Thrust Analysis and Type of Kaplan Series and B Series Torque Propeller on Monohull, Catamaran, and Trimaran Vessels with Variations in Number of Blade using Computational Fluid Dynamic

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Keywords: Propeller, Monohull, Catamaran, Trimaran, CFD.

Abstract: One part of the propulsion system is a propeller. The choice of a good driving device will affect the force of the ship. One way of selecting a ship propulsion is the selection of the propeller type as well as providing new variations of the propeller to produce the maximum thrust force. Kaplan series and B Series are the most widely used blade type propellers on ships. The purpose of this study was to determine the optimum thrust value and the lowest torque from the variation of the monohull, catamaran and trimaran propeller vessels. Variations made are adding the number of blades to 4 and 5. The model was simulated using the computational fluid dynamic method on the Ansys CFX software. The results of this study indicate that the monohull propeller K6 60 Series pitch ratio 0.7 has the greatest thrust value of 333797 N. For catamaran ships, propeller K4 60 Series pitch ratio 0.6 has the greatest thrust value of 61986.4 N. For trimaran ships, propeller K4 60 Series pitch ratio 0.6 has the greatest thrust value of 0.8727 N.

1 PRELIMINARY

Propeller efficiency is influenced by several things including the shape of the ship's hull and the ship's propulsion system itself.

In determining the optimal ship propulsion system, propeller design planning is an important aspect that needs attention. Ship propeller design is also considered for ship operational needs in terms of its economy (Hartono, 2008). Propeller is one aspect that must be planned properly to achieve the purpose of the ship's function in achieving speed. The speed of the ship cannot be separated from the good propeller design in order to get the optimal thrust produced by propeller motion (Nurul, 2013). Seen from its function, monohull, catamaran, and trimaran vessels must have a good propulsion system to produce optimal thrust values in the propeller. Thrust is the driving force that results from the lifting force on the back of the propeller that moves and is in line with the movement of the ship. One of the requirements that need to be considered in the propeller design to get maximum thrust is the number of blades (Trimulyono, 2015).

The greater the value of the blade area ratio, the greater the thrust force (Bangkit et.al, 2016). The previous Kaplan series type propeller design is the addition of the propeller end plate (Andilolo, 2017).

In this study, the propeller planning made is to do variations in the number of blade added. Blade area ratio is the ratio between the blade area of the propeller and the full rotation area of the blade tip or commonly referred to as A0 (Bangkit et.al, 2016). While the pitch ratio is the axial distance round the propeller.

The study conducted is to do variations on the existing propeller model. Variations made include increasing the number of propeller blade to 4 and 5 blade.

The limitation of the problem in this study is to only analyze the thrust and torque values of the variation of the propeller model. This study also ignores the factors and conditions of fluid flow from the ship's hull and only analyzes the flow distribution behind the propeller. The shape of the propeller hub was also ignored in this study. Propeller variation model will be analyzed using computational fluid dynamic method. In this study do not do the cost analysis calculation.

The purpose of this study was to obtain the greatest thrust value and torque from the variation of the propeller model that was carried out. This study is expected to provide benefits in the development of shipping technology, especially in the field of ship

Adietya, B., Chrismianto, D., Erlangga, J. and Harno, .
Thrust Analysis and Type of Kaplan Series and B Series Torque Propeller on Monohull, Catamaran, and Trimaran Vessels with Variations in Number of Blade using Computational Fluid Dynamic.
DOI: 10.5220/0008373000210028
In *Proceedings of the 6th International Seminar on Ocean and Coastal Engineering, Environmental and Natural Disaster Management (ISOCEEN 2018)*, pages 21-28
ISBN: 978-989-758-455-8

propulsion. In addition, this study can be used as a reference source in terms of consideration of the selection of propellers that are appropriately applied to ships and can also be a reference for propeller producers to innovate propeller products to be produced.

2 METHOD

2.1 Data Collection

The data needed for this study are the data of the main size of monohull, catamaran and trimaran ship propellers.

Table 1: Main Size Propeller B-Series.

Tipe	B Series
Number of blade	4
Diameter	0,8 meter
Blade Area Ratio	0,70
Pitch	0,8
Angle of Rake	0
Propeller Rotation	0 rpm

2.2 Modelling and Variation

Modelling of the Kaplan Series propeller is based on data from the main size of the propeller and the addition of variations to the propeller. In this study the parameters used are as follows:

- Constantly Parameter:
  1. Main Size from ship propeller.
- Unconstantly Parameter
  1. Number of blade 4 and 5
  2. Rpm 600, 900, and 1000
  3. Propeller type B-Series and Kaplan

Table 2: Shows Data on 12 Variations of the Kaplan Series Propeller Model.

Model	Number of Blade	*Rpm*	*Propeller Type*
Monohull 1	4	600	B-Series
Monohull 2	4	600	Kaplan
Monohull 3	5	600	B-Series
Monohull 4	5	600	Kaplan
Catamaran1	4	1000	B-Series
Catamaran2	4	1000	Kaplan
Catamaran 3	5	1000	B-Series
Catamaran 4	5	1000	Kaplan
Trimaran 1	4	900	B-Series
Trimaran 2	4	900	Kaplan
Trimaran 3	5	900	B-Series
Trimaran 4	5	900	Kaplan

2.3 Model Simulation

Analysis of variations in propeller models using the Computational Fluid Dynamic method on the Ansys CFX software. This method has often been used to analyze fluid flow especially in thrust analysis and torque propeller in previous studies.

2.4 Study Sites

This research was conducted at the hydrodynamic laboratory, Department of Naval Architecture, Faculty of Engineering, Diponegoro University, Semarang.

3 RESULTS AND DISCUSSION

3.1 Model Making Stage

In making a propeller model, the main size of the propeller is used as the initial data entered in the PropCad software. Variations that will be applied to the propeller are also modeled in this software. Then a 3D propeller model will be produced along with propeller geometry data. Here are the results of the visualization of the propeller model from PropCad software.

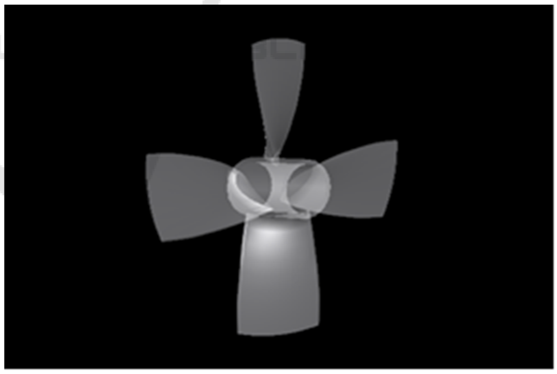

Figure 1: Propeller on Software Prop Cad.

After modelling the PropCad software, it was repeated using Solidwork software to improve the model. The propeller model made is 16 models with variations in the number of blade, blade area ratio and pitch ratio as well as 1 model with the addition of nozzle kort. The following are the results of visualization modelling using solidwork software.

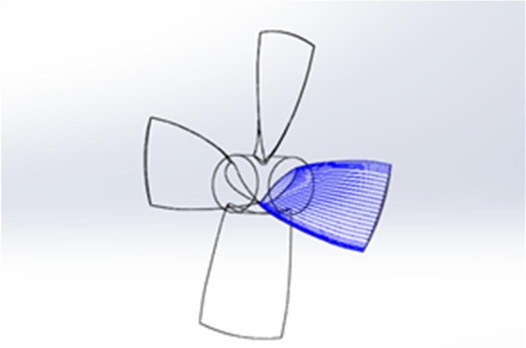

Figure 2: Propeller on Software Solidwork.

3.2 Simulation of Computational Fluid Dynamics

The propeller model created in Solidwork software then exported in the iges format to be imported into the Ansys CFX software. The steps of propeller simulation on Ansys CFX software include:

1. Geometry
2. Mesh
3. Setup
4. Solution
5. Result

3.2.1 Geometry Stage

At this stage the model entered must be solid. The next step is to make a tubular fluid domain. The size of the fluid domain is adjusted to the propeller model to be analyzed.

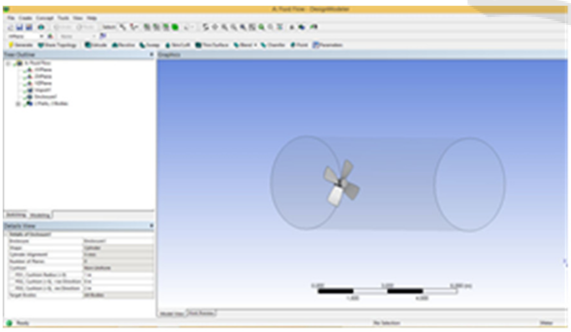

Figure 3: Geometry Stage Visualization.

3.2.2 Mesh Stage

After the fluid domain is formed, the next is meshing the model. The initial step in meshing is to determine the size of the element used. The smaller elements that are made running time are longer and the file capacity is greater.

Statistics	
Nodes	64590
Elements	349484
Mesh Metric	None

Figure 4: Meshing result statistics.

3.2.3 Setup Stage

In the setup stage data input will be used for computational fluid dynamic simulations. The initial step at this stage is to create a default domain. Domains created include domains for fluids and propellers. The next step is making boundaries. Boundaries made include inlet, outlet and wall in the domain fluid.

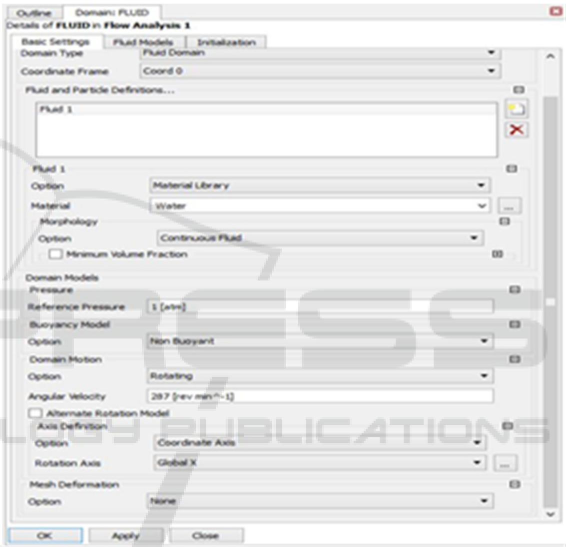

Figure 5: Default domain.

The next step is making initialization. The menu is almost the same as the boundary. The final step is the determination of the solver which one of its functions determines the unit for measures in the simulation process and control solver.

3.2.4 Solution Stage

The solution phase is a running calculation process in the form of literacy from the basic equation of computational fluid dynamic.

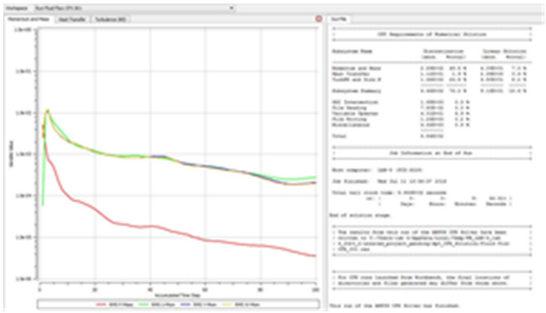

Figure 6: Convergence Running Model.

3.2.5 Result Stage

At the result stage the running results can be known. The amount of thrust and torque can be obtained as well as the model and flow visualization can be displayed.

3.3 Propeller Validation

In this study the validation used was the result of previous research. The main size of the propeller and the main size of the ship in this study are the same as previous studies. Validation is used to determine the right boundary condition at the setup stage, so that it can be used to analyze the propeller model analyzed in this study.

Validation references for propellers use the Wageningen B-Series graph. The propeller model used is the Wageningen B4 70 Series type. The maximum error for validation between computational fluid dynamic and calculation results is 5%.

In general, the characteristics of the ship propellers in the open water test conditions are as presented in the KT-KQ-J diagram.

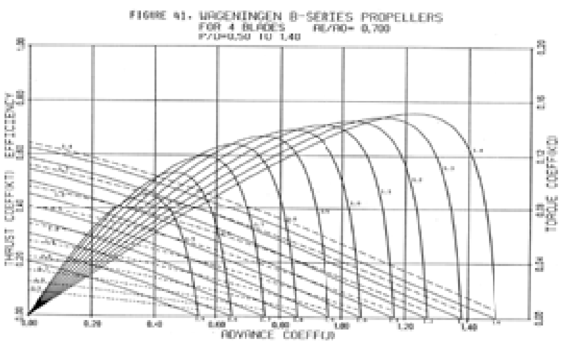

Figure 7: Diagram Kt-Kq-J B4-70 (Bernitsas, 1981).

Mathematical calculations to find thrust and torque are using the formula obtained from the calculation of Wageningen B-Series. Equation models for ship propeller performance characteristics are as follows:

$$KT = \frac{T}{\rho n2D4} \quad (1)$$

$$KQ = \frac{Q}{\rho n2D5} \quad (2)$$

$$J = \frac{Va}{nxD} \quad (3)$$

Where KT is the propeller thrust coefficient, KQ is the propeller torque coefficient, J is the advance propeller coefficient, Va is the advance (fr / s) velocity, D is the propeller diameter (ft), n is the propeller rotation (rev / s), T is the thrust propeller (lbf), Q is the torque propeller (lbf / ft) and ρ is the type of fluid.

The results of thrust and torque calculations on computational fluid dynamic simulations and mathematical calculations using Wageningen B-Series charts are as follows:

Table 3: Thrust Propeller Validation (Wibowo et.al, 2017).

Rotation Speed (rpm)	The Calculation Thrust Results (N)	The CFD Result (N)	Error (%)
287	123006,49	122713,00	0,23

Table 4: Validation Torque Propeller (Wibowo et.al, 2017).

Rotation Speed (rpm)	The Calculation TorqueResult (Nm)	CFD Simulation Results (Nm)	Error (%)
287	39646,94	40196,4	1,38

From the results of computational fluid dynamic calculations compared to the results of mathematical calculations of propellers using the Wageningen B-Series graph, the margin of error is below 5%. This means that the setup parameters in the computational fluid dynamic calculation are quite accurate. Then the setup parameter will be used in this study.

3.4 Results Analysis

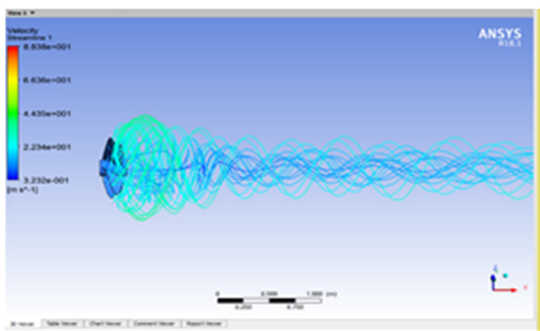

Figure 8: Result Streamline Monohull 1.

In the streamline model Monohull 1 has a less stable and constant fluid flow. Fluid flow is less smooth and turbulence is quite high in front of the propeller.

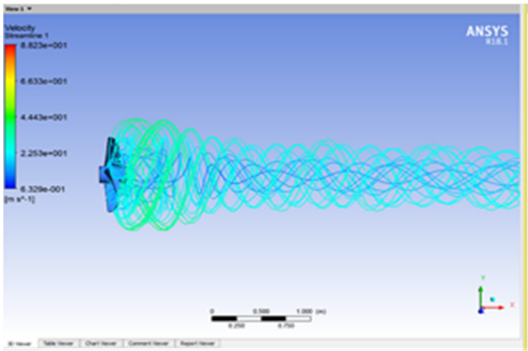

Figure 9: Result Streamline Monohull 2.

In the streamline model Monohull 2 has a stable and constant fluid flow. Fluid flow is quite smooth and turbulence is smaller than before especially the area in front of the propeller and along the flow is quite low.

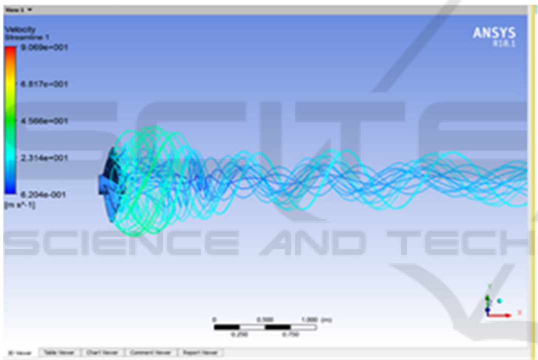

Figure 10: Result Streamline Monohull 3.

In the streamline model Monohull 3 has a fluid flow that is less stable and not constant. The fluid flow is less smooth and the turbulence in front of the propeller is quite high.

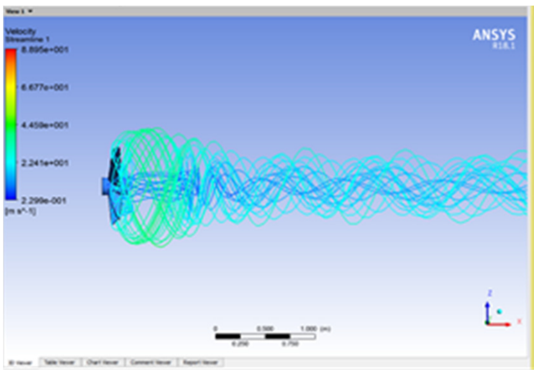

Figure 11: Result Streamline Monohull 4.

The streamline Monohull 4 model has a stable and constant fluid flow. Fluid flow is smooth enough and turbulence is quite low along streamlined flow.

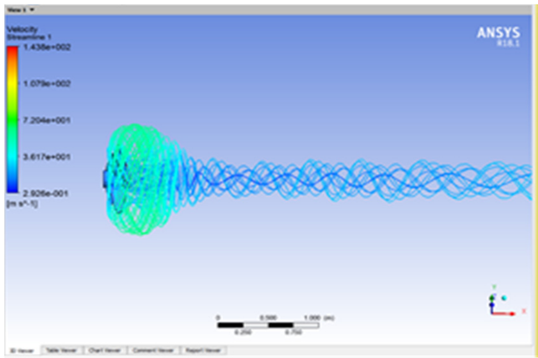

Figure 12: Result Streamline Catamaran 1.

The streamlined propeller model of Catamaran 1 has a fairly stable and fairly constant fluid flow. Fluid flow is still quite smooth but the emergence of turbulence is very large especially in the front area of the hub.

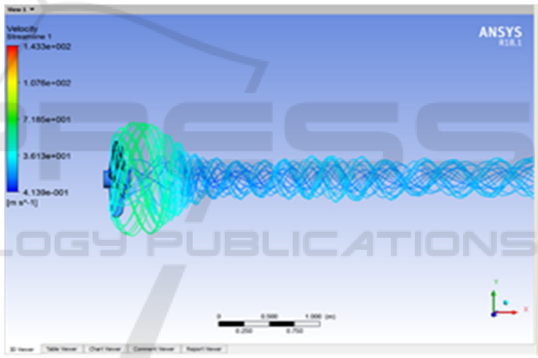

Figure 13: Result Streamline Catamaran 2.

In the streamlined propeller model of Catamaran 2, the fluid flow starts to become unstable but is quite constant. Fluid flow is still quite smooth, but the emergence of turbulence starts large especially in the propeller hub area.

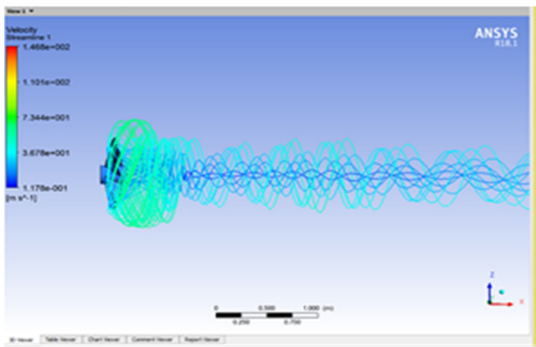

Figure 14: Result Streamline Catamaran 3.

The streamlined propeller model of Catamaran 3 has an unstable and not constant fluid flow. Fluid flow is not smooth enough and turbulence is quite large in front of the hub.

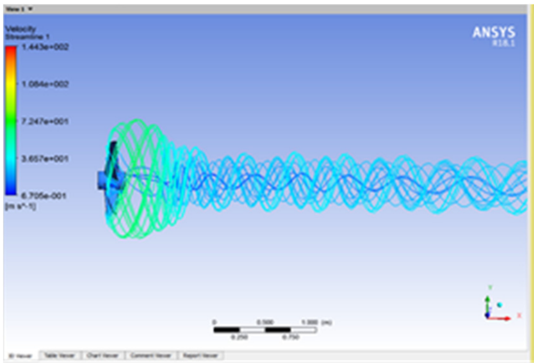

Figure 15: Result Streamline Catamaran 4.

In the stream lined propeller model of Catamaran 4, the fluid flow is still stable and fairly constant. Fluid flow is still quite smooth but the emergence of turbulence is quite low in the hub propeller and along the streamline.

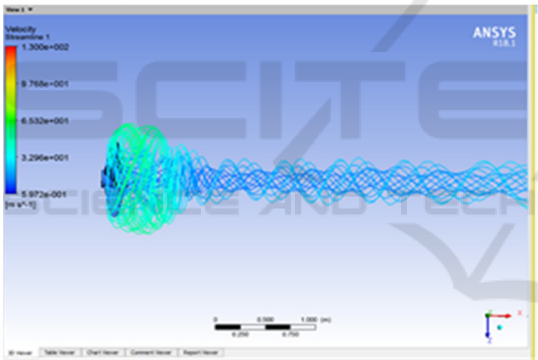

Figure 16: Result StreamlineTrimaran 1.

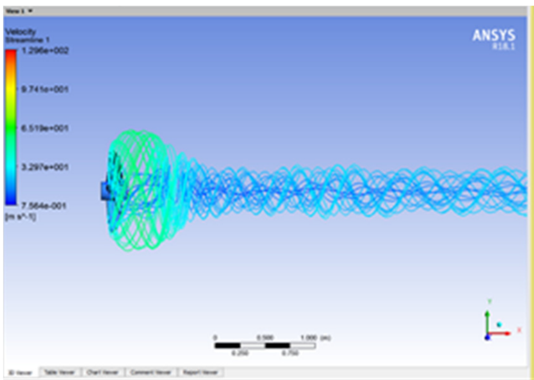

Figure 17: Result Streamline Trimaran 2

In the streamlined propeller model of Trimaran 1 has an unstable but constant flow of fluid. Subtle fluid flow and turbulence are still quite large in the front area of the hub propeller, but turbulence begins to decrease along the streamline flow.

In the streamlined propeller model of Trimaran 2 has a fairly stable and fairly constant fluid flow. Fluid flow is still quite smooth. Turbulence is quite large in the front area of the hub propeller, as well as turbulence as long as the streamline flow begins to decrease.

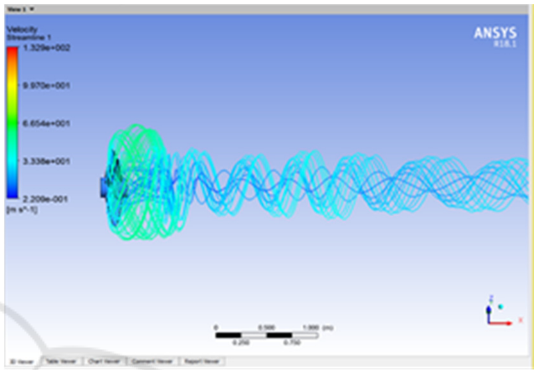

Figure 18: Result Streamline Trimaran 3.

In the streamlined propeller model of Trimaran 3 has an unstable and not constant fluid flow. Less smooth fluid flow and turbulence begin to decrease in the front area of the hub propeller, and turbulence along the streamline flow is quite low.

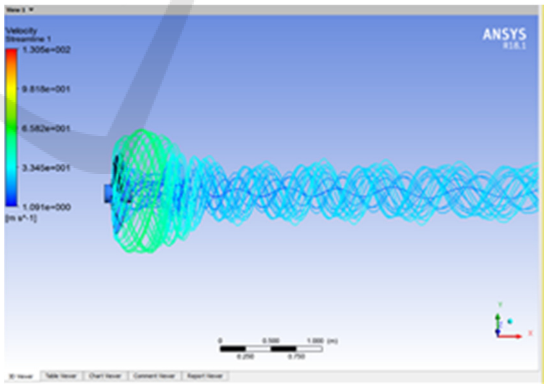

Figure 19: Result StreamlineTrimaran 4.

In the streamlined propeller model of Trimaran 4 has a fluid flow that starts quite stable and is quite constant. Fluid flow is quite smooth and turbulence is still quite large in the front area of the hub propeller but low along the streamline flow.

Table 5: Result of Thrust, Torque, and Efficiency of 16 Variation Propeller Model.

Model	*Thrust (N)*	*Torque (Nm)*
Monohull 1	75706	8745,81
Monohull 2	94624	11171,7
Monohull 3	80239	9300,41
Monohull 4	92666,6	10894,8
Catamaran1	79483	9267,26
Catamaran2	98143,9	11370,1
Catamaran3	87012	10136,2
Catamaran4	104105	12062,7
Trimaran1	79307,1	9193,42
Trimaran2	99067,6	11338,3
Trimaran3	84823,1	9771,13
Trimaran 4	102802	11779,4

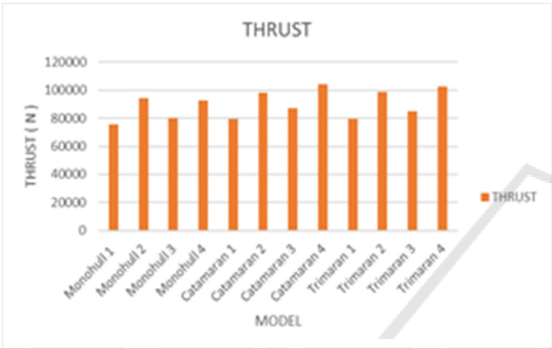

Figure 20: Diagram of Thrust Propeller Value.

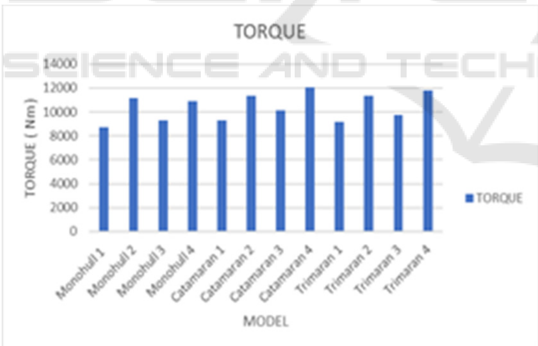

Figure 21: Diagram of Torque Propeller value.

3.5 Discussion

Based on the data in Table 5 and the Graphs in Figures 20 and 21 show that the largest Thrust Value for monohull vessels is obtained from the monohull 2 model, namely 70 Series K4 propellers that have thrust of 94624 N.

The lowest Torque value for monohull vessels is obtained from monohull 1 model, namely 70 Series B4 propeller which has a torque of 8745.81 Nm.

The biggest Thrust value for Catamaran ships is obtained from Catamaran 4 model, namely 70 Series K5 propellers that have a thrust of 104105 N.
The lowest Torque value for Catamaran ships is obtained from the Catamaran 1 model, namely the 70 Series B4 propeller which has a torque of 9267.26 Nm.

The biggest Thrust value for Trimaran ships is obtained from Trimaran 4 models, namely 70 Series K5 propellers which have a thrust of 102802 N.

The lowest Torque value for Trimaran ships is obtained from the Trimaran 1 model, namely the 70 Series B4 propeller which has a torque of 9193.42 Nm.

Based on table 5 shows that the increasing number of blade in the variations carried out will increase thrust propeller. The greater the value of Rpm or propeller rotation, the greater thrust will result.

4 CONCLUSION

Based on the results of the calculation and computational fluid dynamic simulation are obtained, that is:

1. The Monohull 2 model, the K4 70 Series propeller can be used as an alternative choice for monohull ship propellers because it has maximum thrust value.
2. Catamaran 4 model and Trimaran 4, K5 70 Series propeller can be used as an alternative choice for Catamaran and Trimaran ship propellers because they have maximum thrust value.

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