IJARSCT

ISSN (Online) 2581-9429

International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)

Impact Factor: 6.252

Volume 2, Issue 5, May 2022

Design and Analysis of Marine Propeller

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Abstract: *This paper presents a comparison between propellers varying in design to evaluate their performance and efficiency. A propeller is a type of fan that transmits power by converting rotational motion into thrust. A pressure difference is produced between the forward and rear surfaces of airfoil shape blade and fluid is accelerated behind the blades which generates two forces, one along the longitudinal direction of ship which is the axial force called thrust force and tangential force which produce the required torque. As propeller has great influence on the propulsive performance of ship, propeller design is important technology for energy saving in ship propulsion. Generally, alloy of aluminium or bronze material are used for manufacturing of marine propeller. The propeller is a complex geometry which requires high end modelling software. The solid model of propeller is developed in HydroComp PropCad 2005 and SolidWorks 2019 and a tetrahedral mesh is generated for this model using HYPER MESH and simulation is carried out using SolidWorks. By considering all the study and benefits this model helps to find the optimum propeller for defined objectives. Based on optimized parameters the propellers performance is calculated by the simulation of designed model.*

Keywords: Marine Propeller, Simulation, Modelling

I. Introduction

The propeller whose name comes from the Latin "propellare" (to drive forward) is a very old idea. The propeller converts the engine's output by rotation into thrust which balances the resistance against driving forward at that particular throttle speed. A propeller is the most common propulsor on ships, imparting momentum to a fluid which causes a force to act on the ship. Nearly every aspect of a marine propeller-driven ship's performance - such as its nominal pitch, number of blades, and skew angle - is directly influenced by the efficiency and performance of its propeller.

The propeller is designed in a way such that, if you cut the propeller radially at any random radius from its centre, then the cut section of the propeller blades will have a certain pitch (magnitude depends upon how twisted it is along the length of the hub). The propeller design usually starts with determining the main particulars (diameter, mean pitch, blade area). The propeller is determined by the number of blades, its diameter and its pitch.

The propeller is design by using both Bernoulli law and Newton third law. The propeller is very significant part of the propulsion plant. The propeller must be designed carefully in conjunction. with each specific vessel to get not the high efficiency only but also. the perfect level of comfort. The propeller is determined by the number of blades, its pitch, and its diameter and off course the rotation direction (left or right) as shown in figures (1, 2) below. The number of blades is different according to the use of propeller. There are two blades propeller, three blades propeller which is the most often used, four blades propeller and multi blades propeller.

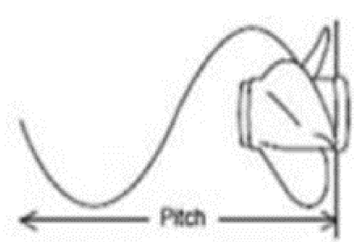

Fig. 1.1 pitch of propeller

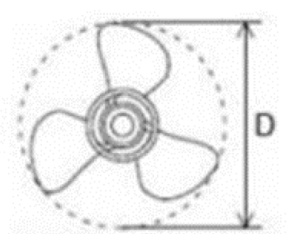

Fig. 1.2 diameter of propeller

1.2 Classification of Propeller

Pitch of a propeller can be defined as the displacement that a propeller makes for every full revolution of 360˚. The classification of the propellers on the basis of pitch is as follows.

A. Fixed Pitch Propeller

The blades in the fixed pitch propeller are permanently attached to the hub. The fixed pitch type propellers are cast and the position of the blades and hence the position of the pitch is permanently fixed and cannot be changed during the operation.

B. Controllable Pitch Propeller

In a Controlled Pitch type propeller, it is possible to alter the pitch by rotating the blade about its vertical axis by means of mechanical and hydraulic arrangement. This helps in driving the propulsion machinery at constant load with no reversing mechanism required as the pitch can be altered to match the required operating condition.

1.3 Propeller Geometry

- Pitch: Propeller pitch is the distance the prop would move forward in one rotation if it were moving through a soft solid
- Leading Edge: forward edge of blade, first to encounter the water stream
- Trailing Edge: last part of the blade to encounter the water stream
- Skew Angle: Tangential component of the angle formed on the propeller between a radial line going through the hub section midchord point and a radial line going through the midchord of the section of interest and projected
- Rake Angle: Rake is the number of degrees the propeller blade angle perpendicular to the propeller hub
- Expanded area ratio: Ratio of total blade area divided by the propeller disc area AE/A0, where expanded area AE = Expanded area of all blades outside of the hub.
- Developed area ratio: AD/A0, where developed area AD = Developed area of all blades outside of the hub.
- Projected area ratio: AP/A0, where projected area AP = Projected area of all blades outside of the hub.
- Mean width ratio: (Area of one blade outside the hub/length of the blade outside the hub)/Diameter.
- Blade width ratio: Maximum width of a blade/Diameter.
- Blade thickness fraction: Thickness of a blade produced to shaft axis/Diameter
- Blade Root: The root of a propeller blade is where the blade attaches to the hub.
- Blade Tip: The tip is the outermost edge of the blade at a point furthest from the propeller shaft.

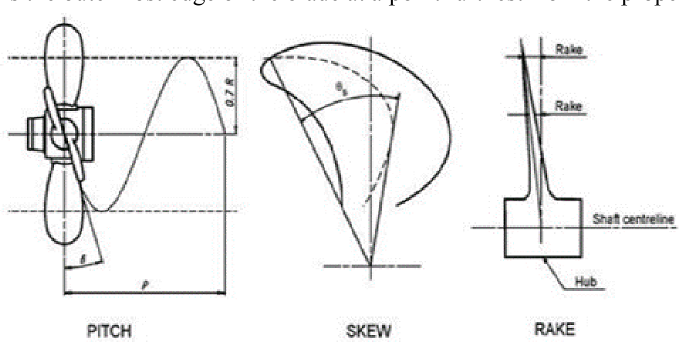

Figure 1.3: propeller geometry

1.4 Objective

Designing a propeller specific to the propulsion system and the ship's performance requirements will best overcome this problem. The objective of this work is to create a process for the design and analysis of marine propeller for best meet mission and performance requirements. The main objective is to increase the thrust force using modified design using the same input power. Also, our motive is to maximize efficiency using input power and minimizing cavitation.

Here we are selecting B-series type of propeller. We will be using this propeller for twin screw ferry passenger ship. This ferry passenger ship is used in saline water in seas. This particular ship has a ship speed of 15.5 kts. The engine of the ship produces delivered power of 1137 HP i.e., 836 kW with number of blades 4 and diameter of propeller 1.98 m revolving at 300 rpm.

SR NO.	PARAMETERS	VALUES (mm)
1.	Propeller Diameters	1980
2.	Hub Diameter	404
3.	Shaft Diameter	330
4.	Nominal Pitch	1000
5.	Skew Angle	20
6.	Rake Angle	10
7.	Root Thickness	57.22
8.	Edge Thickness	5.94

Table 1.1: Parameters of propeller

II. Literature Review

T. Chittaranjan Kumar Reddy, K. Nagaraja Rao. The work is directed towards the study of marine propeller working and its terminology, simulation and flow simulation of marine propeller has been performed. The von misses' stresses, resultant deformation, strain and areas below factor of safety has been displayed. The velocity and pressure with which the propeller blades push the water has been displayed in the results [1].

P. Durga Neeharika, etal. The present work deals with modeling and analyzing the aluminum propeller blade of an underwater vehicle for its strength. A propeller is a complex geometry which requires high end modeling software. The solid model of propeller is developed in CATIA-V5 R20 and a tetrahedral mesh is generated for this model using HYPER MESH and static analysis is carried out using ANSYS [2].

The panel method provides an elegant methodology to solve a class of flow past arbitrarily shaped bodies in both two and three dimensions. The basic idea is to discretize the body in terms of a singularity distribution on the body surface, to satisfy the necessary boundary condition, and to find the resulting distribution of singularity on the surface, thus obtain fluid dynamic properties of the flow [3].

Lerbs extended Glauert's methods to calculate element contributions to thrust and torque along the blade span. The results were integrated over the propeller blades to give overall performance of the propellers. He effectively produced the first ·practical numerical propeller design method applied under various non-optimum conditions of loading [4].

In 1955, Eckhardt and Morgan developed an engineering approach to the lifting line method. They assumed an optimum distribution of circulation, and a reduced thrust, proportional to the Goldstein factor due to the number of blades, and proceeded to calculate induced velocities. This greatly reduced the number of calculations. They also showed that their method produced only small errors under light and moderate loading conditions and therefore it is a very useful design tool [5].

Kerwin's method became known as the lifting line method for marine propellers, because the force produced by the circulation is assumed to act along radial lines in place of the blades, similar to the theory of airscrews [6].

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III. Methodology

3.1 HydroComp PropCad

PropCad keeps your drawings, reports, and 3D geometry together within a single project. Users can design, save, and import their own section blade definitions. These blade sections can be modified by adding camber or cup. Designers can create advanced blade shapes with progressive pitch. PropCad's interface provides full control over the blade parameters and hydrodynamic section shapes. It's powerful and fast. A library of standard designs and distributions allows users to rapidly develop new designs and design variants.

- By the help of PropCad we can analyse and get a proper visualization of our model.
- We also get to know details of the project which helped us to analyse in better way and it also helped us in the calculation part which is very important factor in this project.
- With the help of input factor in PropCad we get a proper view of the propeller. Terms for e.g., Diameter, Pitch, Skew angle, Type of propeller etc.

3.2 SolidWorks

SolidWorks is a solid modelling computer-aided design and computer-aided engineering application published by Dassault Systèms. SolidWorks is a solid modeler, and utilizes a parametric feature-based approach which was initially developed by PTC (Creo/Pro-Engineer) to create models and assemblies. The software is written on Parasolid-kernel.

3.3 Steps of Propeller Design in SolidWorks

STEP 1: As you can see the blades with airfoil is fully designed with the help of SolidWorks.

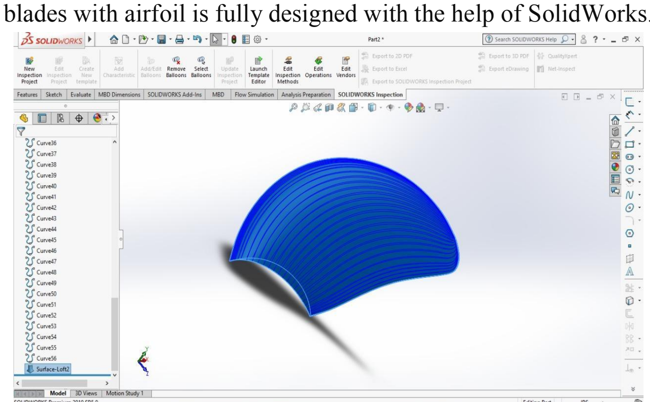

Figure 3.1: SolidWorks step 1

STEP 2: As the blade is developed, we move forward to develop shaft of the propeller which is the most important part of propeller.

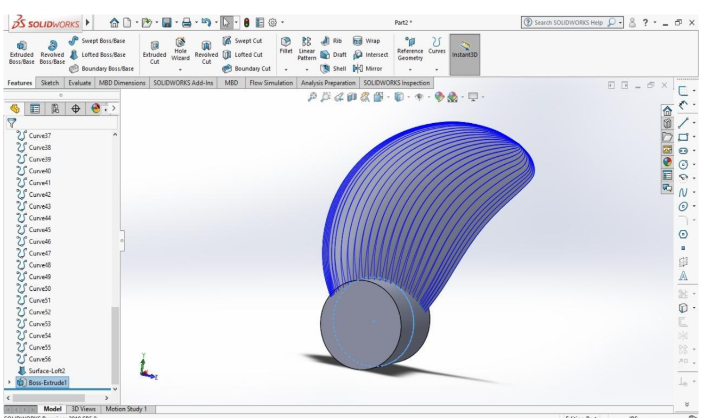

Figure 3.2: SolidWorks step 2

STEP 3: As you can see revolving of blade with the option of circular pattern around it.

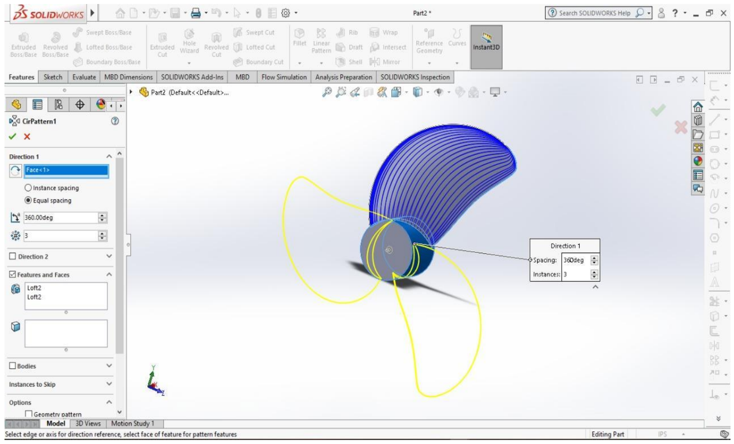

Figure 3.3: SolidWorks step 3

STEP 4: With all input and before steps we can the propeller is formed.

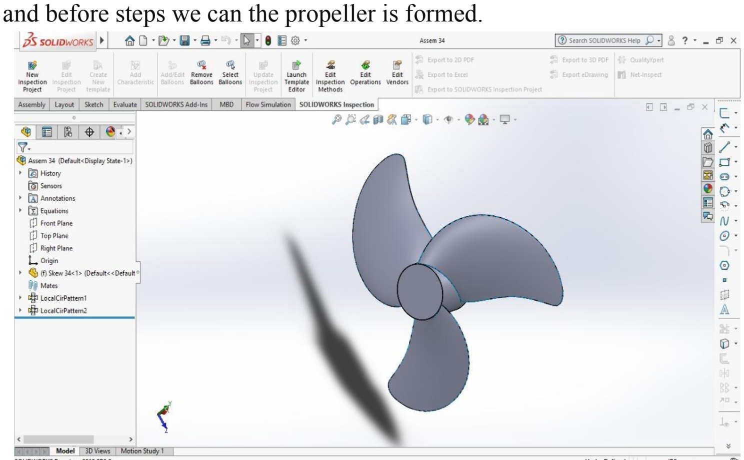

Figure 3.4: SolidWorks step 4

STEP 5: So, after the propeller is formed, we also created a duct surrounding it.

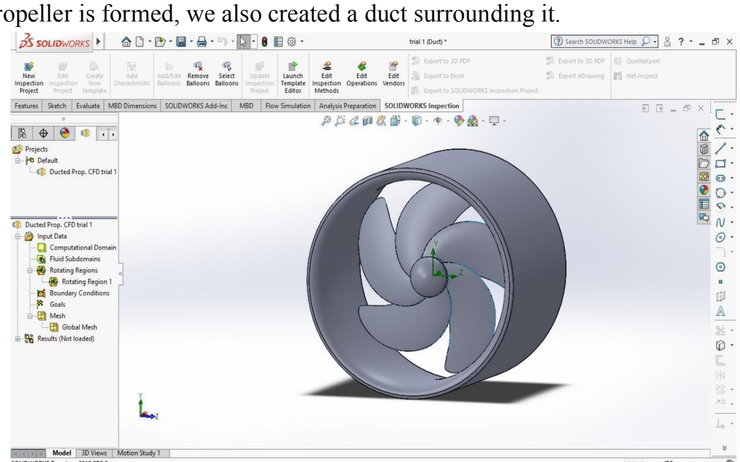

Figure 3.5: SolidWorks step 5

IV. Trials of Model

To achieve the greater thrust force and the efficiency, we have done the calculations with the help of given as well as result parameters. First, we have done designing and modelling of different types of propellers with different geometry. With the reference of the designed model of propeller we have done the simulation and analysis.

So, in total we have done 7 trials of modelling and simulation of propeller. In which first three propellers are of same no. of blades i.e., 3. These 3 trials varies in the angle of skew i.e., 20deg, 30deg and 34deg. Other two trial are taken with the no. of blades equals to 5. And they vary with the angle of skew given as 30deg and 34deg. Sixth trial is done with the no. of blades equal to 4 and the angle of skew equal to 34deg.

Among these trials we got that the sixth model i.e., 4 blades and 34deg skew angle results in the ideal thrust force and efficiency. So, in the last trial we have added the duct/nozzle to the propeller with ideal results. And done the simulation of propeller.

4.1 Trial of Ducted Propeller

In this trial we have added duct to the propeller.

No. of Blades: 4

Skew Angle: 34deg

SR NO.	PARAMETERS	VALUES (mm)
1.	Duct Length	1103.63
2.	Outer Diameter	2191.26
3.	Inner Diameter	1996.94
4.	Duct Area	1000

Table 4.1 Parameters for Duct

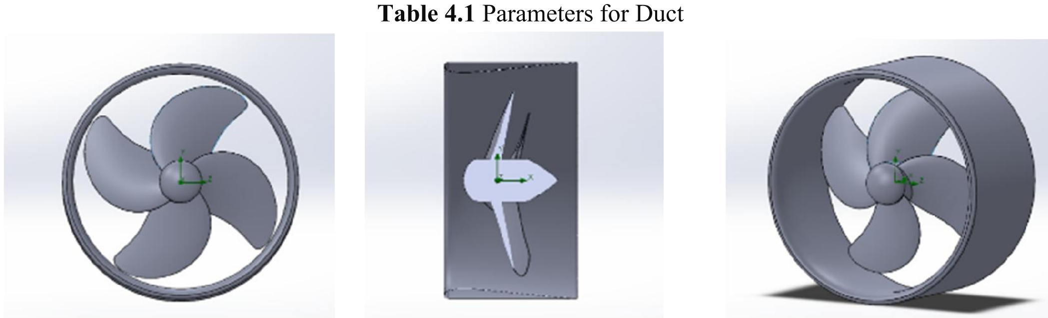

Fig. 4.1 Propeller with Duct

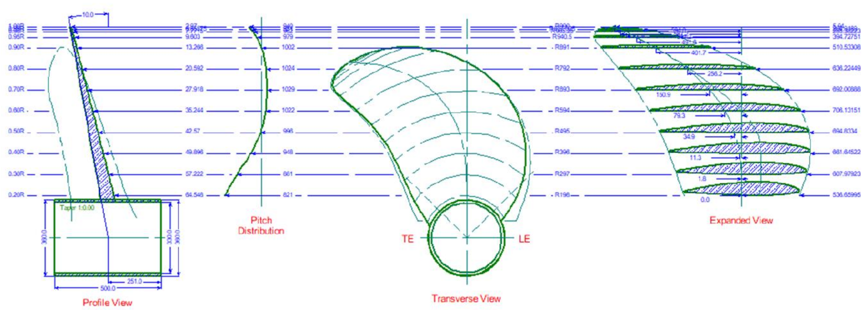

Fig. 4.2 Sectional Data for Propeller

4.2 Results

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value	Progress [%]	Use In Convergence	Delta	Criteria
Thrust Force by Propeller	[N]	23021.60698	23969.17984	23021.60698	24832.91498	100	Yes	1631.250693	12449.82172
Thrust Force by Duct	[N]	3340.32079	3477.89917	3340.32	3603.22686	100	Yes	195.9239036	1230.192768
Total Thrust	[N]	26361.92777	27447.07901	26361.92698	28436.14184	100	Yes	1579.827241	13390.58767

Fig. 4.3 Results for Ducted Propeller

4.3 Result Graphs

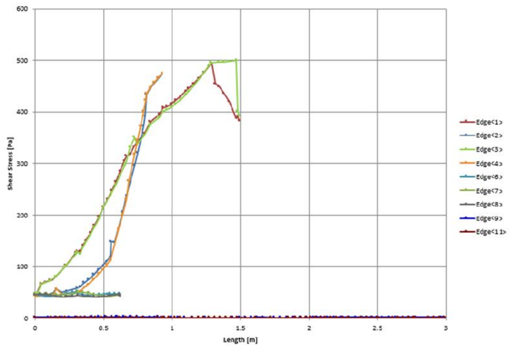
Fig. 4.4 shear stress graph

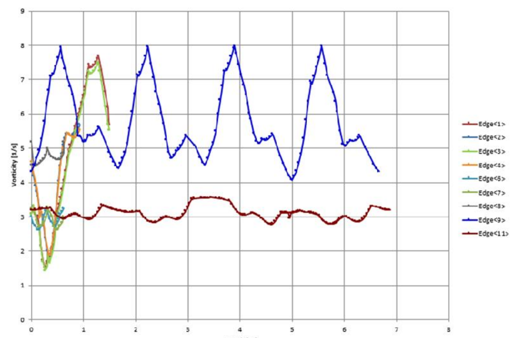
Fig. 4.5 vorticity graph

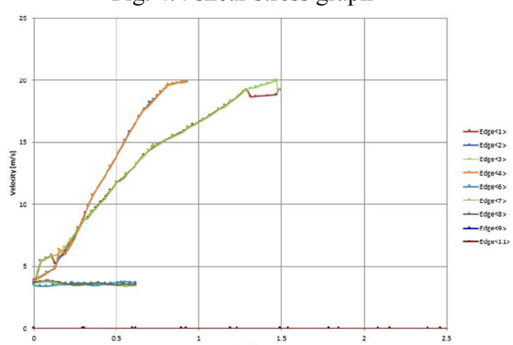
Fig. 4.6 velocity graph

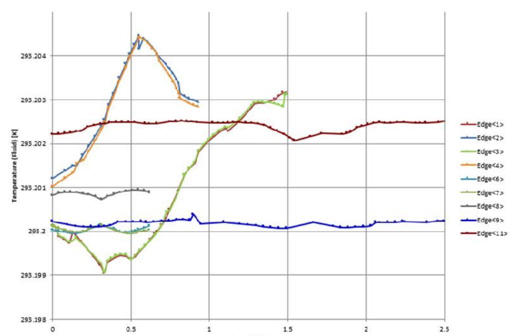
Fig. 4.7 temperature graph

4.4 Surface Plots

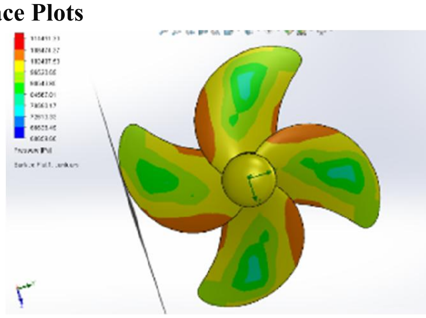
Fig. 4.8 pressure plot

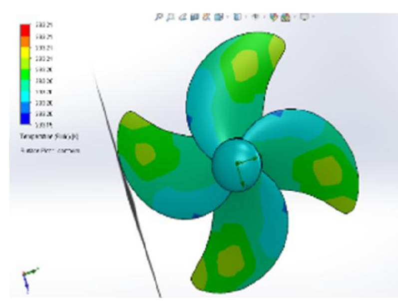
Fig. 4.9 temperature plot

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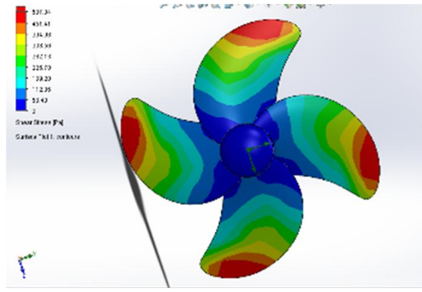

Fig. 4.10 shear stress plot

V. Results Observed

As we observe from the above trails of different blades with blade number as 3 blade, 4 blade & 5 blade, we get different values of thrust force is different for each blade. It is often different for different skew angle for the same number of blades. Closely observing the result table, we observe a relation between thrust force and skew angle for the type of same number of blade propeller.

Trial no.	No. of Blades	Skew Angle	Thrust Force (KN)
Trial 1	3	20°	19.808
Trial 2	3	30°	19.006
Trial 3	3	34°	19.682
Trial 4	5	30°	22.099
Trial 5	5	34°	25.521
Trial 6	4	34°	23.021

Table 4.1 Results for Trials

Considering the number of blades of the propeller with skew angle 34deg, the thrust force for 3 blades, 4blade and 5 blade are different and can be easily observed that with increase in number of blades, the thrust force also increases. But it is also that the same thing is not observed for the factor of efficiency of propeller even though efficiency is directly proportional to thrust force. The reason behind such abnormal behaviour is the concept of drag force. In fluid dynamics, drag is a force acting opposite to the relative motion of any object moving with respect to a surrounding fluid. It is a type of friction acted upon the blades due to surrounding water. The drag Force is directly proportional to the surface area of contact, which increases with increases in number of blades. You can observe the rag force in above table as friction force and can observe that with increase in number of blades, drag increases which is max for 5 blade and minimum for3 blade. So, in normal practical applications, we generally balance thrust force and drag.

Considering the fact, we concluded that a 4-blade 34-degree skew propeller is ideal and efficient propeller with the thrust force of 23.021 kN and efficiency of 72.66%. To increase the efficiency of propeller furthermore we added duct/nozzle to it. As the propeller with 4-blade 34-degree skew is ideal propeller, we have added duct to it to increase the thrust force and efficiency. As per the results we have got that with the addition of duct we can get increase in thrust force by 3.34 kN. As per the results we concluded that a ducted propeller with 4-blade, 34-degree skew angle is ideal and well suited for the problem statement.

VI. Conclusion

As per the results obtained the thrust force will be maximum for the last trial i.e. For the ducted propeller having no. of blades equal to 4 and angle of skew equal to 34deg. Also, if mass becomes higher it will increase the load on engine causing more fuel consumption also the velocity obtained is minimum of all model. The lowest mass with significant amount of thrust force but as per the structural analysis deformation is greater with considerable high equivalent stress.

The main drawback of this study is that no practical experimental proof is done to support the results obtained as the setup or manufacturing is costly. Moreover, not only material change would provide less deformation, reduce cavitation, increase life of blade and corrosion resistance but there is another newly developed method called melonite surface treatment of metal to tackle this objective. Future research would include performing experimental results, advantage of melonite surface treatment technique over material changing, manufacturing and other financial cost analysis.

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