RPM of the two propellers is controlled by each motor controller, and rpm combination of two propellers to determine rpm ratio is possible.

To determine rpm ratio corresponding to pre-determined power ratio at self-propulsion point, rpm combination by matrix method of main and pod propeller is made as figure 4.

For fixed rpm of main propeller, rpm variation of pod propeller is applied and (rpm ratio power ratio) data point could be obtained. At self-propulsion point, power of two propulsion system in model scale is calculated as equation (1).

$$\text{power} = 2\pi Q n \tag{1}$$

where, Q is torque, n is revolution of propeller.

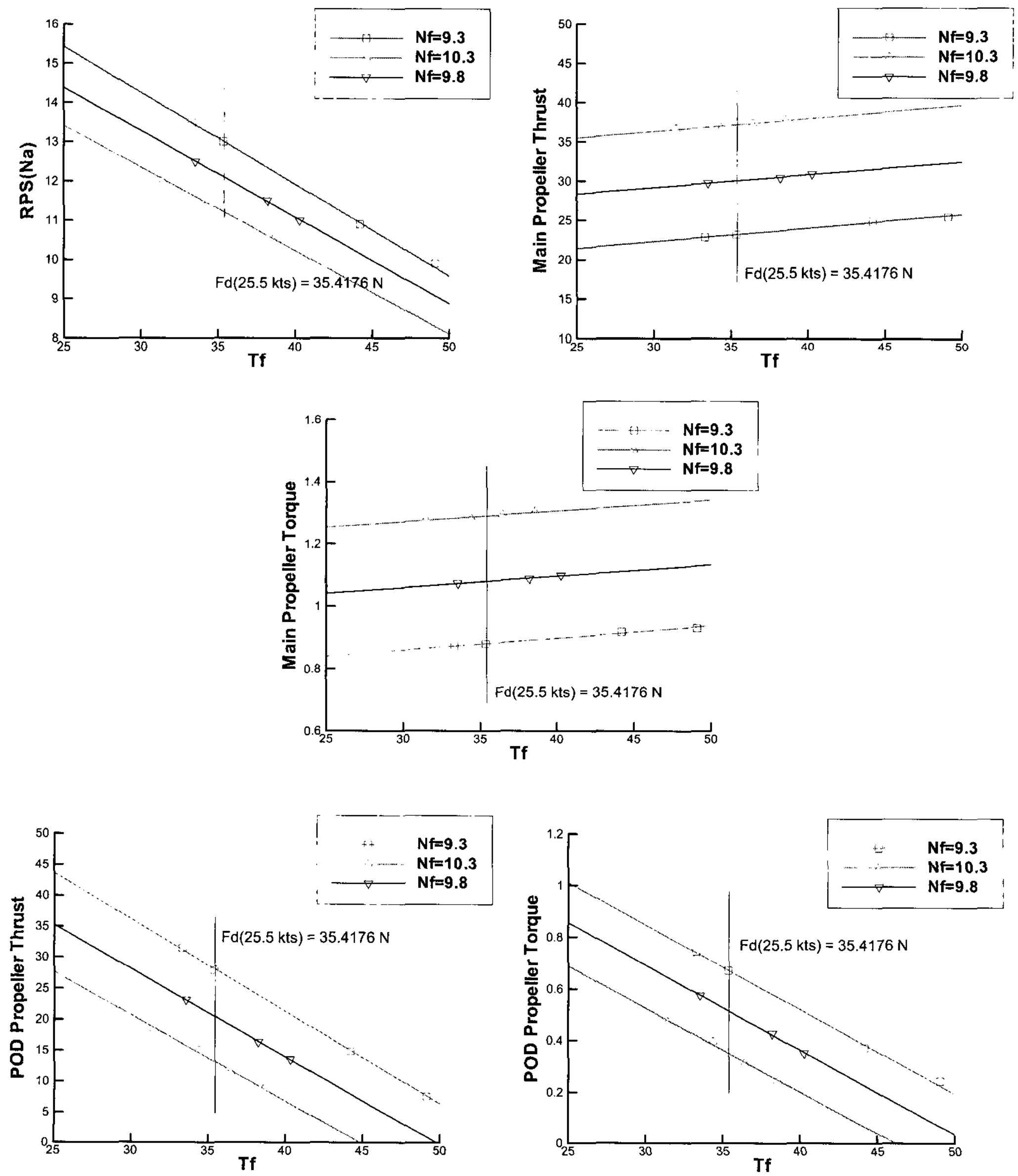


Figure 5: Propeller characteristics of two propellers with rpm matrix of main & pod propeller

Some interesting phenomenon was showed for interaction between two propellers as figure 5. For fixed rpm of main propellers, thrust and torque of main propeller are not constant, varied with change of pod propeller rpm, i.e., if rpm of pod propeller is decreased (pod propeller loading is decreased), thrust and torque of main propeller is slightly increased, and vice versa. This is interaction effect between two propellers.

Self-propulsion tests to find rpm ratio resulted in the ratio 1.15169, that is, pod propeller should rotate with more faster rpm by 15% to absorb 30% power of total propulsion system as figure 6. As showed in figure 6, power and rpm ratio have one to one relation, and it was verified that there is a unique rpm ratio corresponding to given power ratio. Then, the rpm ratio would be fixed throughout the self-propulsion tests with speed variation and POW test of total propulsion unit. From the self-propulsion tests with speed variation, it was also confirmed that the power ratio was maintained for fixed rpm ratio which was obtained by self-propulsion test at design speed.

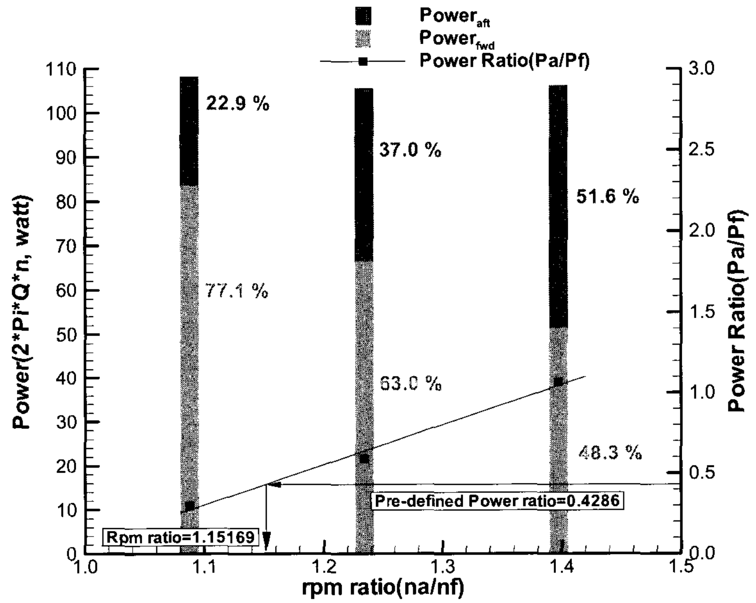


Figure 6: Power ratio of two propulsion system

Figure 7: Test setup for propeller open water test of total unit

POW tests with 4 conditions were carried out as mentioned above and the test setup is as figure 7. In POW characteristics of total unit, thrust and torque coefficients are defined as below equation.

$$K_t = \frac{T_{main} + T_{POD}}{\rho n_{main}^2 D_{main}^4}, K_Q = \frac{n_{main} Q_{main} + n_{POD} Q_{POD}}{\rho n_{main}^3 D_{main}^5} \quad (2)$$

where, T_{pod} is net thrust of pod propeller.

To carry out POW test with total unit, the open boat which main propeller is installed is located in reverse direction, so reverse POW of main propeller only was also carried out to correct the wake effect of open boat.

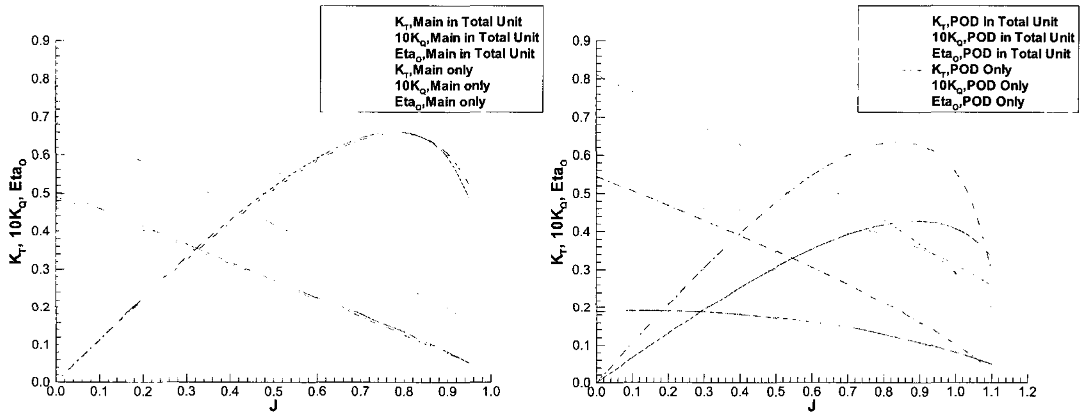


Figure 8: POW Characteristics CRP-POD propellers

Figure 8 shows POW characteristics in the case of main propeller only and main propeller affected by pod propeller in the total unit, and the characteristics of main propeller are not changed by the effect of pod propeller, but the characteristics of pod propeller are more affected by main propeller, because pod propeller is located in the accelerated flow region by main propeller.

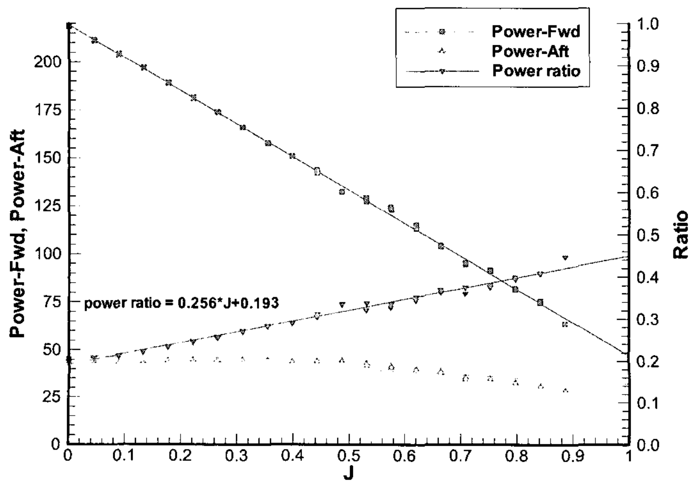


Figure 9: Power and the ratio of main, POD propeller in total unit

As figure 9, in POW test of total unit with fixed rpm ratio, the power of main propeller and pod propeller, and the ratio is obtained. The results show that the power of pod propeller is less sensitive to advance ratio J because the pod propeller is located in aft flow field accelerated by main propeller. Therefore, the power ratio at fixed rpm ratio has functional relation to J.

3 Powering performance prediction

Powering performance prediction for CRP-POD propulsion ship is carried out with 2 methods. To begin with, the scale effect of drag component in net thrust of pod propeller is considered by the scale reduction factor of the drag is 0.5, that is, the drag coefficient in full scale is a half in model scale. The scale reduction factor of the drag is applied to POW characteristics of pod propeller only and component of pod propeller in total unit through out 2 methods.

Method 1 consider the separate propulsion system as a whole one propeller, that is, thrust and torque of two propeller are converted to effective ones as equation (2). Then, traditional powering prediction process as ITTC'78 method could be applied. But, in method 1, interaction between two propellers cannot be considered, especially wake scaling of main propeller and pod propeller should be applied differently.

In method 2, propulsion systems are considered separately, and delivered horse power and rpm in full scale are obtained individually and finally sum up. In details of method 2, delivered horse power and rpm of main propeller are obtained using ITTC'78 method which is scaling of self-propulsion factor, but some modification is needed. Firstly, wake fraction and relative rotative efficiency of main propeller is calculated and converted to full scale as ITTC'78 method. Because main propeller in CRP-POD system is not affected by pod propeller as figure 8, the self-propulsion factors can be deduced by prediction method of single screw ship such as ITTC'78. Calculation of thrust deduction factor of main propeller is revised as below.

$$t_{main} = \frac{T_{main}}{\sum T} \times t_{\text{From method 1}} \qquad (3)$$

That is, sum of thrust deduction factor from method 2 should be same as from method 1, but each of thrust deduction factor is in proportion to each thrust in the model test. And also, to calculate the full scale rpm, thrust-loading coefficient of main propeller is revised as below.

$$K_T / J^2 = \frac{S \times 0.7 C_{TS}}{2D_{main}^2 \left(1 - t_{main}\right)\left(1 - w_{TS,Main}\right)^2} \qquad (4)$$

where, K_T is thrust coefficient, J is advance ratio, S is wetted surface area, C_{TS} is total resitance coefficient, D is propeller diameter in full scale, t is thrust deduction factor, and wts is wake fraction factor.

Main propeller which absorb 70% power of total power supply system can be equal to 70% of full scale total resistance.

Secondly, in the case of pod propeller, we could get wake fraction, relative rotative efficiency, and thrust deduction factor of model scale as in the case of main propeller. But, wake scaling method presented in ITTC'78 cannot be applied to the case of pod propeller which is located in the accelerated flow region by main propeller. So now we propose direct method for pod propeller in full scale. For main propeller, wake fraction in full scale has lower value than model scale, and this cause shift of advance ratio J. From Figure 9, change of power ratio corresponding to shift of J could be obtained. Now, delivered horse power and rpm of pod propeller could be calculated from result of main propeller and corrected power and rpm ratio as below.

$$DHP_{POD} = DHP_{main} \times r_{Power} \times \Delta r_{Power}, N_{POD} = N_{main} \times r_{rpm} \times (\Delta r_{Power})^{1/3} \qquad (5)$$

where, r_{power} is pre-determined power ratio, r_{power} is rpm ratio corresponding to r_{power}, Δr_{power} is change of power ratio due to shift of J

Table 2 summarize powering performance by 2 methods. In the case of method 1, there is no consideration of interaction between two propellers, and in method 2, loading change of two propellers due to wake scaling is considered. In spite of the different method, the powering performance is almost same.

Table 2: Powering performance summary by 2 different method

Method	propeller	T	Q	n	wtm	wts	Jtm	Jts	t	EtaR	PD	NS
1	Total	44.27	1.6819	10.08	0.301	0.214	-	-	0.127	1.035	73431	97.94
2	Main	34.00	1.1936	10.08	0.300	0.199	0.672	0.729	0.098	1.030	50453	98.25
	POD	10.27	0.4240	11.60	0.186	-	0.933	-	0.029	0.892	22509	114.68

* T: thrust; Q: torque; n: revolution of propeller
wtm: wake fraction in model scale; wts: wake fraction in full scale; Jtm: advance ratio in amdel scale
Jts: advance ratio in full scale; t: thrust deduction factor; EtaR: relative rotative efficiency
PD: delivered horse power; NS: revolution of propeller when adsorbing PD

4 Conclusion and future work

Model tests procedures, setup and powering performance evaluation method for CRP-POD propulsion ships are reviewed and presented in this paper. It shows there is a unique value for rpm ratio corresponding to pre-determined power ratio in the CRP-POD propulsion system which are operated separately, but the capacity is limited. Even though the powering performance prediction for CRP-POD is presented, it is only first step and further studies on the full scale correction of self-propulsion factors are required including scale effect of housing/strut drag in net thrust of POD propeller.

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