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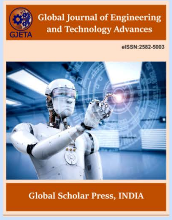

(RESEARCH ARTICLE)

Maneuverability of a vessel using bow thrusters

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Abstract

Vessels entering and leaving ports are faced with the challenge of maneuvering due to weather conditions, bad currents, and traffic dues to congestion in the channels near coastal waters. In order to berth or manoeuver properly the use of tugs is necessary which incurs more cost and more turnaround time for the vessel owner. Over the years, bow thrusters have been introduced to aid easy maneuverability despite these conditions in order to eliminate the cost of hiring tugs as well as reduce turnaround time for the vessels. In this project, a 4-blade bow thruster propeller of 500mm diameter was successfully modelled using Solidworks 2021 (CAD) software. Computational flow dynamics (CFD) was done using flow simulation in Solidworks 2021 and 260 iterations was carried out. The velocity at the body of the propeller was found to be 13.67m/s while the velocities at the front and back of the propeller was 6.841m/s. The values for the performance factors were also gotten for a varying range of BT propeller diameters and charts were develop to show the relationship between the propeller diameter and the performance factors necessary for maneuvering a vessel. It can be concluded that the performance factors necessary for maneuvering a vessel is dependent on the diameter of the bow thruster. For further studies, number of thruster to be fitted to the bow or stern of a vessel should be considered for larger vessel sizes.

Keywords: Performance factors; Computational fluid dynamics; Manoeuvrability; Bow thrusters

1. Introduction

Bow thrusters are a type of propeller-shaped system fitted either on the bow (forward part) and stern part (known as stern thruster) of the ship. They are smaller in size as compared to the ship's propeller and help in better manoeuvrability of the vessel at lower speeds. Bow thrusters are generally used for manoeuverring the ship near the coastal waters, channels or when entering or leaving a port while experiencing bad currents or adverse winds. Bow thrusters help in assisting tugboats in berthing the ship to avoid unnecessary wastage of time and eventually money because of lesser stay of the vessel in the ports. The presence of bow thrusters on a vessel eradicates the need of two tugs while leaving and entering the port, and thus save more money. Nowadays ships have both bow and stern thruster, which makes them independent of the tugboats for manoeuvring in the port limits (if the port regulation does not make it compulsory to use tugboats).

1.1. Statement of the Problem and Research Questions

Ships entering or leaving coastal waters have been confronted with the challenges of manoeuvering the ship especially during bad and adverse wind conditions and as well as the associated cost of using tugboats at the port. The presence of bow thrusters on a vessel eradicates the need of two tugs while leaving and entering the port, and thus save the cost of hiring tug boats. The problem confronting the study is the appraisal of manoeurvrability of a vessel using bow thrusters.

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The following research questions are pertinent for the study

- Why are bow thrusters used?
- What are Types of Bow thrusters?
- How are Bow thrusters operated?
- What constitute the Design and implementation of Bow thrusters?

Aim of Study

The aim of this research is to analyze how bow thrusters can aid in maneuvering of marine vessel,

Objectives of Study

The study shall elucidate on

- Design a typical bow thrusters using SolidWorks computer aided design (CAD) software.
- Perform hydrodynamic analysis on the designed bow thruster using SolidWorks (CAD) software.
- Analyze how the bow thruster will aid a more efficient maneuvering of a vessel.

1.2. Design and Working Principles of Bow Thrusters.

- The bow and stern thrusters are placed in the through-and-through tunnels which open at both sides of the ship (6). The thruster takes suction from one side and throws it out at the other side of the vessel, thus moving the ship in the opposite direction. This can be operated in both the directions, i.e. port to starboard and starboard to port. The bow thrusters are placed below the water line of the ship. For this reason, the bow thruster room should be checked for water accumulation at regular intervals of time.
  The bow and the stern thrusters can be electrically driven or hydraulic driven or diesel driven. Bow thrusters should be located as far forward as possible. Parallel side walls have favorable influence. An attempt should be made to locate the propeller in the mid-ship plane. In short tunnels the propeller is located eccentrically on the portside in order to improve the thruster performance to the starboard (10).
- The thruster used are usually of Controllable Pitch Propeller (CPP) type, i.e., the blades on the propeller boss can be moved to change the direction of the thrust (6). The boss which carries the blades is internally provided with a movable shaft (operated by hydraulic oil) also know and Hydraulic Pod Motor Driven Thrusters. Once the signal is given to change the pitch, the hydraulic oil will be supplied to operate the internal shaft (within the boss) to change the blade angle of the thruster. The motor shaft drives the shaft of the thruster via pinion gear arrangement. The sealing gasket is provided in the motor casing which holds the water which is in the tunnel.

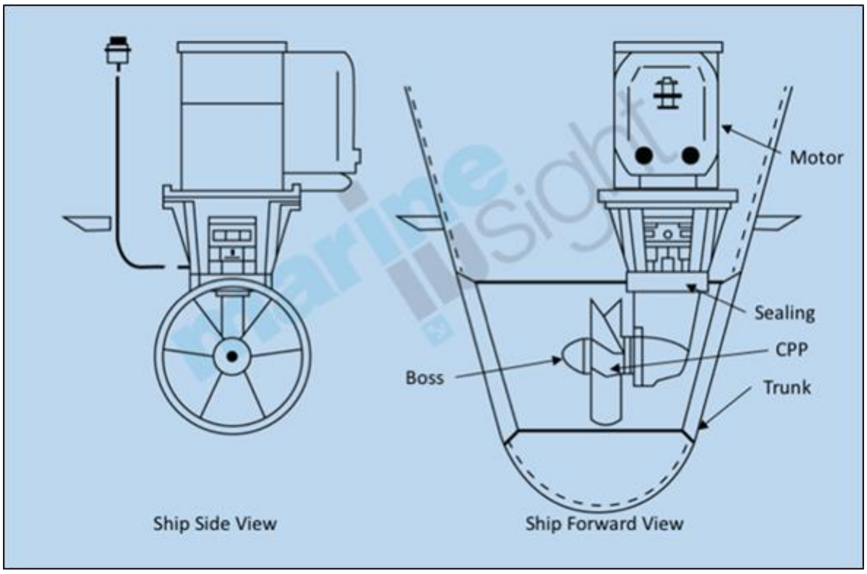

Figure 1 Line Diagram of Bow Thruster (Source: 6)

2. Material and methods

2.1. Performance Factors

The performance of some bow thrusters could probably have been improved if certain information and knowledge had been available during their design. The obvious operational duty of the bow thruster is that it produces a force and body moment to turn the ship to the starboard or port. The following under listed factors is responsible for the performance of a bow thruster.

2.1.1. Static merit coefficient

The useful work output given by the usual definition of propeller efficiency becomes zero at zero propeller advance. Since thrust is still produced, a measure of the static (at rest) efficiency is needed to evaluate thruster performance for the condition.

Most widely used are;

Static merit coefficient

$$C = \frac{0.00182T^{3/2}}{SHP\sqrt{\rho\frac{\pi D^2}{4}}} = \frac{K_T^{3/2}}{\pi^{3/2}K_Q} \quad (1)$$

And Bendeman static thrust factor.

$$\zeta = \frac{T}{P_S^{2/3}.D^{2/3}.(\rho\,\pi/2)^{1/3}} = \frac{K_T}{K_Q^{1/3}}.\frac{1}{\pi(2)^{1/3}} \quad (2)$$

Where;

T	-	Total lateral thrust
SHP	-	Impeller shaft horse power
ρ	-	Mass density of water
D	-	Duct diameter
K_T	-	Propeller side thrust coefficient expressed as $\frac{T}{\rho n^2 D^4}$
K_Q	-	Propeller torque coefficient expressed as $\frac{Q}{\rho n^2 D^5}$
n	-	Propeller frequency of revolution
Q	-	Propeller Torque

2.1.2. Force, moment, and velocity

In general, body total force and moment is non dimensional in terms of impeller frequency of rotation or an average jet velocity U_j.

The K_T and K_Q coefficients just defined in connection with the static merit coefficient are an example of the former case. It is also appropriate to use a nondimensional form of body coefficient which is independent of impeller characteristics. The jet velocity is convenient for this purpose as follows:

$$\text{Body force coefficient } K_F = \frac{T}{\rho\, A\, U_j^2} \quad (3)$$

$$\text{Body moment coefficient } N' = \frac{N}{\rho\, A\, U_j^2 x_T} \quad (4)$$

$$\text{Average thrust velocity } Uj = \sqrt{\frac{T}{\rho A}} \quad (5)$$

Where;

N	-	Body turning moment,
T	-	Total lateral thrust
ρ	-	Mass Density of water
A	-	Cross-sectional area of duct
x_T	-	Characteristic distance from duct axis to mid-ship (Lever arm)

2.1.3. Turning rate

A design thrust for a bow thruster can be obtained if the ship response to the side force is specified. The turning rate ω_o (deg/sec) when the ship is dead in the water is one performance criterion. The steady rotation of a ship not underway is basically a drag problem. (5) calculated ω_o for comparison with measured value of ω_o for a number of ships.

Fig. 2 represents Hawkins curves of measured turning rates as a function of displacement.

Fig. 3 is a graph of the rotation rate constant M_o and non-dimensional pivot point p as a function of non-dimensional side force.

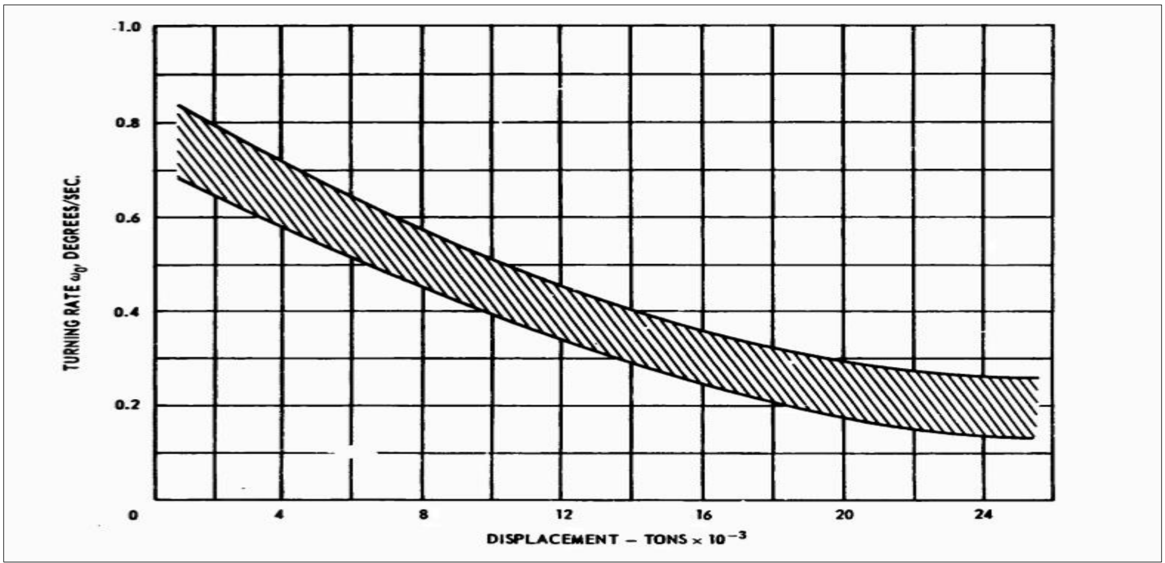

Figure 2 Band of Rotation Rates versus Displacement with Marine Propulsion Device at Zero Ship Speed (Source: 5)

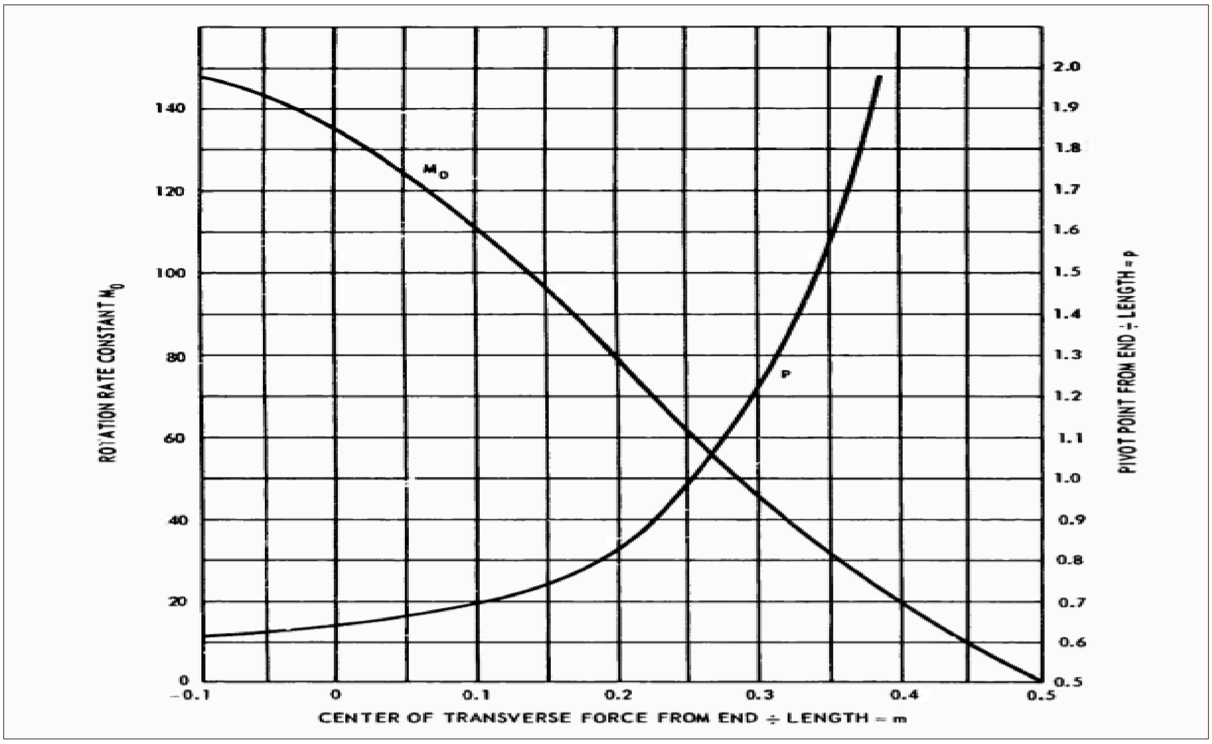

Figure 3 Pivot Point and Rotation Rate Constant for a single side force acting on a ship (5)

2.2. Geometric Modelling

The geometric modelling of the propeller was carried out using SolidWorks 2021 CAD software as shown in fig 4

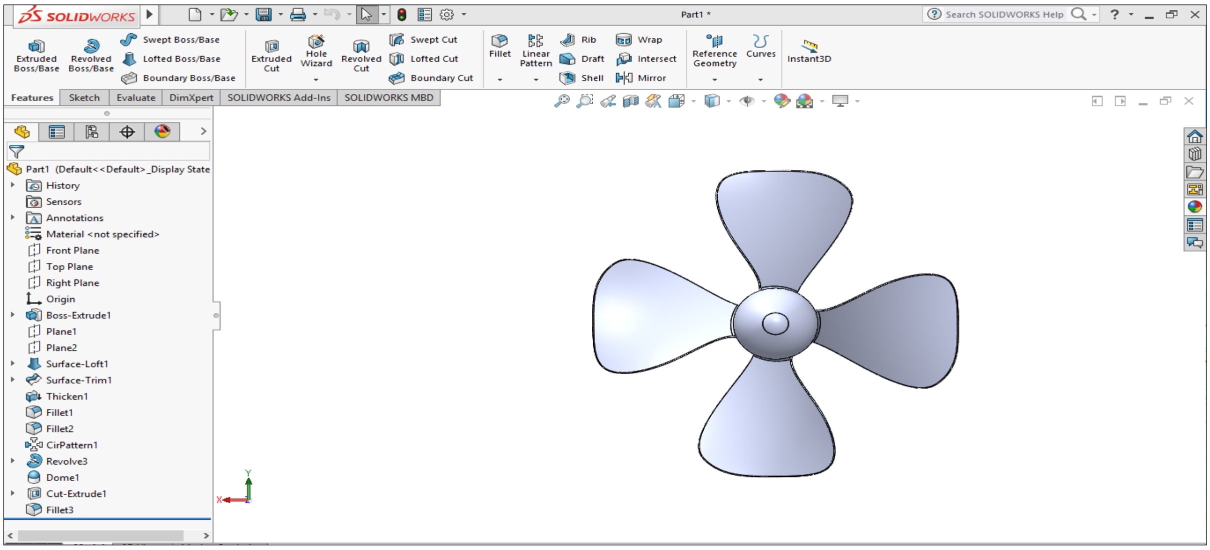

Figure 4 Modelled 4-blade fixed pitch propeller

2.3. Computational Fluid Dynamics

Computational fluid dynamics which involve the analysis of systems involving fluid flow, heat transfer etc. involves three specific methods including: finite element method, finite difference method, finite volume method.

SolidWorks flow simulation is an intuitive computational fluid dynamics (CFD) solution embedded within SolidWorks 3D CAD. SolidWorks flow simulation which is a general parametric flow simulation makes use of the Finite Volume

Method (FVM) to calculate product performance and perform optimization using the results was used to carry out flow simulation on the bow thruster propeller.

2.3.1. Computational domain

The designed bow thruster propeller was enclosed in a cylindrical domain to enable steady state result. Fig 5 shows the cylindrical domain enclosing the propeller.

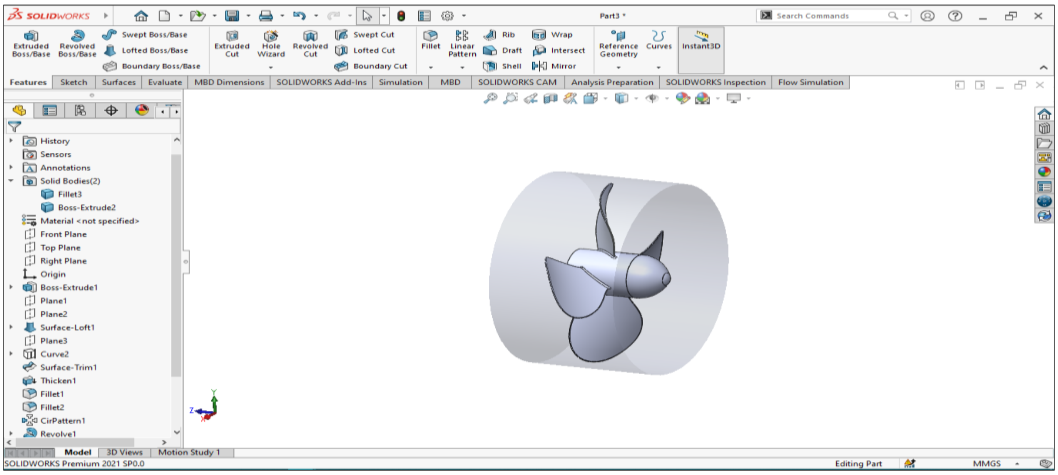

Figure 5 Cylindrical domain enclosing propeller

2.4. Meshing

Meshing is the process in which the continuous geometric space of an object is broken down into thousands or more of shapes to properly define the physical shape of the object. Fig 6 shows the structured mesh of the bow thruster propeller in the computational domain.

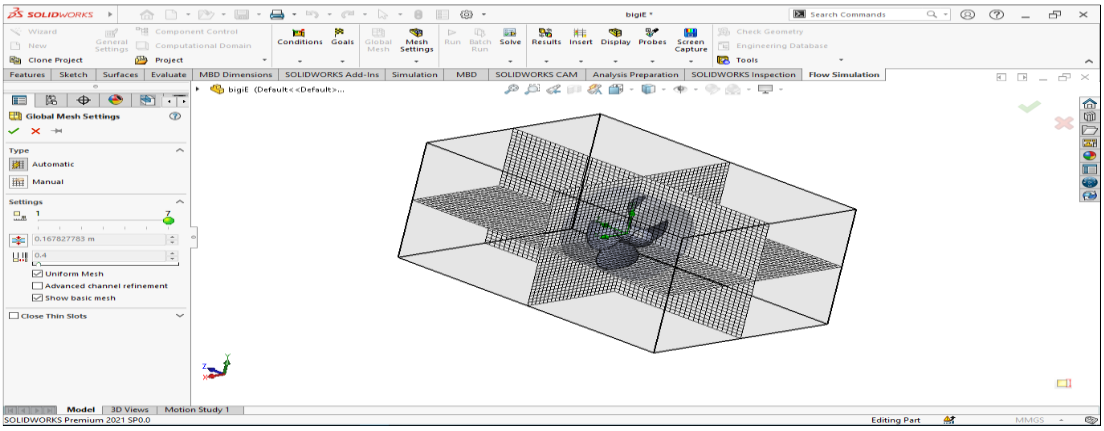

Figure 6 Structured mesh in computational domain

2.5. Mathematical Model

The k-ε turbulence model is one of several two-equation models that have been developed over the years. It is probably the most widely and thoroughly tested of them all. As it is well known that SKE is a semi-empirical model based on model transport equations for the turbulence kinetic energy, k (Eq.1) and its dissipation, ε (Eq. 2).

$$\frac{\partial \rho k}{\partial t} + \frac{\partial (\rho u_i k)}{\partial x_i} = \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{Pr_k}\right)\frac{\partial k}{\partial x_i}\right] + \mu_T G - \rho\varepsilon + S_{k.p} \qquad (6)$$

$$\frac{\partial \rho \varepsilon}{\partial t} + \frac{\partial (\rho u_i \varepsilon)}{\partial x_i} = \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{Pr_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_i}\right] + \frac{\varepsilon}{k}(C_1 \mu_t G - C_2 \rho \varepsilon) + S_{\varepsilon.p} \qquad (7)$$

Where:

C1 and C2 - additional dimensionless model constants
Prk and *Prε* are the turbulent Prandtl numbers for kinetic energy and dissipation, respectively *Sk,p* and *Sε,p* are source terms for the kinetic energy and turbulent dissipation
G is the turbulent production rate defined in Eq. 3:

$$G = \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\frac{\partial u_i}{\partial x_j} - \frac{1}{\rho^2}\frac{\partial \rho}{\partial x_j}\frac{\partial \rho}{\partial x_j} - \frac{2}{3}\left(\frac{\rho k}{\mu_T} + \frac{\partial u_i}{\partial x_j}\right)\frac{\partial u_j}{\partial x_j} \quad (8)$$

3. Results and discussion

3.1. Solid works Simulation Results

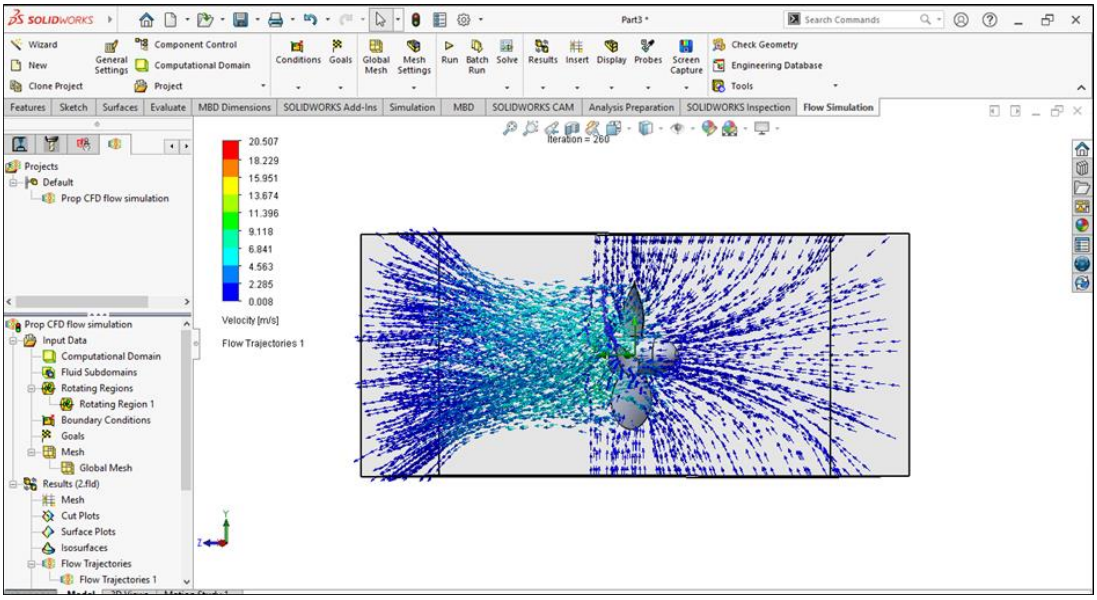

Figure 7 Velocity Flow Through computational domain

3.2. CFD Performance Factors Results

The performance factors obtained after 260 iterations while varying propeller diameter between 500mm-2000mm shown in table 1.

Table 1 CFD Performance Factors Results

Propeller Diameter (mm)	Max. Input speed (rpm)	Max. Input Power (kW)	Propeller Speed (rpm)	Maximum Thrust
500	1600	68	1050	10
700	1600	150	770	22
800	1600	190	660	30
1000	1600	285	560	44
1100	1600	328	560	47
1300	1600	463	420	67
1650	1600	705	340	100
2000	1600	1050	270	150

3.3. Performance Factors Charts

As shown in fig 8 an increase in bow thruster propeller diameter results to an increased required input power. Likewise, an increased bow thruster propeller diameter results to and increased maximum thrust as shown in fig 8 Also, as shown in fig 9 an increased bow thruster propeller diameter results to reduced propeller speed which corresponds with theoretical background that propeller diameter will increase as rpm decreases.

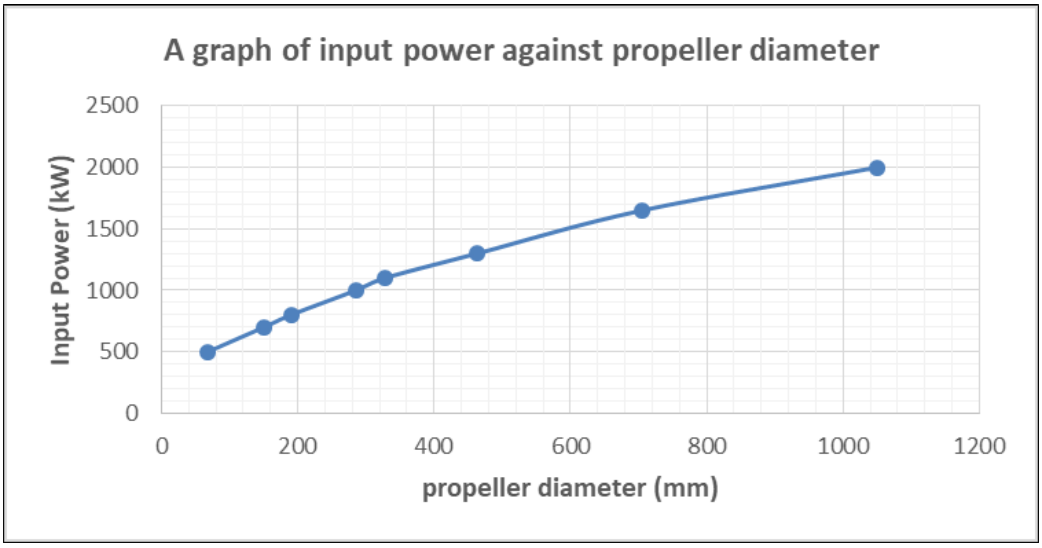

Figure 8 Graph of input power against propeller diameter

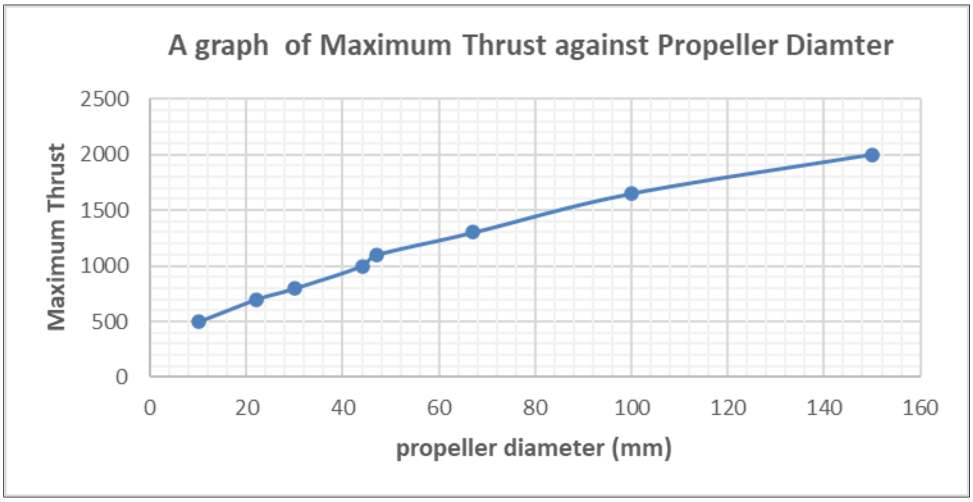

Figure 9 Graph of Maximum thrust against propeller diameter

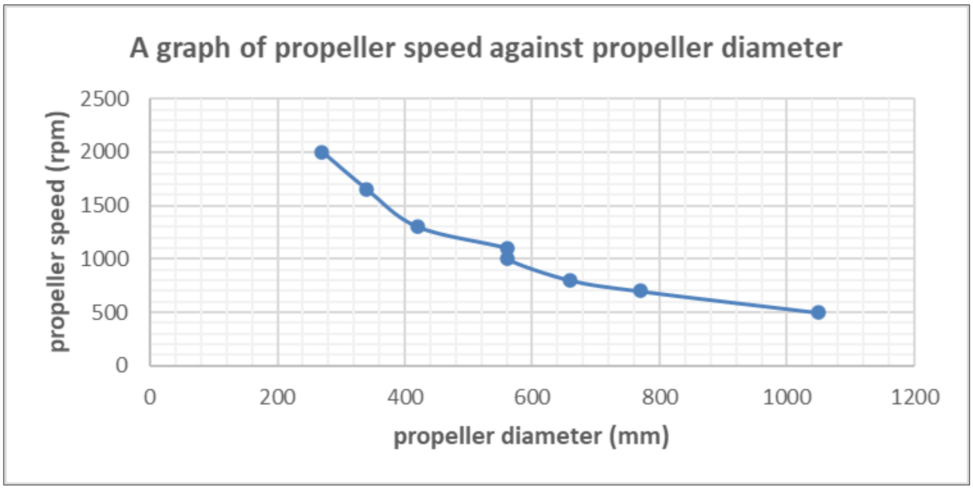

Figure 10 Graph of propeller speed against propeller diameter

4. Conclusion

In this project, a 4-blade bow thruster propeller of 500mm diameter was successfully modelled using solidworks (CAD) software. Computational flow dynamics (CFD) was done using flow simulation on solid works and 260 iterations was carried out. The velocity at the body of the propeller was found to be 13.67m/s while the velocities at the front and back of the propeller was 6.841m/s. The values for the performance factors was also gotten for a varying range of bow thruster propeller diameters and charts were develop to show the relationship between the propeller diameter and the performance factors.

It can be concluded that solidworks CAD software is proficient in design and flow simulation (CFD) as it proved very useful in carrying out simulation to generate performance factors of the bow thruster. It can also be deduced that the diameter of the bow thruster affects the performance factors which is necessary for maneuvering as can be seen from the charts. The bow thruster propeller diameter is directly proportional to the power and thrust, but inversely proportional to the velocity, hence depending on the size of the vessel the diameter of the bow thruster used determines the thrust produced to maneuver the vessel.

Compliance with ethical standards

Acknowledgments

This work would not have been a success but for the collaborating efforts of Mr. Joseph Maurice, Prof. E. A. Ogbonnyaya and Mmeyene Udoh. I appreciate them for every bit of their contributed efforts.

Disclosure of conflict of interest

All authors would like to declare that there is no conflict of interest relevant to this article.

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