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Numerical Study of Marine Propeller Performance

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Abstract

The paper deals with the calculation of the performance of a marine propeller. For this the geometrical characteristics and operating conditions have to be known. In order to analyze the marine propeller performance, the calculation of section lift co-efficient (C_L) and section drag co-efficient (C_D) of a particular blade section will develop a particular advance co-efficient, J which is required. This calculation is performed using Ansys Fluent Software. After Knowing C_L ,C_D, other section particulars are calculated by using propeller theories and then the corresponding thrust co-efficient (K_T), torque co-efficient (K_Q) as well as efficiency of different blade sections can be calculated. Finally after that overall performance of the propeller is calculated. Then the calculated results are compared with available experimental results.

Keywords: Marine propeller performance, Lift co-efficient, Drag co-efficient, CFD

1. Introduction

Now a days, for the calculation of propeller performance various methods has been implemented to analyze more accurate rate of performance of a propeller. Different types of NACA sections have been taken into experimental or CFD analysis for ensuring better performance of the propeller. Lift coefficient and drag coefficient are one of the vital components for the calculation of propeller performance. In the case of CFD analysis, for the flow around NACA sections, well suited turbulence model has to determined, unless it may lead to accuracy degradation in the prediction of propeller performance.

Computational fluid dynamics (CFD) simulations employing Reynolds-averaged Navier-Stokes (RANS) turbulence models have made considerable contributions to propeller theory and become useful tools for propeller design and analysis [1]. A study over NACA 63-415 airfoil profile used different turbulence model in FLUENT [2]. Another study has investigated performance of wind turbine NACA0012 airfoil using FLUENT programs by Spalart Allmaras turbulence model [3]. An investigation about the lift and drag performances of NACA 0015 wind turbine airfoil were found as where there was the use of different turbulence models [4]. A propeller performance analysis program has been developed and integrated into a Genetic Algorithm for design optimization. The design tool will produce optimal propeller geometries for a given goal, which includes performance and/or acoustic signature [5]. A design tool has been developed by Miller [6] about the optimum geometry of 3D propeller. In his approach, employed to determine the aerodynamic propeller performance. The first and simplest method to predict propeller performance was developed by Rankine [7]. The blade element theory was formulated by Froude [8] and Drzewiecki [9]. The implementation of a combined momentum-blade element theory for light and moderately loaded marine propellers also studied [10].

In this research, the lift and drag coefficient of the blade sections of NACA 66 at different angle of attack has been calculated with the help of Ansys Fluent at a specific turbulence model to obtain required lift and drag coefficient at a defined angle of attack for various blade sections. The main aim of our study is to obtain the overall performance of the propeller with the help of that lift and drag coefficient and make a comparison with the available experimental result.

2. Lift and Drag coefficient analysis

In order to calculate the performance of NACA 66 first approach is to determine the C_L and C_D of the NACA 66 of different blade sections. The coefficient was evaluated in turbulent flow (0.3476 x 10^6) having viscous model of water density and dynamics viscosity of water 8.9 x10^{-4}around the airfoil using Ansys fluent. The First of all co-ordinate file was imported in geometry (Fig.1-4). Mesh analysis is performed by assuming relevance center is fine and smoothing is high presented in C-mesh domain presented in (Fig.5).quadrilateral method and structured mesh has been done for having finer mesh around the hydrofoil.

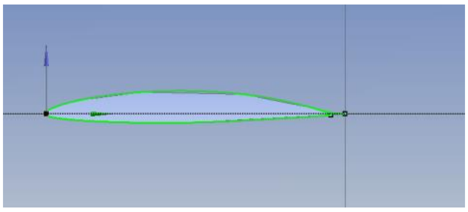

Fig.1.Profile of NACA-66, r/R=0.3

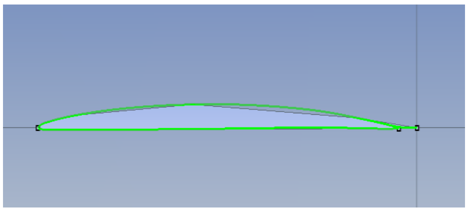

Fig.2.Profile of NACA-66, r/R=0.5

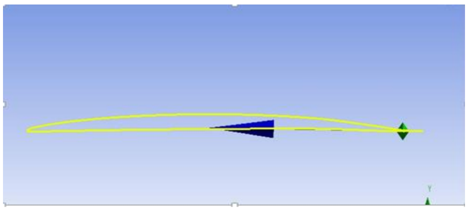

Fig.3.Profile of NACA-66, r/R=0.7

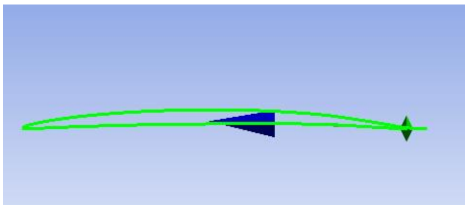

Fig.4.Profile of NACA-66, r/R=0.9

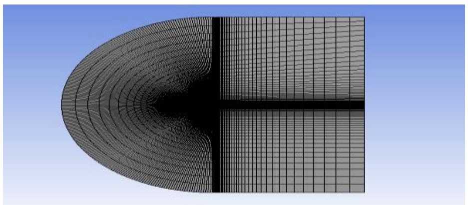

Fig.5.Mesh Sample of NACA-66

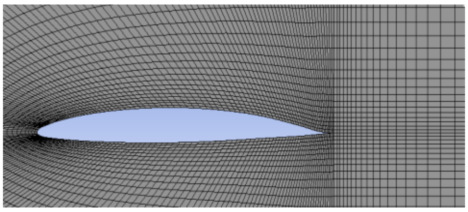

Fig.6.Sample of Detailed mesh of NACA

To do analysis of the NACA 66 section widely used two equation k-ε model has been employed .For the calculation of Lift coefficient and Drag coefficient least square Cell based gradients and second order upwind method are used for better convergence .The simulation has been done in different angle of attack(AOA) that varies from 0 degree to 15 degree

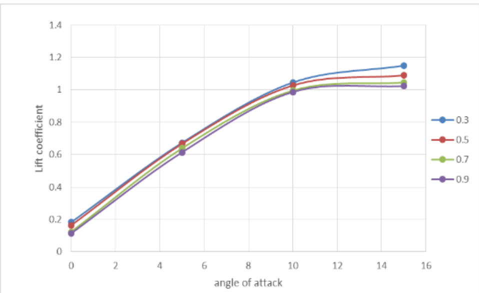

Fig.7.Lift coefficient vs angle of attack

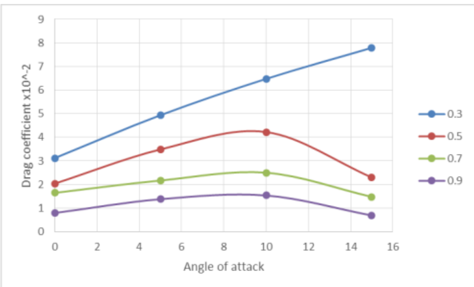

Fig.8.Drag coefficient vs angle of attack

3. Performance Calculation:

A propeller creates a thrust force out of the supplied power. The magnitude of this force is not constant for a given propeller, but depends on the velocity of the incoming water and the rotational velocity of the propeller itself. Thus tests of propellers usually cover a wide regime of operating conditions. Similar to airfoils and wings, the performance of propellers can be described by dimensionless (normalized) coefficients. While an airfoil can be characterized by relations between *angle of attack*, *lift coefficient* and *drag coefficient*, a propeller can be described in terms of *advance ratio*, *thrust coefficient*, and *power coefficient*.

For the calculation of the performance of the propeller from the analyzed data of the NACA 66 section the following mathematical formulation has been used: [11]

Our defines non dimensional lift and drag coefficient as follows

$$C_L = \frac{L}{\frac{1}{2}\rho A V^2} \quad (1)$$

$$C_D = \frac{D}{\frac{1}{2}\rho A V^2} \quad (2)$$

Where L is the lift force and D is the drag force of the sections.

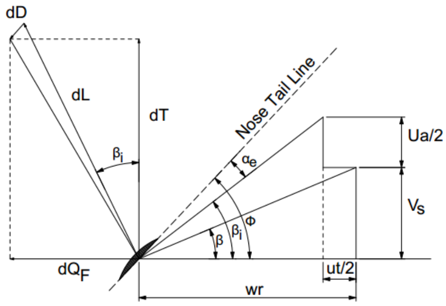

Fig.9.Diagram of velocities and forces for a propeller blade element

The blade element will then produce a lift dL and a drag dD (Fig.9), where

$$dL = C_D \cdot \frac{1}{2}\rho c dr V_R^2 \quad (3)$$

$$dD = C_D \cdot \frac{1}{2}\rho c dr V_R^2 \quad (4)$$

Here

$$V_R = V_A \frac{\cos(\beta_i - \beta)}{\sin\beta} \quad (5)$$

Where, β is the advance angle and V_R is the resultant velocity.

The thrust and torque produced by an element for all the z blades as dT and dQ, then from figure

$$\frac{1}{z}.dT = dLCos\beta_i - dD\sin\beta_i = dLCos\beta_i(1 - \frac{dD}{dL}\tan\beta_i) \quad (6)$$

$$\frac{1}{r.z}dQ = dL\sin\beta_i - dDCos\beta_i = dLCos\beta_i(\tan\beta_i + \frac{dD}{dL}) \quad (7)$$

Here, β_i is the hydrodynamic pitch angle

Putting $\tan\gamma = \frac{dD}{dL}$ and writing dL and dD in terms of C_L and C_D the following expressions can be found

$$dT = z.C_L.\frac{1}{2}\rho c dr V_R^2 Cos\beta_i (1 - \tan\beta_i \tan\gamma) \tag{8}$$

$$dQ = r.z.C_L.\frac{1}{2}\rho c dr V_R^2 Cos\beta_i (\tan\beta_i + \tan\gamma) \tag{9}$$

Calculation of overall thrust coefficient, torque coefficient and efficiency

$$K_T = \int_{x_h}^{1} \frac{dK_T}{dx}.dx \tag{10}$$

$$K_Q = \int_{x_h}^{1} \frac{dK_Q}{dx}.dx \tag{11}$$

Where,

$$\frac{dK_T}{dx} = z.C_L \frac{\frac{C}{D}}{4n^2D^2} V_R^2 \cos\beta_i (1 - \tan\beta_i . \tan\gamma) \tag{12}$$

And

$$\frac{dK_Q}{dx} = z.C_L.r \frac{\frac{C}{D}}{4n^2D^3} V_R^2 \cos\beta_i (\tan\beta_i + \tan\gamma) \tag{13}$$

z is the number of blades in these equations. The above equations are the general equations for finding the thrust coefficient (K_T) and the torque coefficient (K_Q) which are needed to calculate the optimum efficiency of the propeller from the formula of propeller theory which can be written as

$$\eta = \frac{J}{2\pi} \times \frac{K_T}{K_Q} \tag{14}$$

Where

$$J = \frac{V_A}{nD}$$

J denotes here as advance coefficient.

4. Numerical Procedure

To calculate the thrust and torque coefficient, for using the above mentioned formula there are some common variables which are specific properties of a particular propeller that has been constant throughout all the formulas. These are tabled below

Table 1. Common values

No of blades	Propeller Diameter(m)	Ship Speed(knots)	Propeller r.p.s	J
5	3.8125	35	5	0.9444721311

Now with these values and with the help of the Fig.5 and Fig.6 different C_L and C_D values of different section with corresponding variation of α_e values, values of different $\frac{dK_T}{dx}$ and $\frac{dK_Q}{dx}$ have been calculated.

Table 2. C_L and C_D values of corresponding α_e [12]

x	φ°	β_i°	α_e°	C_L	C_D
0.3	54.01	52.66	1.35	0.32	0.036
0.5	38.76	37.42	1.34	0.26	0.025
0.7	28.55	27.38	1.17	0.24	0.021
0.9	21.75	20.81	0.94	0.20	0.017

Using all these values and using the equations that are mentioned above, graphs of dK_T and dK_Q have been plotted.

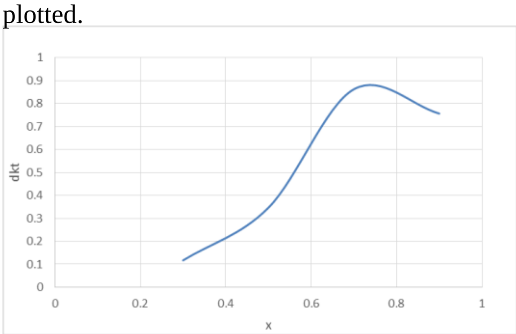

Fig.10. dK_T vs x curve

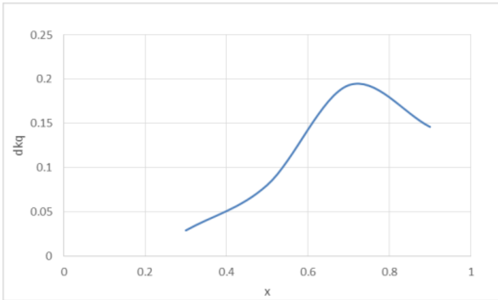

Fig.11. dK_Q vs x curve

After calculating the values of dK_T and dK_Q for four sections and plotting them into the graph, seventeen values of dK_T and dK_Q from the section x=0.2 to x=1.0 at a regular interval of 0.05 has been identified from Fig.10 and Fig.11 and these are being integrated using simpson's formula to evaluate the value of K_T and K_Q . And then using equation (14) the efficiency of the propeller has been calculated.

5. Results and Discussion

After calculation the final thrust coefficient is K_T =0.385333 and K_Q =0.639977 and the efficiency of this propeller is η = 63.99%. There are various approaches for analyzing the performance of a propeller. Our objective was to use CFD solver to analysis the propeller performance and make a comparison with standard results. Therefore a standard value is K_T is plotted in graph and compared with result which has been obtained from using Ansys Fluent.

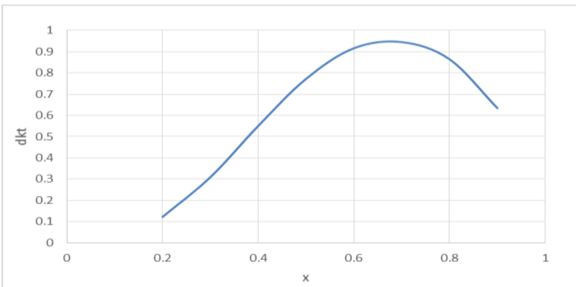

Fig.12. Standard value of dK_T vs x curve

After integrating the standard value the K_T we get the value 0.397966 and our approached value was 0.385333.This thrust co-efficient will play a vital role for calculation of further efficiency calculation. The efficiency of NACA 66 is usually varies for various solution method. The causes of deviation of our result from standard thrust co-efficient is the C_L and C_D which has been determined by CFD methods. Therefore, it can be stated that better numerical solution and more iteration number will certainly minimize the error and will ensure more accurate results.

6. Conclusion

In a summary it has been found that co-efficients are vital properties of any blade sections. Therefore if accurate value of co-efficient can be ensured, that will lead to perfect calculation of a marine propeller performance. Through this research study it can be said that CFD solver will be very useful for calculating propeller performance. The approach which has been implemented in this study can be used for any types of propeller and the approach will ensure relatively more accurate results than any other approaches.

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