International Journal of Scientific Research and Engineering Development-– Volume 3 Issue 6, Nov-Dec 2020

Available at www.ijsred.com

RESEARCH ARTICLE OPEN ACCESS

CFD USED TO DESIGN AND OPTIMIZATION THE MARINE PROPELLER

Rohit Suryawanshi

(Mechanical Engineering, Mumbai University/ Lokmanya Tilak College of Engineering, navimumbai)

--************************----------------------------------

Abstract:

Fuel-saving and emission reduction are two of the main motivating factors for the current developments in the improvement of Marine Propulsion Technology. The prediction of the flow around marine propellers enjoys noticeable interest from the hydrodynamic sciences communities and has become one of the challenges of CFD. The complex geometry of marine propellers, grid generation, and turbulence modeling remains the significant problems as opposed to the numerical simulations. The present paper gives a detailed review of how different parameters influence the hydrodynamic performances of the propeller. The commercial Computational Fluid Dynamics (CFD has been used to illustrate the effects of rudder and blade pitch, Induction Factor Method Based on Normal Induced Velocity, geometrical configuration, pre-swirl stators, and ice controllable on the hydrodynamic performances of a propeller.

.

Keywords **—Marine Propeller, CFD, Hydrodynamic, Pre-Swirl, Ship, NACA 66.**

--************************----------------------------------

I. INTRODUCTION

There have been many theories advanced to explain how a propeller produces thrust. Although the concept of most of the theories is quite simple, the mathematics can be quite complex and certain simplifying assumptions have to be made. Practical application of theories is possible using computers but one has to be careful in following theories and computer programs to avoid major mistakes. Therefore, the practical design of a propeller to suit a given set of conditions still often depends on the results of systemic experiments with model propellers. On the other hand, some theoretical knowledge of how a propeller works are essential to naval architects to guide them to the best propeller design.Propellers usually operate in the ship's stern, where the inflow wake generates periodic and fluctuating pressure, due to which, as a result, vibratory forces can occur. The induced forces may transfer to the ship's hull directly via the shaft-line or indirectly through the fluid. Therefore, conditions for the crew and passengers become unpleasant and uncomfortable. The inflow wake is strongly dependent on the shape of the ship hull and, so, each ship may have a unique wake. The purpose of a pre-swirl stator ahead of a propeller is to generate a swirling flow opposite to the sense of the rotation of the propeller. The propeller blades experience this rotating flow as an additional blade loading, through which the delivered thrust per unit of power is raised. Of course, this increase of the propeller thrust should be greater than the resistance experienced by the pre-swirl stator itself to attain a positive net gain. In terms of the energy balance, the power saving can be explained just as easy because the objective of the pre-swirl stator is to reduce the kinetic rotational energy in the flow behind the propeller.

From a propulsion point of view CPP (Controllable Pitch Propeller) is a better design option compared to FPP (Fixed Pitch Propeller) for ice-going ships. A current comparison (Lee, 2008) of ice propulsion capability for open CPP, open

FPP, and ducted FPP showed that CPP design not only is the best energy-saving propulsion among the designs but also can continuously generate enough thrusts for severe ice conditions even when the FPP designs are broken down. While there are aforementioned energy saving and high thrust capability advantages of CPP (Controllable Pitch Propeller) for ice propulsion, the introduction of the CP mechanism makes the propulsion system more vulnerable when operating in heavy ice conditions. The CPP design can only be safely applied if the propulsion strength, including propeller blade and CP mechanism, for resisting extreme ice loads can be sufficiently assessed.

Basically, a marine propeller design is carried out using the results of the open-water tests on a series of model propellers and finding suitable laws that govern the propeller shape such as chord length, pitch ratio, thickness, skew and rake angles and as well as the section profile. After the selection of the criteria design which acts as a boundary condition, the propeller design can be initiated by setting some key parameters such as thrust, ship wake distribution and rotational speed.

II. LITERATURE REVIEW

Ngo Van He [1] used CFD to illustrate the effect of the rudder and blade pitch on the hydrodynamic performance of the propeller. The author used a propeller diameter of 3.65 m; a speed of 200 rpm; an average pitch of 2.459 m and a boss ratio of 0.1730 for investigation. The first case: To cope with effects of blade pitch on the propeller's hydrodynamic features, the team employed the calculation and simulation of the free propeller with advance ratio J changing from 0.1 to 0.75 and attack angle of the blade in the range of -7 degree to 7 degrees. The second case: To study the effects of the rudder on hydrodynamic characteristics of the propeller, the authors executed the computation of the free propeller and propeller in the rudder propeller system with advance ratio J changing from 0.1 to 0.75. In this research, the domain is a cylinder, with the length of thirteen times of the propeller's diameter (13D) and the diameter of seven times (7D) of the propeller's diameter, divided by the two components: The static domain and rotating domain. In the third step, the domain is imported, meshed, and refined in the Ansys meshing ICEM-CFD tool.

In computation, the turbulent viscous model RNG k-ε is used. Velocity inlet, which is axially uniform and has a magnitude equal to the ship's advance velocity, is selected as the inlet. Pressure outlet is specified as the outlet and gauge pressure on the outlet is set to be 0 Pa. With wall boundary conditions, the no-slip condition is enforced on the wall surface and standard wall function is also applied to an adjacent region of the walls. The moving reference frame (MRF) is used to establish the moving coordinate system rotating with the propeller synchronously and the stationary coordinate system fixed on the static shaft of the propeller, respectively. The first-order upwind scheme with numerical under relaxation is applied for the discretization of the convection term and the central difference scheme is employed for the diffusion term. The pressure velocity coupling is solved through the PISO algorithm. The Pressure distribution over the surface of the blade of the propeller is shown in fig: 1.

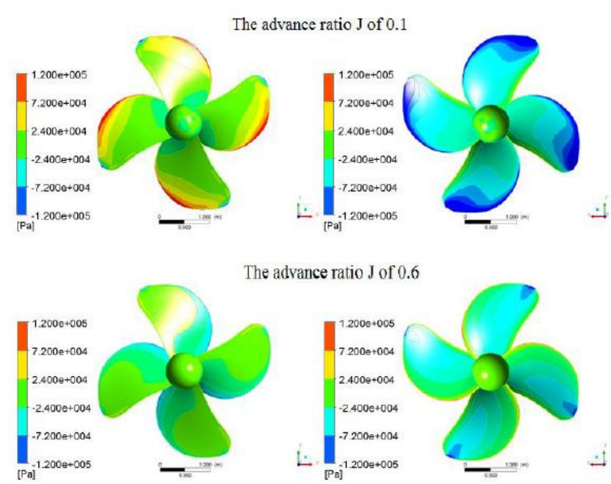

Fig. 1. Pressure distribution over blade surface of the propeller in both cases at J = 0.6

The blade pitch has a significant impact on pressure distribution of the propeller blade's surfaces. Consequently, the propeller thrust increases steadily when the blade pitch rises. Fig. 2 shows propeller efficiency at the different blade pitch angles. We can see from the figure that the propeller efficiency changes to the principle of the axial turbomachinery and it is a function of the advance ratio J at each pitch. In the investigated pitches, the propeller efficiency goes up dramatically when the blade pitch increases. The maximum efficiency of the propeller is 0.724 corresponding to the advance ratio J of 0.8 at the blade pitch of 7 degrees.

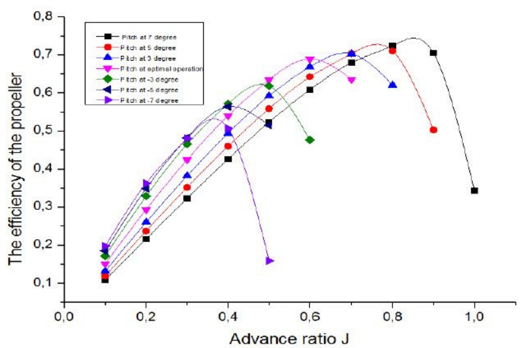

Fig. 2. Efficiency of the propeller with the different blade pitch angles

The interaction between the propeller and the rudder makes the horizontal force on the rudder in the ship operation, this force reaches the maximum value of 4.5 kN at corresponding to the advance ratio J = 0.4. The force-generating on this interaction reduces the stability of the ship's maneuvering.

ArnobBanik [2] used the Biot Savart Law, to calculated induction factor to calculate induced velocities and thus determined the characteristics of the propeller. In the first phase of the design process no detailed data are needed for the flow around the propeller blades themselves but rather the disturbing flow field which interacts with the blade is needed. They consider a 2-bladed propeller and assume that the trailing vortex sheets springing from the propeller blades make helical surfaces extending infinitely backward with constant pitch and diameter. The diagram of velocities for the propeller blade is shown in fig: 3.

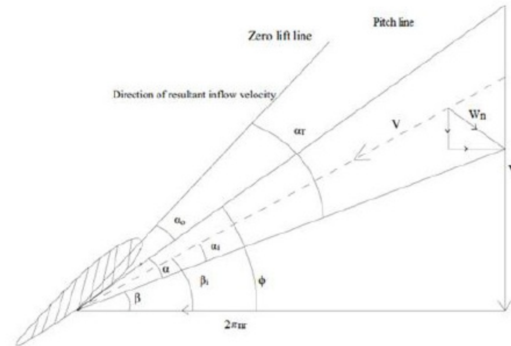

Fig. 3: Diagram of velocities for a propeller blade element under the influence of induced velocities.

φ = Blade Pitch Angle
β = tan−1(J/πx) = Advance angle
αi = angle for induced velocity
α0 = zero lift angle
αT = α + α0
βi = β + αi
Now, x = r/R, Advance coefficient, J = VA/nD and
Resultant Velocity

$$V = \sqrt{V_A + (2\pi nr)^2}$$

$$V = \sqrt{J + (\pi x)^2} \times nD$$

From the given advance coefficient, J and blade angle, φ at different propeller blade sections advance angle, β and geometrical angle of attack, α is calculated. A relation between circulation, Γ and lift coefficient, CL at different propeller blade sections is used by the circulation theory as

$\Gamma = 0.5V.C.C_L$

The circulation cannot be obtained at once as the lift coefficient CL depends on the normal induced velocity, which, alternatively is affected by circulation. Finally, the values of thrust and torque coefficients and efficiency are calculated for other values of advance coefficients,

J=0.4,0.6,1.0 and 1.2 and plotted in fig. 4. In the figure, a comparison with the values from the experiment is also presented and it is seen that the calculated characteristics and those from experimental ones are in very close agreement.

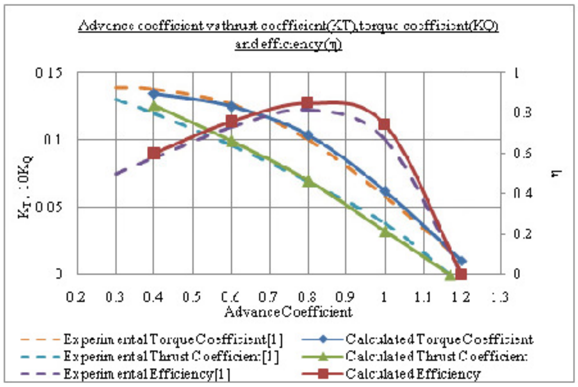

Fig. 4: Comparison among the values of thrust coefficient, torque coefficient and efficiency

The conventional SeiunMaru propeller is chosen by Samir [3] as a reference case. It is a Japanese AU series with a modified NACA 66 section and has taken the name of the SeiunMaru ship. It contains 5 blades with a diameter of D=3.6 m. It has also a fixed pitch and an expanded area ratio of AE/A0 =0.65. A FORTRAN program lists the geometric characteristics found in reference and provides the spatial point coordinates for different cross-sections. For each radius, the corresponding profile is moved by the skew in the x-direction and by the rake in the y-direction to obtain the expanded section. Finally, the profile is deflected by its geometric pitch angle to obtain the projected section. The obtained point coordinates are then exported to the pre-processor GAMBIT and are connected with spline lines. Surfaces are generated by connecting lines and then the volume of the blade is created. To examine the effect of geometric characteristics, a series of marine propellers are generated by changing blade numbers, expanded area, and geometric pitch ratios using the FORTRAN program. All the subsequent simulations will be done in uniform open water flow conditions and using the standard model. Three new propellers with different blade number (Z = 4, 6, 7) are created by keeping the same expanded area ratio, AE/A0 = 0.65, and the similar pitch ratio, P/D = 0.95. In the second step, the number of the blade is kept equal to five (Z=5) with the pitch ratio P/D=0.95. While, the expanded area ratio is varied (AE/A0) *=0.3, 0.5, 0.8, 1.0, 1.2 and 1.4. In the third step, the pitch ratio P/D is varied and both blade number and expanded area are kept constant as the reference case. Fig. 5 shows the six new propeller geometries created by changing the geometric pitch ratio P/D.

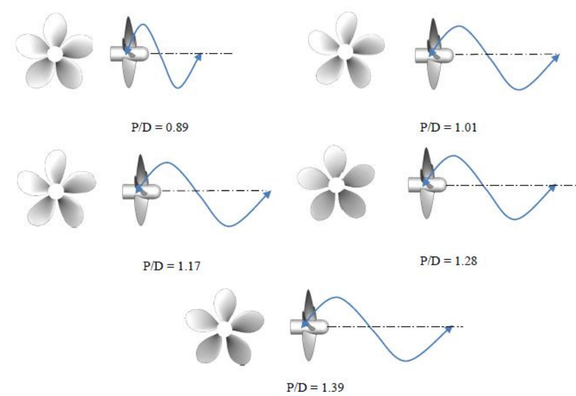

Fig. 5 Propeller geometries with different pitch ratio

Table 1 shows the comparison of the open water characteristics for different geometric pitch ratio for the fixed advance ratio J=0.7. Overall, the propeller efficiency decreases with the increase of the pitch ratio expecting for the SeiunMaru. This latter remains the best comparing with other configurations.

Table 1. Open water characteristics

P/D	K_T [−]	10 K_Q [−]	η_0 [−]
0.89	0.1510	0.2630	0.639
0.95 ($\kappa-\varepsilon$)	0.1830	0.3120	0.653
0.95 (Exp.)	0.1597	0.2837	0.651
1.01	0.2070	0.3620	0.637
1.17	0.2973	0.5653	0.586
1.28	0.3570	0.7210	0.552
1.39	0.4080	0.8760	0.519

Overall, the numerical tests show satisfactory agreement with available data in the literature. The predictions of the RANS models in open water conditions revealed that the standard $k\text{–}\varepsilon$ model returns superior results as well as the commonly used $k\text{–}\omega SST$. Both models can guarantee an acceptable level of accuracy in uniform and non-uniform inflow cases and could be used as data for fatigue predictions. Concerning the pitch ratio effect, the same value as the conventional SeiunMaru propeller gives the best efficiency. As a conclusion, the four bladed propellers with an expanded area of 0.65 and a pitch ratio of 0.95 is suggested for further experimental tests. Moreover, for vibration thoughts, the pair blades propeller is advised for their balance comparing to odd propellers.

From a hydrodynamic viewpoint, the difference between the pre-stator propeller combination and counter-rotating propellers is small. The pre-swirl stator is the front-propeller of which the rotation is zero. Zondervan [4] focuses on the pre-swirl stator device providing the possibility to reduce the rotational losses incurred by the propeller. The design process of the stator blades consists of two stages. In the first stage, the solution to finding the best geometry for the circumferential-average wake field is determined. The wake data are represented by the radial distributions of the axial and tangential velocity components, the latter being zero for symmetric single-screw ships. In the second stage of the design process, the pitch of the stator blades is corrected for the difference between the local flow and the circumferential average flow condition. The angle between these flow vectors is imposed as a pitch correction of the stator blades. As a result, the blades are oriented to the local flow direction and experience a shock-free entry condition and their hydrodynamic loading is mutually equal.

Here we present preliminary results for the flow around the container ship fitted with the 6-bladed pre-swirl stator. Wave making is neglected, i.e., we performed double body calculations using symmetry conditions at the water surface. This simplifies the calculation and, hence, avoids additional inaccuracies due to the free surface with respect to the prediction of the resistance of the ship and stator. All calculations were done for a ship speed of 18 knots which gives a Reynolds number of 1.35x107 and 2.65x109 for model- and full-scale, respectively. To avoid a non-physical flow around the bow, due to the double body conditions, we used a deeper draught of 14.0. All calculations were done using the k - ω turbulence model of Menter. To incorporate the propeller action, an actuator disk model is used, with a thrust coefficient equal to 0.636 and 0.703 for the bare hull and hull fitted with the pre-swirl stator respectively.

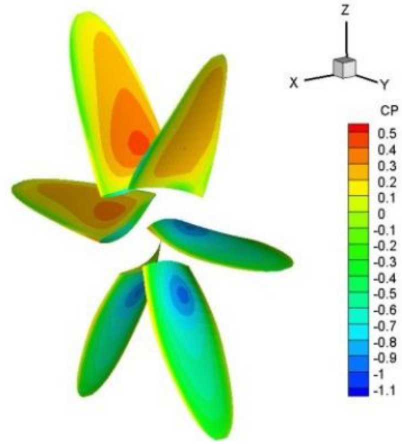

Fig. 6: Illustration of pressure distribution on Pre-Stator as computed with PROCAL

Further work will consist of a validation of the cavitation extent and dynamics from PROCAL with experimental results. Using calculated pressure distributions (see, for example, Fig. 6) and cavitation patterns on the propeller behind the stator, the propeller stator combination can be further tuned to obtain acceptable cavitation and pressure fluctuations on the hull. A reliable procedure for designing and optimising propeller-stator combinations includes both the application of numerical methods as well as validation of the results by means of dedicated model experiments.

Lee [5] study of the ice loads formulae in URI3 for open and ducted CPP will be adopted for an existing ice CPP for its mechanism check to evaluate the rationality of the Rule. The propeller design ice loads given in URI3 are different from the ice torque traditionally used in the past and are the results of extensive research activities. Included in the activities were analyses of the service history of propeller damages, propeller and shaft load measurements on full-scale trials, laboratory investigations, and numerical simulation of propeller-ice interaction. In URI3 Rule, the design forces on the propeller blade resulting from propeller-ice interaction, including hydrodynamic loads are provided. These forces are the expected ice loads for the whole services life of the ship under normal operationalconditions, including loads resulting from the changing rotational direction of fixed pitch propellers. The Rules cover open- and ducted-type propellers with fixed or controllable pitch designs for the following Polar ice classes defined in URI1 (IACS). Instead of the design using the lifetime expected maximum forces, blade failure force is another alternative for CPP mechanism scantling design if the so-called ‘selective strength design principle’ is used. The 5 different loaded case was used for study and loaded condition shown in fig. 7. Under the principle, the design of the CPP mechanism is based on the blade failure force so that the blade will be failed first to protect the CP mechanism. According to URI3, the blade failure force is acting at 0.8R in the weakest direction of the blade and at a spindle arm of 2/3 of the distance of the axis of blade rotation of leading and trialing edge whichever is the greatest.

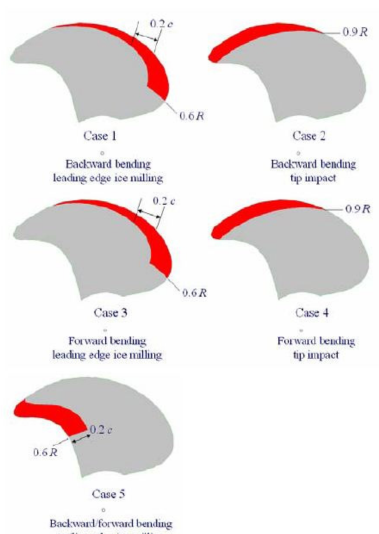

Fig. 7 Loaded area for different cases

CONCLUSIONS

In this study, hydrodynamic performances of a marine propeller ware were reviewed with different operational parameter. The effects of the rudder and blade pitch angle of the propeller are investigated. The obtained results reveal that the rudder has a slight effect on the propeller’s hydrodynamic characteristics. Some of the investigators used induction factor to obtain normal induced velocity on the propeller. Whereas some investigator predicts the effect of the geometric characteristics on the propeller hydrodynamic performances is numerically studied and the study concluded also that the propellers with lower expanded area ratio give the best efficiency. Pre-swirl stators mounted in front of the propellers can bring a substantial energy saving of up to 5 % for both single and twin-screw ships as well. a successful design of the propeller-stator combination can be made using an effective combination of traditional lifting-line theory.

REFERENCES

[1] 1) L.N. Loi, N.C. Cong, N. Van He, CFD results on hydrodynamic performances of a marine propeller, TạpChíKhoaHọcvàCôngNghệBiển. (2019). doi:10.15625/1859-3097/19/3/13246.

[2] 2) Banik, M.R. Ullah, Computation of hydrodynamic characteristics of a marine propeller using induction factor method based on normal induced velocity, in: Procedia Eng., 2017. doi: 10.1016/j.proeng.2017.08.125.

[3] 3) E. Belhenniche Samir, A. Mohammed, I. Omar, Ç. Fahri, Effect of geometric configurations on hydrodynamic performance assessment of a marine propeller, Brodogradnja. (2016). doi:10.21278/brod67403.

[4] 4) [G.-J. Zondervan, J. Holtrop, J. Windt, T. van Terwisga, On the Design and Analysis of Pre-Swirl Stators for Single and Twin Screw Ships, 2nd Int. Symp. Mar. Propulsors. (2011).

5) S.K. Lee, Ice controllable pitch propeller - Strength check based on IACS polar class rule, in: Int. Conf. Exhib. Perform. Ships Struct. Ice 2008, ICETECH 2008, 2008.

