Prediction of Open Water Propeller Performance Using Steady Quasi-Continuous Method

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ABSTRACT

This research is targeted to apply the numerical method in the ship's propeller design and analysis. In this thesis, the Quasi Continuous Method developed based on lifting surface theory is applied to predict the performance of propeller in open water condition. To fulfill the desire of industry to obtain an accurate, fast and low cost solution in propeller design, this design and analysis process is proposed made by computer programming software. This is because fast development on computer technology provided the possibility to carry propeller design task by using numerical software. In this research, the Quasi Continuous Method for propeller performance evaluation is applied. This method allows the fast propeller prediction process and low computer cost required. In this research, the VLCC ship model and it propulsion system is preselected. The propeller of the VLCC ship is designed and analyzed using the propeller database system in the numerical software OCARI S-Power. Next, the function of Quasi Continuous Method in the software is applied to predict the open water performance of the designed propeller. Finally, the appropriate propeller model and it dimension is determined in this research. In conclusion, application of numerical software in propeller design is an advance solution where this solution is relatively high efficient compare to the traditional method.

KEY WORDS: *Propeller Blade Design; Quasi Continuous Method; Lifting Surface Theory*

1.0 INTRODUCTION

Ship propulsion system is the important system to ensure the designed ship to sail with requires speed. The system is consisted with several important sub-systems such as the powering system like marine engine, power delivering system like shaft, reduction gear and power extraction system like the propeller. To able the ship sail with determined condition, the propeller play an important role to generate the thrust to push the ship. The function of propeller in the propulsion system is converting the power from engine to thrust where the thrust is worked as the pushing force for ship to move in desire speed.

Due to the interaction between ship hull and propeller, typically the propeller of the ship is custom made to ensure it can work with the optimum performance once install on the ship model. The designed propeller also will test in model scale to confirm the accuracy of the estimated result before it is constructed in the actual scale. However, due to the complexity of the fluid flow phenomena and cavitation effect, the propeller design and analysis task is become very complicated.

The complexity of the propeller working behavior become a main problem in estimate it performance. In current industry development, the propeller design is mostly depended on the empirical method which developed base on the previous experience gain by the company in previous design.

To improve the overall efficiency of the ship propulsion system, more suitable propeller of ship is required. Due to this requirement, many of ship design firms are searching an effective method to optimize the propeller design in the effective way. Besides, the more effective propeller evaluation method can be contributed to improve the propeller design process. Due to the limitation on the evaluation on propeller, most of the propeller evaluation required to have a model scale experiment test.

The objective of this study is to design geometry of propeller of ship, and apply the Quasi Continuous Method to predict open water performance of the designed propeller. The computational method to optimum propeller of the ship was introduced in the research, after that, the Quasi Continuous Method applied in this research to study the performance of the propeller. This research was investigate the possibility of design the ship propeller by fully computational approach where the approach is more time and cost efficient approach in the design process compared to the experimental approach.

2.0 LITERATURE REVIEW

This chapter is proposed to study the related research achieved by the previous researchers. Besides, this chapter also presented the relate information and finding of QCM method on propeller analysis.

Naoto Nakamura (1985) has conducted research on estimation of propeller open-water characteristics base on QCM. QCM was originally developed by Lan (1974) for solving planar thin wing problems. QCM has both advantages of continuous loading method and discrete loading method; loading distribution is assumed to be continuous in chordwise discrete loading method are also retained [1].

The Propulsor Hydrodynamics (1999) shows the design system of marine propeller ,the basic equations and process of design with a new blade sections based on the lifting-line method and lifting surface method, such as the QCM. In order to improve the cavitations performance, the new blade sections with the prescribed three-dimensional pressure distribution over blade surface are design by the numerical optimization technique [2].

Jun Ando (2009) conducted a calculation method which based on a simple surface panel method “SQCM” which satisfies the Kutta condition easily. For the method, there is some descriptions of how to apply SQCM to the calculation of non-linear cavitations on propeller and show some calculated results about cavitations patterns, cavity shapes and cavity volumes in steady and unsteady flow [5].

3.0 METHODOLOGY

The process of research is show in the Figure 1. To start the research, firstly the objective should be identified and then learn about propeller design and QCM by read literatures. Besides, the ship power test need to do before propeller design because the requirement of power result is necessary for blade design, then apply design and calculations to QCM and study the code. Finally collect the calculation result and analysis the performance.

Besides, due to the limited on the experimental data and propeller model data, this design research only can be using the internal propeller data from the provided propeller design software OcARI S-Power.

To able the performance of the propeller can be analysis by the Quasi Continuous Method and achieve the objective of this research, the dimension of the propeller and it geometry must be determined and obtained from the OcARI S-Power first.

The data analysis process can be separated into two main stage where the first stage of data analysis is propose to study the geometry of the designed propeller and how the propeller include the overall propulsion system performance. While, the second stage of data analysis is the study of performance of the propeller in open water condition.

In the first stage of data analysis, this research will highlight the designed dimension of the propeller.

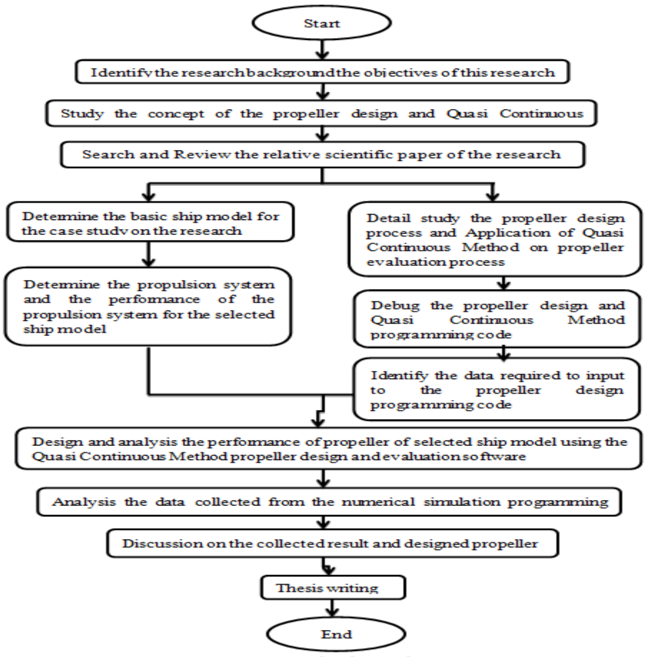


Figure 1: Research Flow Chart.

The second stage of the data analysis is focused in the study of designed propeller open water performance; the data collected from the numerical software provided the information to analysis the distribution force loading on propeller surface.

Besides, the performance of the propeller can be analysis through the open water chart estimate by the Quasi Continuous Method. From the collected open water chart of the designed propeller, the efficiency of the propeller in the selected operating speed range can be identifying.

The performance on the propeller to generate the thrust to the in different engine speed can be analyzed from the open water chart data. This analysis can estimate the overall performance of the ship in different speed due to different operation condition such as voyage and maneuvering during the design.

4.0 MATHEMATICAL MODEL

4.1 Lifting Surface Theory

$$\xi_{\mu v}^{CP} = \xi_L(\bar{r}_\mu) + \frac{\xi_T(\bar{r}_\mu)-\xi_L(\bar{r}_\mu)}{2}(1\text{-}\cos\frac{v}{N_\gamma}\pi) \quad (1)$$

$$\nu_{k\mu l}^{w} = \nu_{k\mu l}^{ws} + \nu_{k\mu+1l}^{wc} - \nu_{k\mu l}^{wc} - \nu_{k\mu l+1}^{ws} \quad (2)$$

$$\vec{F}_{\mu\nu} = \rho\vec{V}_{\mu\nu} \times \vec{\gamma}_{\mu\nu} - \rho\vec{V}_{\mu\nu}\sigma_{\mu\nu}\left|\vec{l}_{\mu\nu}\right| \quad (3)$$

$$Fs=\frac{1}{4}\pi pcCs^2 \quad (4)$$

$$\vec{V}_{ij\pm} = \vec{V}_{ij}^{G} + \vec{V}_{ij}^{S} + \vec{V}_{ij}^{I} \pm \frac{1}{2}(\gamma_{ij}\cdot\vec{\tau}_{ij} + \sigma_{ij}\cdot\vec{n}_{ij}) \quad (5)$$

$$Cpij(+-)=\frac{Pij(\pm)-Po}{\frac{1}{2}\rho Wo^2} = 1 - \frac{|Vij\pm|^2}{Wo^2} \quad (6)$$

$$\mathrm{Wo} = \sqrt{\mathrm{Va}^2 + (\gamma \mathrm{ci}\Omega)^2} \tag{7}$$

$$\mathrm{T=To +Ts +Td,} \tag{8}$$

$$\mathrm{Q=Qo +Qs +Qd} \tag{9}$$

$$\mathrm{Kt} = \frac{\mathrm{T}}{\rho n^2 D^4}, \tag{10}$$

$$\mathrm{Kq} = \frac{\mathrm{Q}}{\rho n^2 D^5} \tag{11}$$

$$\eta_p = \frac{\mathrm{J.Kt}}{2\Pi \mathrm{Kq}} \tag{12}$$

$$T_o = -K\int_{r_B}^{r_o} dr' \int_{s_L}^{s_T} F_x ds' = -K\sum_{\mu=1}^{M} \frac{\pi c_\mu^*}{2N} \sum_{\nu=1}^{N} (F_x)_{\mu\nu} \sin\alpha_\nu \tag{13}$$

$$\begin{aligned} Q_o &= K\int_{r_B}^{r_o} dr' \int_{s_L}^{s_T} \left(-F_{y\cdot z} + F_{z\cdot y}\right) ds' \\ &= K\sum_{\mu=1}^{M} \frac{\pi c_\mu^*}{2N} \sum_{\nu=1}^{N} \left[-\left(F_y\right)_{\mu\nu} z_{\mu\nu} + (F_z)_{\mu\nu} y_{\mu\nu}\right] \sin\alpha_\nu \end{aligned} \tag{14}$$

$$\begin{aligned} T_s &= K\int_{r_B}^{r_o} F_s(\gamma') \sin\varphi(\gamma') dr' \\ &= K\frac{\pi(\gamma_o - \gamma_B)}{2M} \sum_{i=1}^{M} F_s\,(\gamma_{ci}) \sin\varphi(\gamma_{ci}) \sin\beta_i \end{aligned} \tag{15}$$

$$\begin{aligned} T_s &= K\int_{r_B}^{r_o} F_s(\gamma') \sin\varphi(\gamma') dr' \\ &= K\frac{\pi(\gamma_o - \gamma_B)}{2M} \sum_{i=1}^{M} F_s\,(\gamma_{ci}) \sin\varphi(\gamma_{ci}) \sin\beta_i \end{aligned} \tag{16}$$

$$\begin{aligned} Q_s &= -K\int_{r_B}^{r_o} F_s(\gamma') \cos\varphi(\gamma') \gamma'^{dr'} \\ &= -K\frac{\pi(\gamma_o - \gamma_B)}{2M} \sum_{i=1}^{M} F_s\,(\gamma_{ci}) \cos\varphi\,(\gamma_{ci}) \gamma_{ci} \sin\beta_i \end{aligned} \tag{17}$$

$$\begin{aligned} T_D &= -K\frac{1}{2}\rho\int_{r_B}^{r_o} C_{D(\gamma')} \overline{W}_{(\gamma')} \overline{V}_{x(\gamma')c(\gamma')d\gamma'} \\ &= -K\rho\frac{\pi(\gamma_o - \gamma_B)}{4M} \sum_{i=1}^{M} C_D\,(\gamma_{ci}) \overline{W}(\gamma_{ci}) \cdot \overline{V}_x(\gamma_{ci}) c(\gamma_{ci}) \sin\beta_i \end{aligned} \tag{18}$$

$$\begin{aligned} Q_D &= K\frac{1}{2}\rho\int_{r_B}^{r_o} C_{D(\gamma')} \overline{W}_{(\gamma')} \overline{V}_{\theta(\gamma')c(\gamma')d\gamma'} \\ &= K\rho\frac{\pi(\gamma_o - \gamma_B)}{4M} \sum_{i=1}^{M} C_D\,(\gamma_{ci}) \overline{W}(\gamma_{ci}) \cdot \overline{V}_\theta(\gamma_{ci}) c(\gamma_{ci}) \sin\beta_i \end{aligned} \tag{19}$$

5.0 SHIP PARTICULAR AND HYDROSTATIC DATA

In this research, the selected VLCC ship has the overall length of 335.115 meter and breadth of 58 meters. Principle dimension, hydrostatic data and full load operation condition of selected ship as shown in Table 1 to Table 3 as follow.

Table 1: Principle dimension

Length over all (Loa)	335.115
Length water line (Lwl)	326.85
Length between perpendicular (Lpp)	320
Length between perpendicular model (Lppm)	3.5
Breadth molded (Bm)	58
Depth molded (Dm)	30

Table 2: Hydrostatic Data

Block Coefficient (Cb)	0.8045
Prismatic coefficient (Cp)	0.8084
Prismatic Coefficient at after (Cpa)	0.7557
Prismatic Coefficient at fore (Cpf)	0.8611
Midship Coefficient (Cm)	0.9952
Water plane coefficient (Cwp)	0.8878
LCB (% LPP)	-2.45

Table 3: Operation Condition

Draft molded (dm)	19.3
Wetted Surface (m2)	26330
Displacement (m3)	288175

Table 4: Propulsion factor

Form Factor (K)	0.23

6.0 DESIGNED PROPELLER GEOMETRY AND PERFORMANCE

By using the empirical equation from the OcARI S-Power software, the propeller of selected ship is designed. The diameter of the designed propeller is 9.13 meter in full scale. The detail information of this propeller and cross section dimension of the propeller is presented in Table 5 and Table 6 respectively. While, the cross section design of this propeller is showed in Figure 2.

Table 5: Propeller data output (design input)

Propeller diameter	9.13
Propeller pitch ratio	0.714
Propeller expanded ratio	0.473
Propeller working condition (J)	0.4612

Table 6: Propeller Blade Geometry and Cross Section Dimension

Radi(mm)	Chord	CE	Pitch(mm)	Rake	LER	Skew	T-max	Camber	P/D	r/R	P-tang
821.700	1275.328	462.218	6518.820	71.889	0.000	-175.446	374.061	187.031	0.714	0.180	75.851
913.000	1312.190	484.080	6518.820	79.877	0.000	-172.014	366.398	183.199	0.714	0.200	74.352
1141.250	1403.441	541.106	6518.820	99.846	0.000	-160.615	345.670	172.835	0.714	0.250	70.703
1369.500	1492.885	601.126	6518.820	119.816	0.000	-145.317	323.040	161.520	0.714	0.300	67.209
1826.000	1663.768	727.644	6518.820	159.754	0.000	-104.240	273.769	136.884	0.714	0.400	60.741
2282.500	1819.670	857.383	6518.820	199.693	0.000	-52.452	221.973	110.987	0.714	0.500	54.997
2739.000	1955.425	982.306	6518.820	239.632	0.000	4.593	171.045	85.523	0.714	0.600	49.958
3195.500	2065.866	1092.995	6518.820	279.570	0.000	60.062	124.375	62.188	0.714	0.700	45.567
3652.000	2145.826	1179.246	6518.820	319.509	0.000	106.333	85.355	42.677	0.714	0.800	41.749
4108.500	2190.137	1230.844	6518.820	359.447	0.000	135.776	57.374	28.687	0.714	0.900	38.426
4336.750	2197.311	1240.687	6518.820	379.417	0.000	142.031	48.583	24.292	0.714	0.950	36.928
4565.000	2193.634	1238.526	6518.820	399.386	0.000	141.709	43.824	21.912	0.714	1.000	35.527

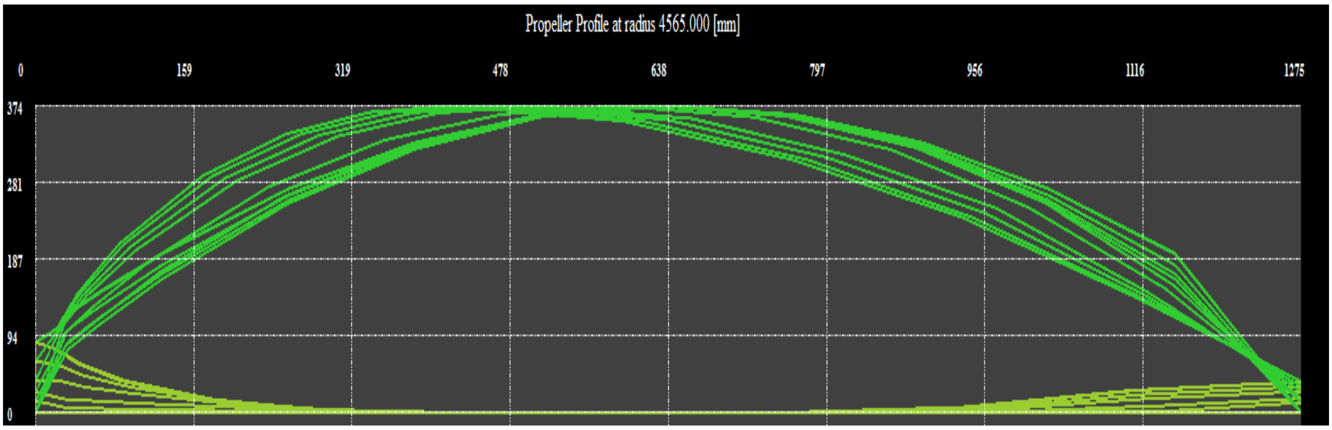


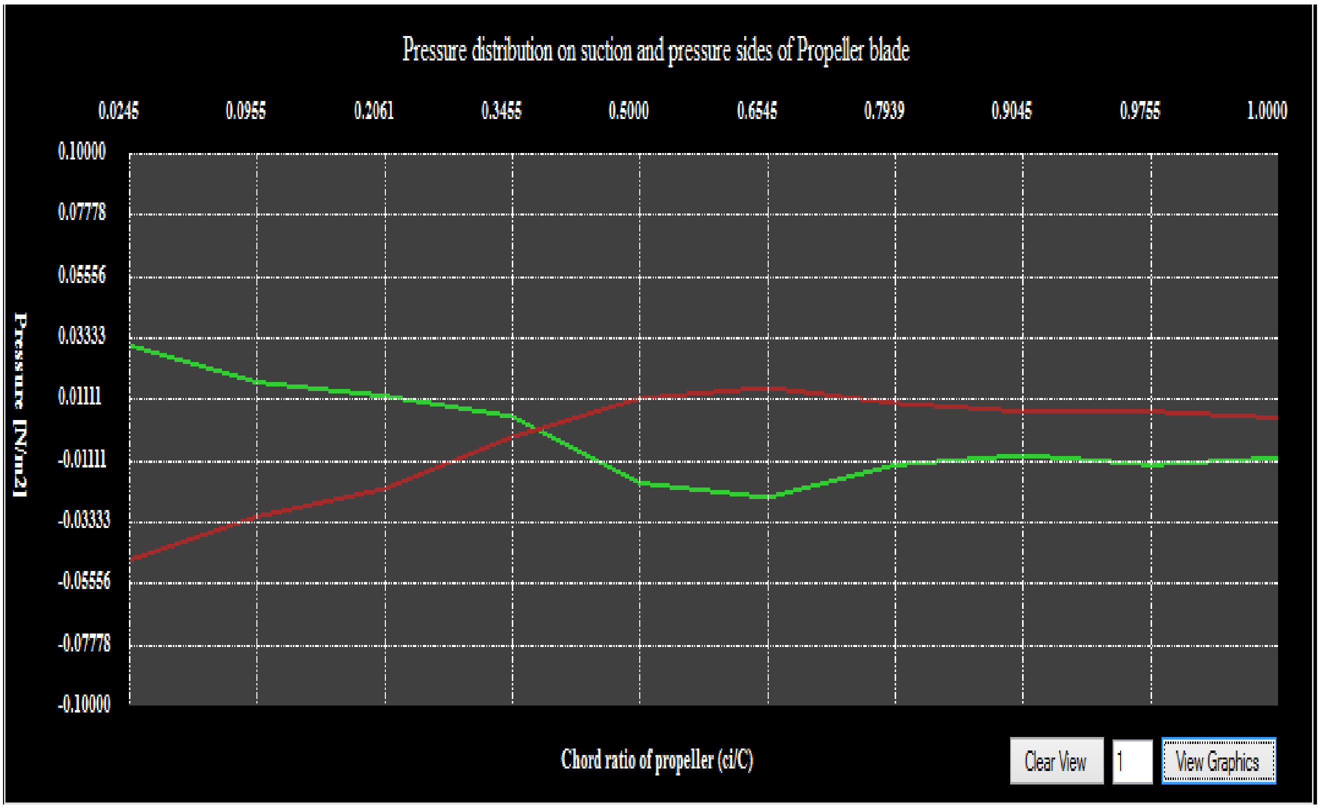
Figure 2: Geometry of blade.

The figure 2 shows geometry after combines these 12 cut surfaces of sections of blade. Every point in these two line design depend on these data in table 6. The propeller blade cross section is having the aerofoil design and the maximum blade thickness is around 374 mm.

By using the Quasi Continuous Method which applied the Lifting Surface Theory and the mathematical model as showed from equation 1 to 19, the pressure distribution on the propeller surface was determined. The suction side pressure and pressure side pressure calculated by the mathematical model is showed in Table 7. In the figure 3, the green line is for suction loading pressure and the red line is pressure surface pushing. The blade is divided into 10 section on lengthways be marketed with cj/Cj. The total pressure distribution is D-value of these two pressures on opposite surfaces. The change tendency of total pressure every point on blade directly can be predicted.

In this figure 4, the yellow line shows Kt, green line shows Kq, red line shows efficiency. Efficiency of our ship working at J = 0.4612 with is not the maximum, but it's appropriate. Maybe the condition of J more than 0.5 has more higher efficiency, but the effectives of cavitation around blade on thrust and stability will increase with the efficiency. The efficiency in the area shows in graph must be chosen with considering cavitation.

From the figure 5, it is also observed that the different pressure on the blade surface is negative for r/R=0.8799. The reason for the negative difference pressure on this cross section is due to the change of the pressure direction between pressure side and suction side pressure line. There will be 10 same graph which can combine to discusses the whole blade.

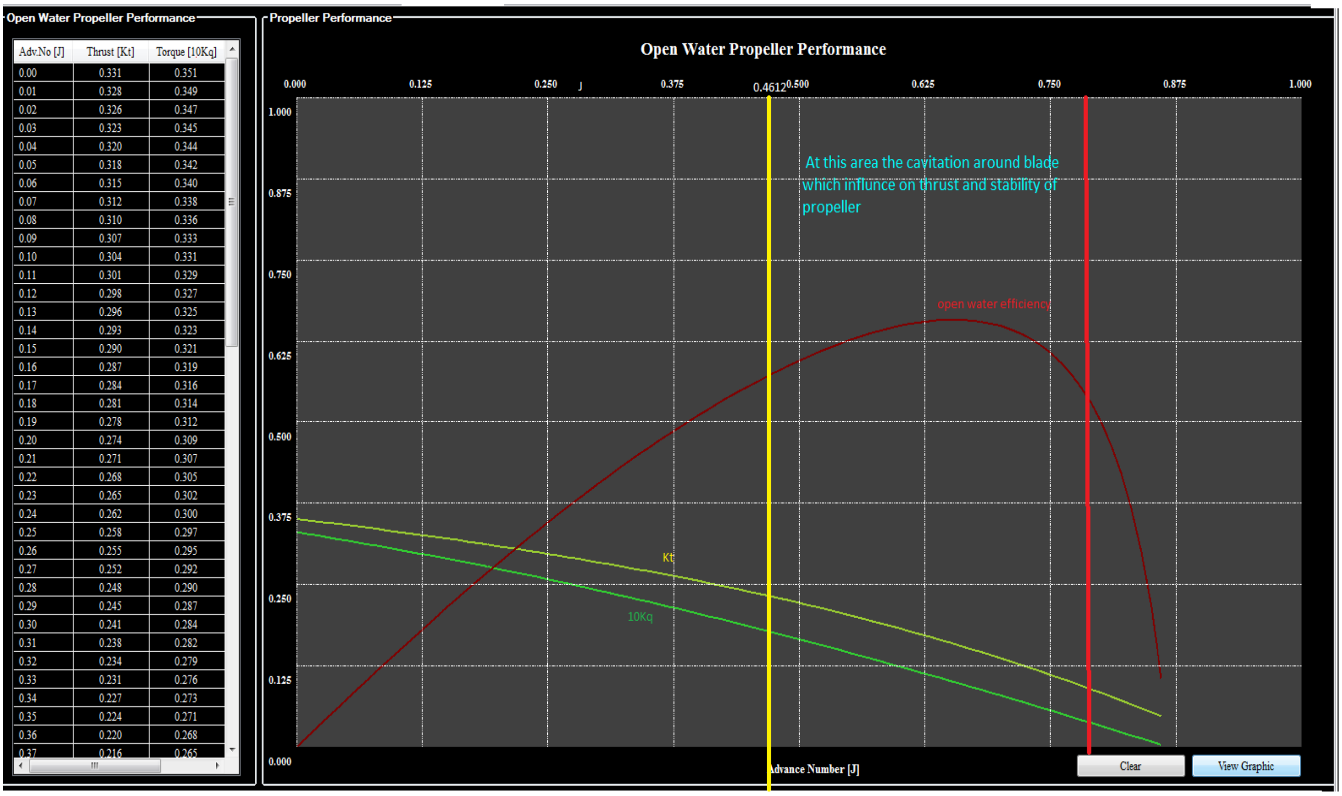


Figutre 3: Pressure distribution on blade r/R=0.18

Table 7: Pressure Distribution on Propeller Blade Surface

	cj/Ci	0.0245	0.0955	0.2061	0.3455	0.5	0.6545	0.7939	0.9045	0.9755	1
r/R= 0.18	Suction +	0.0307	0.0174	0.0125	0.0049	-0.0191	-0.0243	-0.0125	-0.009	-0.0124	-0.01
	Pressure -	-0.0469	-0.0312	-0.0211	-0.0024	0.0116	0.0155	0.0099	0.0068	0.0068	0.0045
r/R= 0.2247	Suction +	0.0223	0.0128	0.0168	0.0179	0.0137	0.0065	0.0025	0.0031	-0.0159	0.0066
	Pressure -	-0.0339	-0.0183	-0.0143	-0.016	-0.0157	-0.013	-0.0102	-0.0083	0.0083	-0.0137
r/R= 0.3001	Suction +	-0.0091	0.0015	0.009	0.0113	0.0087	0.003	-0.0037	-0.0131	-0.0351	0.0081
	Pressure -	0.0064	0.0007	-0.0007	-0.0009	-0.0007	0.0002	0.0031	0.012	0.0347	-0.0083
r/R= 0.4039	Suction +	0.0036	0.0104	0.0149	0.0157	0.0116	0.0035	-0.0067	-0.022	-0.0531	0.0012
	Pressure -	-0.0023	-0.0059	-0.0057	-0.0016	0.0032	0.0069	0.0116	0.024	0.0545	0
r/R= 0.5259	Suction +	-0.0115	0.0042	0.0121	0.0143	0.0118	0.0043	-0.0065	-0.023	-0.057	-0.0003
	Pressure -	0.0159	0.0011	-0.0027	0.0002	0.0055	0.0104	0.0158	0.0282	0.0624	0.0057
r/R= 0.6541	Suction +	0.001	0.0118	0.0177	0.0182	0.0152	0.0089	0.0016	-0.008	-0.0213	-0.0018
	Pressure -	0.002	-0.0105	-0.0135	-0.0077	-0.0012	0.0036	0.0069	0.0126	0.0251	0.0056
r/R= 0.7761	Suction +	0.0227	0.0192	0.0199	0.0201	0.0175	0.012	0.0045	-0.0065	-0.0309	0.0086
	Pressure -	-0.0164	-0.0167	-0.016	-0.0113	-0.0065	-0.0027	0.0021	0.0107	0.0324	-0.0066
r/R= 0.8799	Suction +	-0.0558	-0.0199	-0.0086	-0.0051	-0.0065	-0.0106	-0.016	-0.0239	-0.0487	-0.0032
	Pressure -	0.0745	0.0316	0.0196	0.0209	0.0252	0.0294	0.0346	0.0414	0.0632	0.0175
r/R=	Suction +	0.1857	0.0913	0.0563	0.0344	0.0161	-0.0012	-0.0179	-0.0394	-0.0771	-0.027

0.9553	Pressure -	-0.1759	-0.0894	-0.0548	-0.0287	-0.0087	0.0075	0.0238	0.0452	0.0811	0.0315
r/R= 0.995	Suction +	0.1568	0.0823	0.0596	0.0487	0.0399	0.0308	0.0228	0.0143	0.0061	-0.0061
	Pressure -	-0.1482	-0.0816	-0.06	-0.0455	-0.0354	-0.0281	-0.021	-0.0135	-0.008	0.0045



Open Water Propeller Performance

Adv.No [J]	Thrust [Kt]	Torque [10Kq]
0.00	0.331	0.351
0.01	0.328	0.349
0.02	0.326	0.347
0.03	0.323	0.345
0.04	0.320	0.344
0.05	0.318	0.342
0.06	0.315	0.340
0.07	0.312	0.338
0.08	0.310	0.336
0.09	0.307	0.333
0.10	0.304	0.331
0.11	0.301	0.329
0.12	0.298	0.327
0.13	0.296	0.325
0.14	0.293	0.323
0.15	0.290	0.321
0.16	0.287	0.319
0.17	0.284	0.316
0.18	0.281	0.314
0.19	0.278	0.312
0.20	0.274	0.309
0.21	0.271	0.307
0.22	0.268	0.305
0.23	0.265	0.302
0.24	0.262	0.300
0.25	0.258	0.297
0.26	0.255	0.295
0.27	0.252	0.292
0.28	0.248	0.290
0.29	0.245	0.287
0.30	0.241	0.284
0.31	0.238	0.282
0.32	0.234	0.279
0.33	0.231	0.276
0.34	0.227	0.273
0.35	0.224	0.271
0.36	0.220	0.268
0.37	0.216	0.265

At this area the cavitation around blade which influnce on thrust and stability of propeller

Figure 4: KT-KQ chart

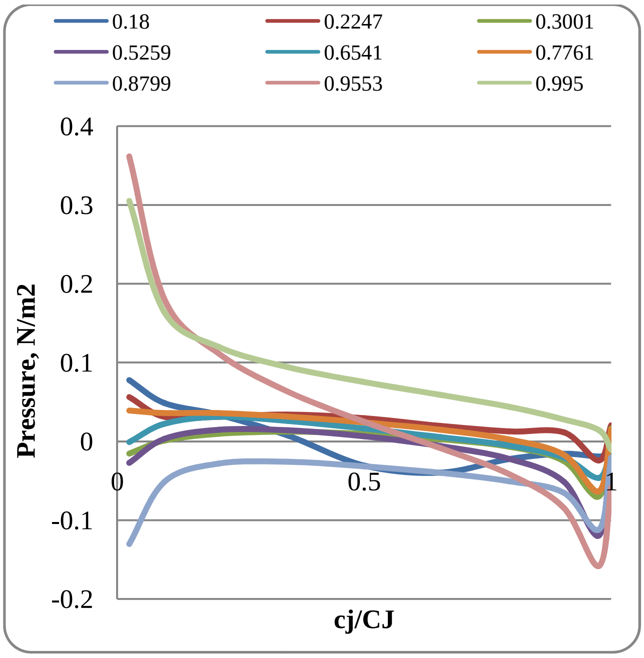


Figure 5: The pressure distribution on blade.

6.0 CONCLUSION

From this research study, the propeller design and optimization process was completed by using the software OcARI S-Power. Besides, the Quasi Continuous Method is also applied in this research. From the study, the open water performance of the designed propeller was predicted by the Quasi Continuous Method, and the data of propeller was designed can be used to analysis the propeller performance and predicted the performance of overall propulsion system. But, the pressure distribution data is useful information can be used for propeller structure analysis. For the future research, the experiments studies are recommended to be done that get the performance of the designed propeller and validate the result from Quasi Continuous Method. Besides, new studies with improving the propulsion performance by rerun the propeller design process by using different geometry of propeller.

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