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Analysis of Thrust & Torque B-Series Propeller using CFD: Variation of Blade and nProp

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***Abstract*— the propeller is an important part of determining the ship's maneuverability. The propeller itself is a tool to produce thrust that comes from engine power which is transmitted through the shaft. At their defined radial position, Propeller thrust (N) and torque (Nm) are formed from propeller blade foil sections at the local lift and drag. Particularly, the total propeller thrust will be integrated into an axial lift vector for the sections from root to tip. The selection of a good propulsion device will affect the force of the ship. One way to choose the propulsion of the ship is the selection the type of propeller and the provision of new propeller variations to produce maximum thrust. For that reason, this study aims to analyze of thrust and torque of B-series propellers using CFD by varying the number of blades: 3, 4, and 5 blades; and the propeller speed (nProp) i.e., 325, 525, and 725 rpm. The numerical analysis using computational fluid dynamics (CFD) was conducted to identify the thrust (N) and force (Nm) of the propeller. The CFD simulation consists of three main steps: pre-processor, solver manager, and post-processor. The results show that the thrust and torque significantly increased at the higher number of blades and nProp.**

Keywords— CFD, B-series, thrust, torque, nProp.

I. Introduction

The ship's propeller or commonly referred to as the propeller is one part of the ship that is driven by an engine, which has the function to get the thrust for the speed of the ship [1]. With the thrust generated by these propellers, the ship can move forward or backward. With such a construction and form, when the propeller is rotated, assisted by other components, it will produce a thrust for the ship.

A propeller is used as the main propulsion (M/E) on various types of ships. The various kind of propellers used based on the needs or requirements and types of ships operated while sailing i.e., K-Series Propeller, B-Series Propeller, Controllable Pitch Propeller (CPP), and Fixed Pitch Propeller (FPP) [2-4]. To improve the propeller thrust, torque, and efficiency (propeller performance), various modifications have been made.

Propeller thrust (N) and torque (Nm) are formed from propeller blade foil sections at the local lift and drag at their defined radial position [5]. Particularly, the total propeller thrust will be integrated into an axial lift vector for the sections from root to tip. Figure 1 illustrates how the three principles of thrust forces, torque, and centrifugal are applied as point loads acting on a radial span of the blades of the propeller.

The thrust on the screw propeller occurs because of the difference in pressure distribution between the back of the blade and the face of the blade [6]. The distribution of pressure on the area/front of the propeller leaf is relatively larger than the distribution of pressure on the area/back of the propeller leaf, so this causes a lift force. The vector projection of the lift force on the lateral axis of the ship is then called the thrust of the ship (thrust).

Until now, the public assumes that the magnitude of the thrust of the ship is directly proportional to the power absorbed by the propeller. So, if it is desired to increase the service speed of the ship, it is necessary to increase the thrust of the ship, and the increase leads to the need for an increase in the thrust of the ship.

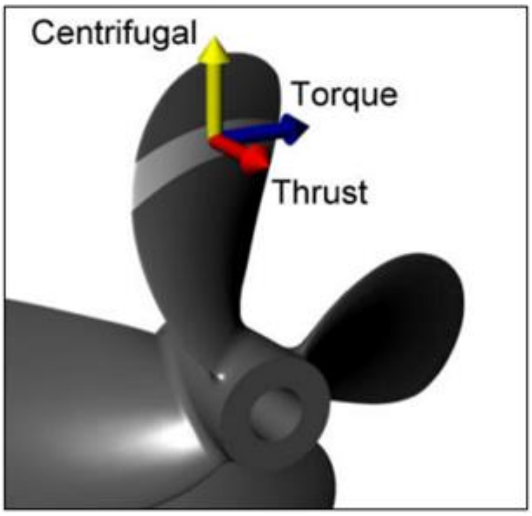

Figure. 1. Illustration of Force Diagram

Some researchers focus on the analysis of the force and thrust of the propeller i.e., analysis of Propeller C4-40 with the variation of pitch and the addition of the Kort Nozzle [7]. It shows that the thrust, torque, and efficiency values changed significantly with the addition of Kort nozzle 37 on the propeller C4-40

Arifin et.al, have researched the B-screw ship propeller performance by identifying the effect of the tubercle ship propeller on the result of the force and thrust that has been developed by using CFD [5]. It is shown that the modification of Tubercle Leading Edge (TLE) performance (thrust, torque, and efficiency) has been influenced by the modification of the blade.

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II. METHOD

This study used B-screw propeller types to be simulated. The simulation method using the Computational Fluid Dynamic (CFD) approach was used by varying the number of blades 3, 4, and 5 blades; also, as the nProp by 325, 525, and 725 rpm. The principal dimension of the propeller to be simulated in this research is shown in the following Table. 1.

TABLE 1.
PRINCIPAL DIMENSION OF THE MODEL

No	Propeller Parameter	Dimension
1	Type	B-3, B-4, B-5
2	Diameter	30 cm
3	Number of Blades	3, 4, 5
4	Blades Section	B-Series
5	nProp variations	325, 525, 725
6	P/Db	0.8

A. Propeller Characteristics

Each type of each ship's propeller has characteristics of different performance curves. So, the study of the characteristics of the propeller ship cannot be generalized to the overall shape or type of propeller. The characteristics of the propeller load can be displayed with a graph by some coefficients in the form of sizes. The diagram gives Torque and Thrust as functions of speed. The characteristics of the propeller consist of the (KT), (KQ), and (J) [8]. The equation is as follows:

$$KT = \frac{Tprop}{\rho \; x \; n^2 \; x \; D^4} \quad (1)$$

$$KQ = \frac{Q}{\rho \; x \; n^2 \; x \; D^5} \quad (2)$$

$$\eta o = \frac{J \; x \; KT}{2\pi \; x \; KQ} \quad (3)$$

$$J = \frac{VA}{n \; x \; D} \quad (4)$$

Where:
KT : Thrust coefficient
KQ : Torque coefficient
J : Advanced coefficient
Va : Advanced Speed (knots)
D : Diameter (m)
n : Propeller rotation (rps)
Tprop : Thrust propeller (N)
Qprop : Torque propeller (Nm)
ρ : Fluid density (Kg/m^3)

B. Propeller Modelling

The model of the propeller to be simulated was constructed based on the principal dimension of the propeller, which is remodeled by using the propeller modeling software PropCad. PropCad is defined as the software used to design propeller display drawings with 2D and 3D views and produce design drawings with actual sizes that are displayed in CAD format. The data used is derived from the calculation results of the MARIN DESP Program.

The result of the 3D geometry ordinate of the propeller modeled by PropCad is shown in Figure 2 to Figure 4.

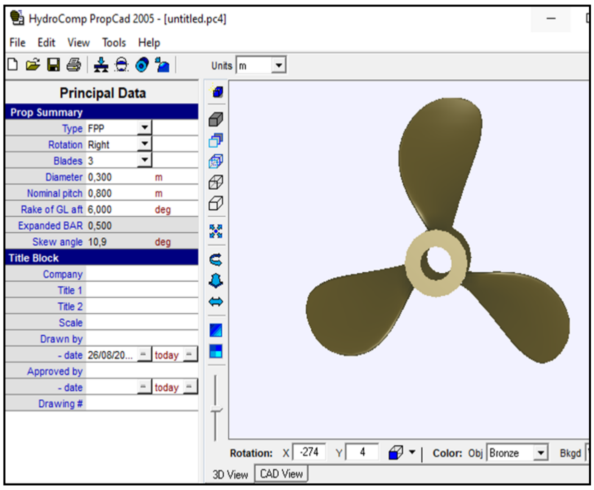

Figure. 2. 3D Geometry Ordinate B3

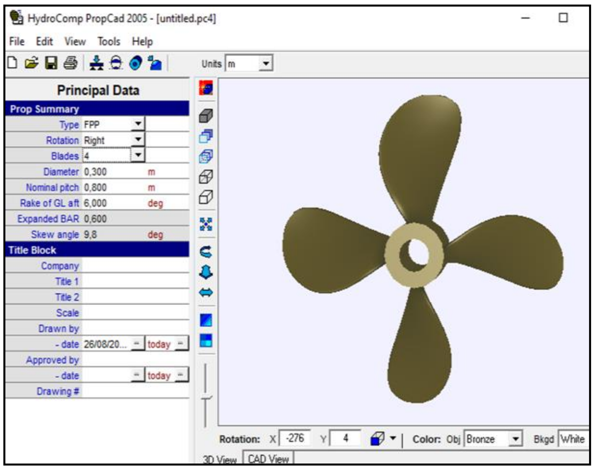

Figure. 3. 3D Geometry Ordinate B4

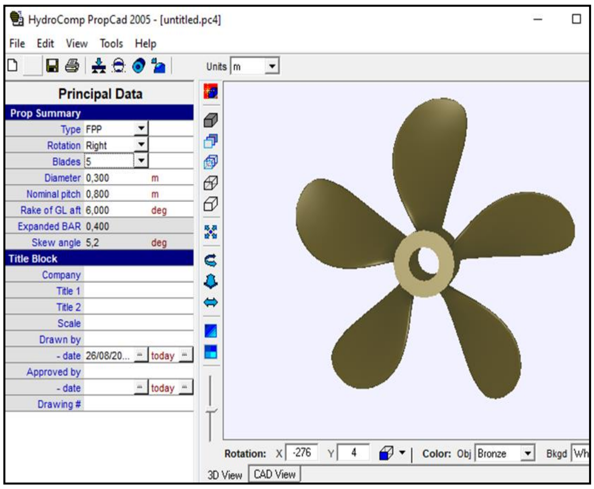

Figure. 4. 3D Geometry Ordinate B5

To design the solid model from the 3D geometry ordinate from PropCad, the model should be exported to the SolidWorks format. Below is the visualization of the design using Solidwork.

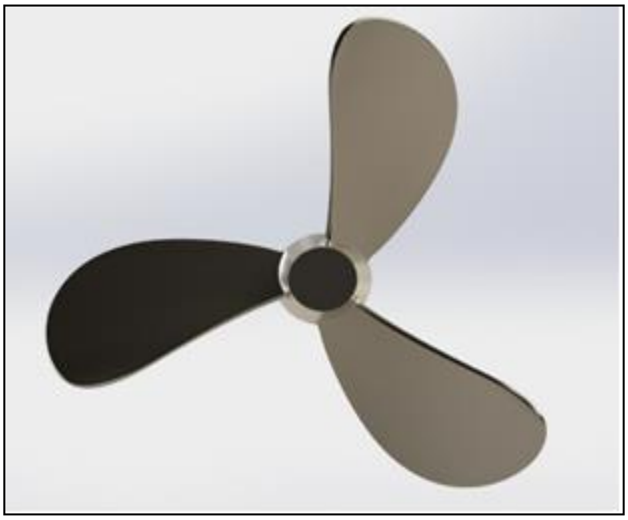

Figure. 5. Exported Model of B3 using Solidworks

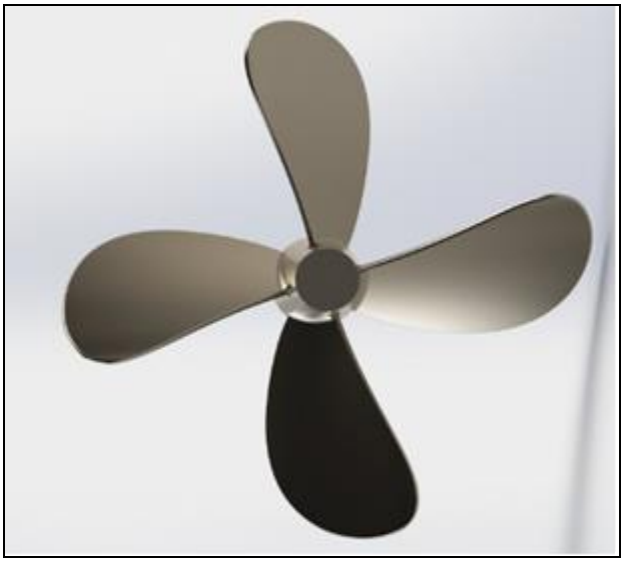

Figure. 6. Exported Model of B4 using Solidworks

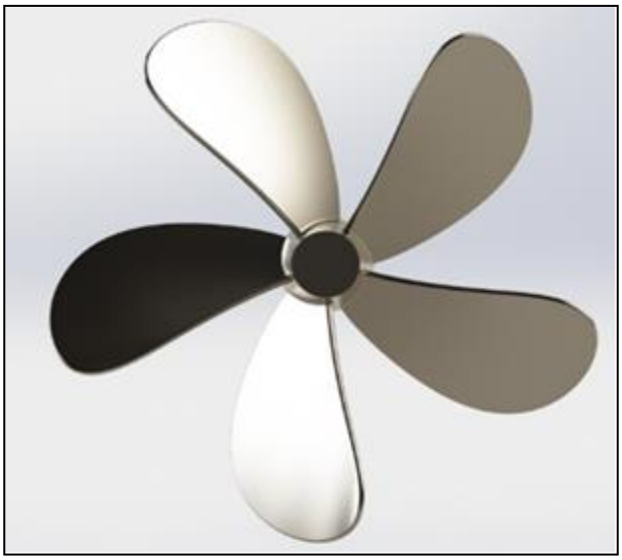

Figure. 7. Exported Model of B5 using Solidworks

The configuration of the propeller to be simulated is shown in Table 2. The total of the model to be simulated is 3 x 1 x 1 x 3 = 9 model.

TABLE 2.
CONFIGURATION OF THE MODEL

Type	Blade	Db (cm)	P/Db	N (rpm)
B-Series	3 Blades	30	0.8	325
	3 Blades	30	0.8	525
	3 Blades	30	0.8	725
B-Series	4 Blades	30	0.8	325
	4 Blades	30	0.8	525
	4 Blades	30	0.8	725
B-Series	5 Blades	30	0.8	325
	5 Blades	30	0.8	525
	5 Blades	30	0.8	725

C. Simulation Using CFD

The CFD program used here is a tool to help model the propeller configuration that will be analyzed. The next step is to modify the shape or variations, starting from the number of blades, diameter, and pitch propeller. From this modeling will be obtained data pressure distribution to be further processed so that the result is an overview of the distribution of pressure, area, and wall shear.

The most basic thing is why the concept of CFD (CFD software) is widely used in the world industry is with CFD analysis can be done of a system by reducing the cost of experiments and course a long time to experiment. Or in the engineering design process, shorter steps are to be taken. Another thing that underlies the use of the CFD concept is understanding deeper into a problem to be solved or in this case a deeper understanding of fluid flow characteristics by looking at the results in the form of graphics, vectors, contours, and even animation. As for some of the advantages obtained by using CFD among others:

- Minimize time and cost in designing something product if the design process is carried out by testing experiments with high accuracy.
- Have the ability to study systems that can control a difficult trial or not possible in experiments.
- Have the ability to study under any conditions dangerous at or after passing the critical point (including safety studies and accident scenarios).
- Accuracy will always be controlled in the design process.

The application of CFD for solving flow problems on the propeller has progressed quite rapidly lately. Even currently, the CFD technique is part of the design process in the design spiral diagram [9].

Computational Fluid Dynamics is the science of determining the numerical solution of fluid dynamics. In general, the CFD calculation process consists of 3 parts main: (a) pre-processor, (b) processor, and (c) post-processor [10].

- Pre-processor: the pre-processor is the stage where data is input starting from domain definition and boundary condition definition or boundary conditions. At this stage, it is also an object to be analyzed divided by the number of grids or often referred to as meshing. After the fluid domain is formed the next step is to mesh the model. It should be noted that the smaller the elements are made, the more elements are formed and later the mesh and computation process will take a long time and take a lot of time. Below is the meshing result at the pre-processor stage.

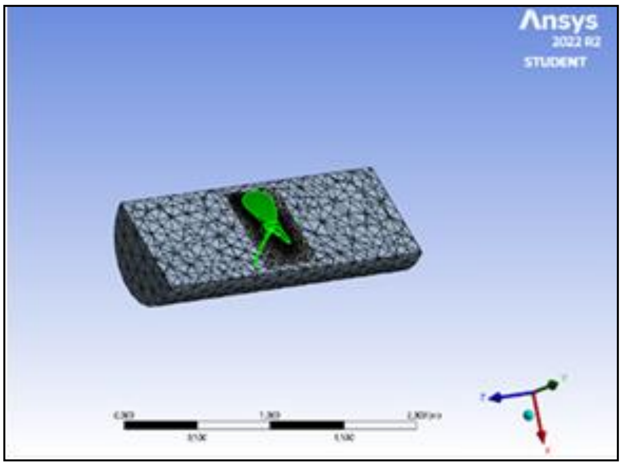

Figure. 8. Meshing boundary and propeller

Next, we set each criterion that we use by setting the Set-up. The set-up used is criteria that have been validated beforehand so that get a result that has an error not far from the results of research that has been done. The following domain physics is used.

TABLE 3.
DOMAIN ROTATING DEFAULT

Domain - rotating	
Type	Fluid
Location	B131
Materials	
Water	
Fluid Definition	Material Library
Morphology	Continuous Fluid
Settings	
Buoyancy Model	Non Buoyant
Domain Motion	Rotating
Angular Velocity	3.2500e+2 [rev min^-1]
Axis Definition	Coordinate Axis
Rotation Axis	Coord 0.3
Reference Pressure	1.0000e+0 [atm]
Heat Transfer Model	Isothermal
Fluid Temperature	2.5000e+1 [C]
Turbulence Model	k epsilon
Turbulent Wall Functions	Scalable

TABLE 4.
DOMAIN STATIONARY DEFAULT

Domain - stationary	
Type	Fluid
Location	B265
Materials	
Water	
Fluid Definition	Material Library
Morphology	Continuous Fluid
Settings	
Buoyancy Model	Non Buoyant
Domain Motion	Stationary
Reference Pressure	1.0000e+0 [atm]
Heat Transfer Model	Isothermal
Fluid Temperature	2.5000e+1 [C]
Turbulence Model	k epsilon
Turbulent Wall Functions	Scalable
Domain Interface – Default Fluid Fluid Interface	
Boundary List 1	Default Fluid Fluid Interface Side 1
Boundary List 2	Default Fluid Fluid Interface Side 2
Interface Type	Fluid Fluid
Settings	
Interface Models	General Connection
Frame Change	Frozen Rotor
Mass and Momentum	Conservative Interface Flux
Mesh Connection	GGI

Here is a picture of the set-up settings on the boundary that has been made in the previous stage.

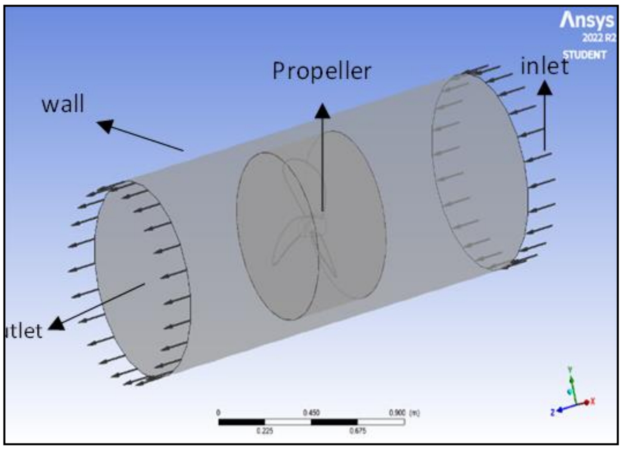

Figure. 9. Boundary Set-up

- Processor: this stage is the process of calculating the input data with the equation that is involved iteratively. This means that the calculation is done until the result goes to the smallest error or until it reaches a convergent value. Calculations are carried out through volume control by process integration of discrete equations. An illustration of the convergency result is shown in Figure 10.

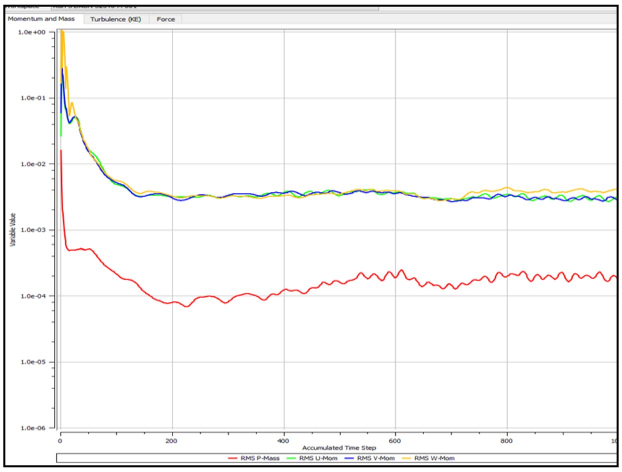

Figure. 10. Convergence Model

- Post-processor: the final stage is the post-processor stage where calculation results are interpreted in pictures, graphics, and even animation with patterns of a certain color.

III. Results and Discussion

A. Total Pressure of the Propeller

By using the CFD simulations, the total pressure of the propeller could be analyzed, and it was illustrated based on the following figure.

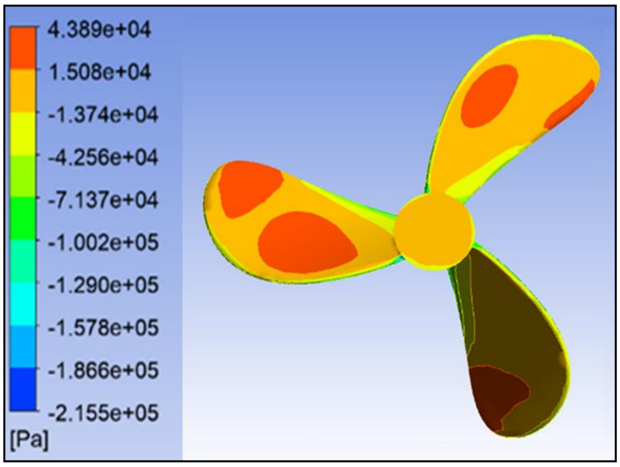

Figure. 11. Total Pressure of 3 Blades 725 rpm

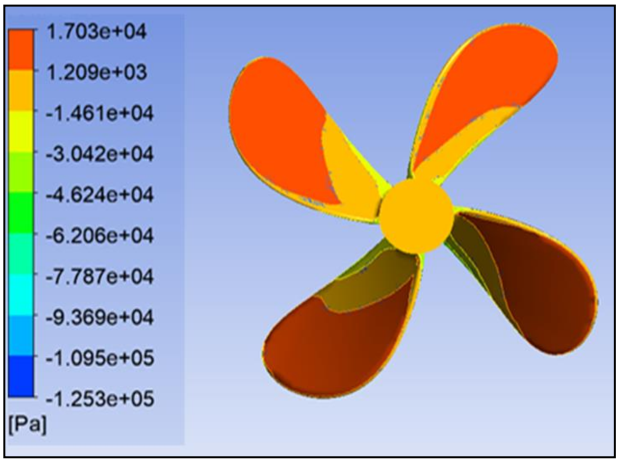

Figure. 12. Total Pressure of 4 Blades 725 rpm

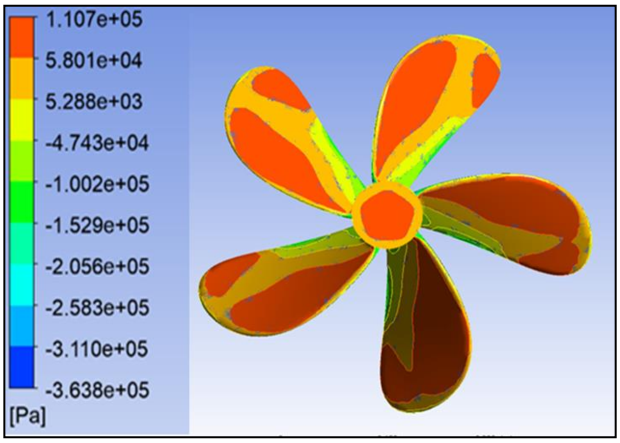

Figure. 13. Total Pressure of 5 Blades 725 rpm

Based on Figure 11-13 it is shown that the total pressure of the propeller significantly increases followed by the increased number of blades and propeller speed (nProp). The detailed results of the total pressure are shown in Figure 14.

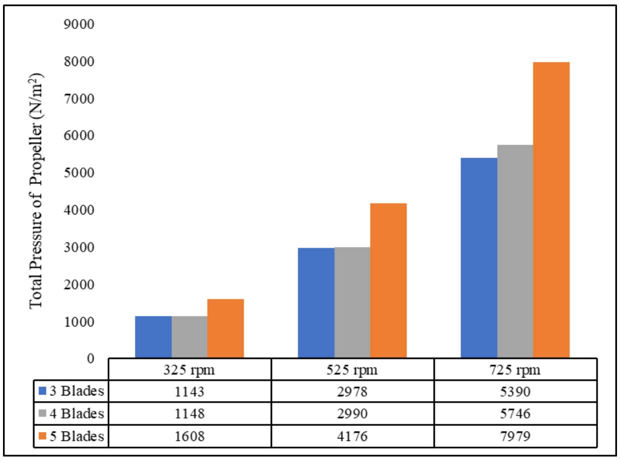

Figure. 14. Total Pressure of Propeller

B. Propeller Thrust

Propeller thrust which is refers to the amount of force that the propeller behind it can produce to propel the vehicle forward. Propeller thrust is developed by changing the pitch of the blade to the optimal angle to develop the most thrust.

The result of propeller thrust using CFD of B3, B4, and B5 with varied speed propellers 325, 525, and 725 rpm is shown in Table 5.

TABLE 5.
PROPELLER THRUST (KN)

Type	Blade	Db (cm)	nProp (rpm)	Thrust (kN)
	3 Blades	30	325	2.10
B-Series	3 Blades	30	525	5.51
	3 Blades	30	725	10.0
	3 Blades	30	325	2.26
B-Series	3 Blades	30	525	5.94
	3 Blades	30	725	11.4
	3 Blades	30	325	3.19
B-Series	3 Blades	30	525	8.28
	3 Blades	30	725	15.7

Based on the CFD simulations, the propeller thrust result of the model increased due to the change in blade number and propeller speed. It was illustrated in Figure 15.

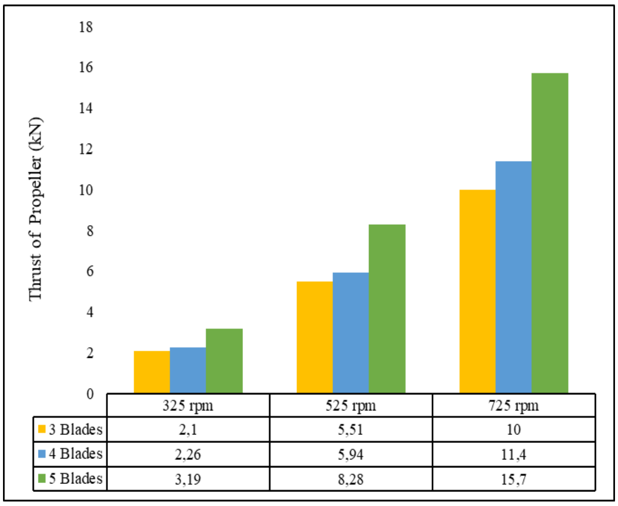

Figure. 15. Propeller Thrust Results

C. *Propeller Torque*

Through Table 6, the calculation value is obtained, the greater the propeller rotation, the larger the propeller will be. It is illustrated in Figure 16.

TABLE 6.
PROPELLER TORQUE (NM)

Type	Blade	Db (cm)	nProp (rpm)	Torque (Nm)
	3 Blades	30	325	346
B-Series	3 Blades	30	525	907
	3 Blades	30	725	1727
	3 Blades	30	325	364
B-Series	3 Blades	30	525	957
	3 Blades	30	725	1840
	3 Blades	30	325	512
B-Series	3 Blades	30	525	1333
	3 Blades	30	725	2530

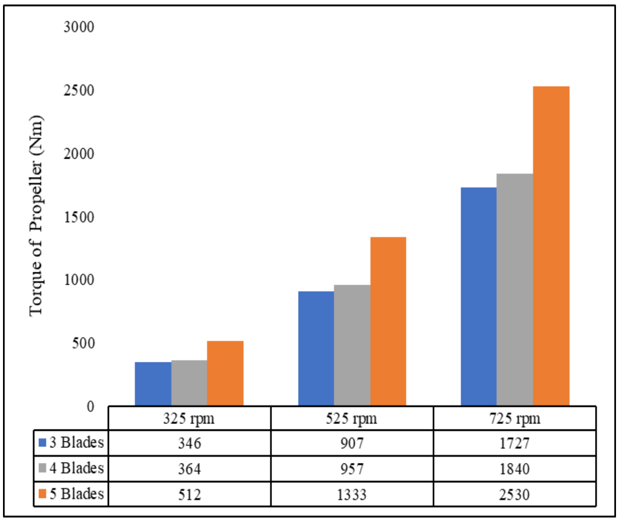

Figure. 16. Propeller Torque Results

Based on the simulation results, it can be identified that by increasing the speed of the propeller from 325, 525, and 725 rpm, the thrust force and torque propeller significantly increased at the higher number of blades and nProp as shown in Table 7 and Figure 17. This is also because rpm is directly proportional to thrust, which can be seen from the Wageningen data formula eq. 1 Tprop = KT x ρ x n^2 x D^4.

TABLE 7.
PROPELLER THRUST & TORQUE

Type	Blade	nProp (rpm)	Thrust (N)	Torque (Nm)
	3 Blades	325	2100	346
B-Series	3 Blades	525	5510	907
	3 Blades	725	10000	1727
	3 Blades	325	2260	364
B-Series	3 Blades	525	5940	957
	3 Blades	725	11400	1840
	3 Blades	325	3190	512
B-Series	3 Blades	525	8280	1333
	3 Blades	725	1570	2530

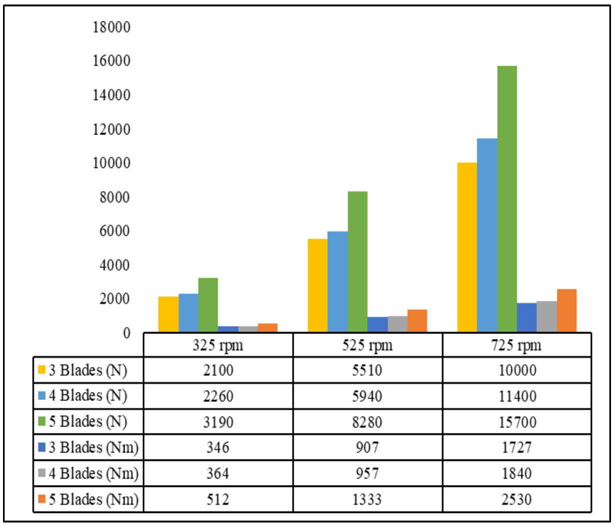

Figure. 17. Thrust and Torque Propeller Results

As shown in Figure 17, it can be understood that the propeller thrust tends to increase on the higher propeller speed and higher number of blade propellers. For example, on the propeller with 3 blades, the thrust propeller at nProp 325 rpm is 2100 N, increased to 5510 N at nProp 525 rpm, and gets higher to 10000 N at nProp 725 rpm. In the case of the influence of the blade number, the thrust increased from 2100 N at 3 blades, 2260 N at 4 blades, and 3190 N at 5 blades.

From Figure 17, also can be understood that the value of the torque tends to increase on the higher propeller speed and higher number of blade propellers. For example, on the propeller with 3 blades, the torque propeller at nProp 325 rpm is 346 Nm, increased to 907 Nm at nProp 525 rpm, and gets higher to 1727 Nm at nProp 725 rpm. In the case of the influence of the blade number, the torque increased from 346 Nm at 3 blades, 364 N at 4 blades, and 512 N at 5 blades.

IV. CONCLUSION

By analyzing the thrust and torque of B-series propellers using CFD by varying the number of blades: 3, 4, and 5 blades; and the propeller speed (nProp) i.e., 325, 525, and 725 rpm it can be concluded that the thrust force and torque of propeller tend to increase on the higher rotation and higher number of blade propeller. The higher thrust and torque propeller value was produced by the B5 at 725 rpm with 15700 N, and 2530 Nm.

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