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The Study of Ducted Propeller in Propulsion Performance of a Malaysia Fishing Boat

Koh K. K.,* Omar Y., Azreen E., Nurhaslinda K.

Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor bahru, Johor, Malaysia

*Corresponding author: koh@fkm.utm.my

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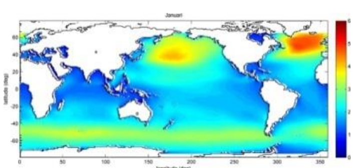
Graphical abstract



Abstract

Through the installation of ducted propeller,fishing vessels are able to operate with more towing power and will be more economic in terms of fuel usage. The application of the shroud or ring to the propeller made the propeller more practical for tugs, pushboat, supply ship and trawler. The study of this paper is focused on the propulsive performance by ducted propeller when operating at tow speed and low rpm. From the research on the ducted propeller, the design characteristics such as length-diameter ratio and thickness-length ratio are determine from the chart provided by previous researcher. The design selection of nozzle is done with the use of CFD program, Javafoil to analyze the flows of the profile and it's characteristic. Model tests were conducted by using a 26m fishing boat model with and without nozzle.It is foundthat by using ducted propeller to a fishing vessel, thrust can be increase up to 23%.

Keywords: Ducted propeller; fishing vessel; thrust

1.0 INTRODUCTION

In Malaysia, fishing is an important industry as they had contribute an amounted of 1239434 tonnes valued at RM3.84 billion, constituting about 1.54% of the national Gross Domestic Product (GDP) in year 1996 by Omar.[1] Trawlers and purse seiners together contributed 84 percent of total fish landings and 74 percent of total wholesale value of fish in Peninsular Malaysia in 1990 referring to Viswanathan.[2]

In terms of their propulsion units, Malaysian fishing vessels are still using an open water propeller to operate instead of practicing the use of ducted propeller as their propulsor which is because of cost constraint in installation, and this had left us further behind compared to the other developing country which had implemented it as their main propulsion unit. For a fishing vessel, it is usually operate at low speed with high loading propeller. Therefore, ducted propeller would be a good addition in increasing the propulsion performance at low speed.

2.0 DUCTED PROPELLER

Ducted propeller is a propeller shrouded by a nozzle of with an aerofoil shape. There are 2 types of nozzle, accelerating and decelerating. Accelerating duct is formed when the high pressure side of the aerofoil faces outwards so the top looks like an aircraft wing upside down and the decelerating duct is formed when the low pressure side of aerofoil faces outward so the top looks like an aircraft wing right way up. The accelerating nozzle is now being used extensively for a ship with heavily loaded. It offers a means of increasing the efficiency of heavily loaded propellers, and it produces a positive thrust. An accelerating duct will generally increase efficiency performance on ships with a high thrust coefficient, according to Breslin.[3] E.g. tug boats, trawlers, tankers, AUVs etc.

With the second type which is decelerating nozzle, the inflow velocity is reduced, whereby pressure is increased, thus reducing cavitations. A decelerating duct is a major contributor to noise reduction which is why it is getting more popular with modern warship designs.

2.1 Advantages of Ducted Propeller

A nozzle provides an improvement in the efficiency of propulsion system and the efficiency of the propeller itself. As the blades turns in the water, high pressure areas are generated behind each blade while a low pressure area occurs at the front of the blades. The different between these pressures provides the force to drive the vessel through the water. However, losses occur at the tip of each blade as water escapes from high pressure to low pressure side that give a little benefit in pushing the vessel forward. These loses can be reduced by the used of close-fit nozzle or duct around the propeller.

The application of nozzle on fishing vessels can save fuel because the vessels can carry out the same trawlnet at the same speed, but at lower RPM. Furthermore, the fuel savings should be slightly smaller than the thrust gain which is around 20 percent which stated by Anon.[4] From the work done by Chung K.S.[5] it also shown proved that the installation of ducted propeller to a fishing vessel can give an increase of thrust at low speed for almost 20 percent.

■3.0 RESEARCH METHODOLOGY

There are various methods in calculating the propulsion performance of a ship which includes the used of CFD programs for design optimization and model tests in towing tank. The design of the nozzle was studied in order to improve the efficiency of a propeller. In designing the nozzle, Kort nozzle 19A and geometry set by Tadeusz[6] are used as a reference for its dimensions parameters.

The designed nozzles will be tested using a program called Javafoil for calculating the profile drag and to estimates the airfoil performance. It was followed by fabricating the nozzle according to the dimension of propeller for a trawler model with a model code MTL038, taken from UniversitiTeknologi Malaysia Marine Technology Laboratory. After the construction of the nozzle, an experiment will be conducted for the analysis of the performance of trawler with and without nozzle.

■4.0 NOZZLE DESIGN

From the test on ducted propeller that had been carried out by *MARIN* with different profile and designs, result shows that the efficiency of the nozzle is depend on the parameters of the nozzle such as length-diameter ratio (⁄) tip clearance (C), maximum thickness-length ratio (⁄) trailing edge and dihedral angle (α).

4.1 Propeller Particulars

The parameters of nozzle will be designed according to the existing propeller with a diameter of 138 mm. The propeller used is a B4.70 propeller, and the characteristic for the model size propeller is shown in the Table 1 below:

Table 1 Characteristic for model size propeller

Propeller Characteristic	Value
Diameter	138 mm
Pitch at root	114 mm
Pitch at 0.7R	114 mm
Pitch at blade tip	114 mm
No. of blade	4
Material	Bronze
Direction of rotation	Right handed
Scale ratio	1 : 31.935

4.2 Length-diameter Ratio, ⁄

Length-diameter ratio is the ratio for the length of the nozzle and diameter of nozzle. The ratio will determined the suitable length and diameter for the design nozzle correspond to the type of ship. *MARIN* has made an investigation on the effect of the dimension or shape of different nozzle with different length-diameter ratio to emphasize their effect to the ducted propeller. Figure 1 below shows the result from the research made by *MARIN* on the nozzle with different length-diameter ratio, ⁄ .

Figure 1 show a graph of propeller efficiency η_P against thrust coefficient C_T, that nozzle 3 has a higher efficiency with a length-diameter ratio of 0.5, compared to other nozzle with different ratios within the range of 60 to 100 of power coefficient, Bp. This is the range of Bp for a trawler to operate. Therefore, the ratios of Length-diameter for the design of nozzle had been obtained which is 0.5, since the nozzle design is to be attached to a trawler.

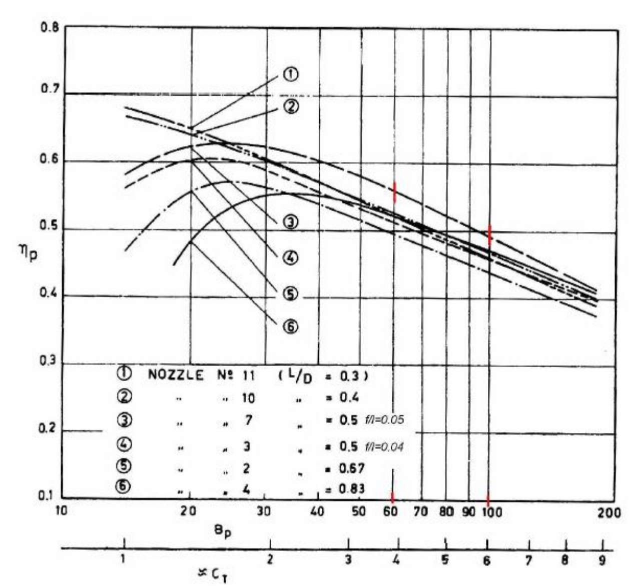


Figure 1 Results from the comparison of nozzle with different length-diameter ratio (Van Manen J. D., 1966)[7]

4.3 Thickness-length Ratio, ⁄

The thickness-length ratio has an important role in determining the risk of flow separation on the interior surface of the nozzle. Flow separation can cause an unsteady velocity of the fluid thus causing some losses in thrust. Separation of flow will produce resistance that make the fluid flow becomes detached from the surface of the nozzle, and instead takes the forms of eddies and vortices.

Oosterveld [8] made a research on the sectional lift coefficient C_L with different thrust ratios τ and different thickness ratios of nozzle, the result as in the Figure 2, shows that the loading of the accelerating nozzle is strongly restricted by the risk flow separation on the interior part of nozzle.

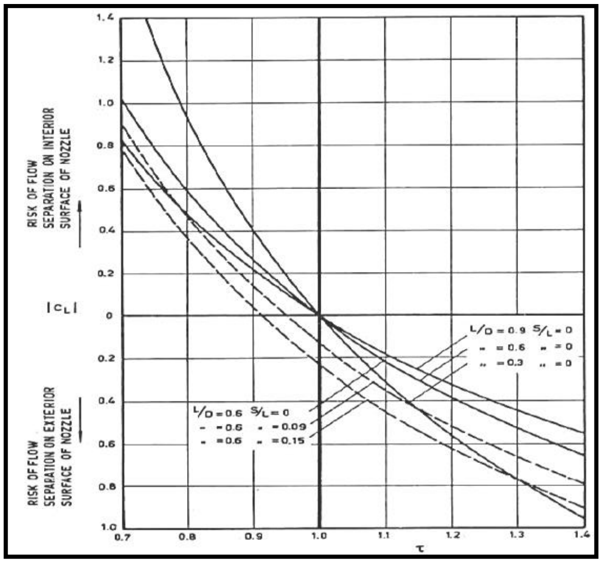


Figure 2 Sectional lift coefficient of nozzle profile (Oosterveld, 1970)

By referring to the result in Figure 2, nozzle with thickness-length ratios of 0.15 give a minimum risk of separation flow. So, the ratio of 0.15 will be used in the design of nozzle.

4.4 Tip Clearance, C

According to Anthony F. M.,[9] it is not least in maintaining the circularity of the nozzle and providing reasonable clearances between the blade tips and the nozzle, but from the hydrodynamic viewpoint that the clearance should be as small as possible. The efficiency of the nozzle will decrease when the tip is big because of cavitation occur with the clearance flow.

Referring to the work by Tadeusz,[6] they stated that the tip clearance between the blades of propeller and the inner surface of nozzle should be equal to 1.0 to 1.5 percent of the propeller diameter.

4.5 Nozzle Dimensions

The dimensions of the designed nozzle need to be calculated. The length-diameter ratio is 0.5 and thickness-length ratio is 0.15. The final dimensions and ratios for the designed nozzle is listed in Table 2.

i. $/ = 0.5$

$= 0.5 \times 138 = 69$

ii. $/ = 0.15$

$= 0.15 \times 69 = 10.3$

Table 2 Final dimensions and ratios for the designed nozzle

Description	Value
Length (mm)	69
Diameter (mm) + clearance	141
Thickness (mm)	10.3
Length-diameter ratio, $/$	0.5
Thickness-length ratio, $/$	0.15
Dihedral angle, α	< 10°
Outlet angle, β	< 5°

4.6 Designs

The design nozzle will follow the geometry set by Tadeusz [6] as he stated that this simple nozzle provide better performance at high advance coefficient than the MARIN 19A nozzle due to the smaller drag of the nozzle as a result from better flow conditions on the outside surface of the nozzle.

Several modifications will be made on the geometry of the nozzle as shown in Figure 3 (Nozzle 1 to Nozle 5), in order to get the desired and better characteristic out of the designs. Modifications will be focused on the diameter of the inlet section of the nozzle, the outlet angle and also the outlet diameter. The different in the diameter will somehow give an effect in the flow of the water through the surface. Parameters measured will be on the drag produce by the nozzle plus with the inlet flow velocity at the inlet section.

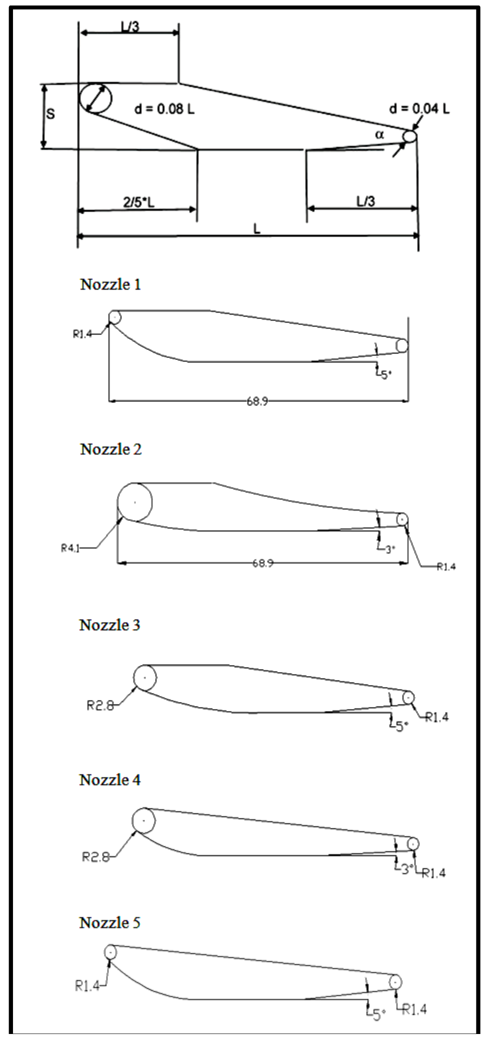


Figure 3 The geometry of the technological simple nozzle

4.7 Design Analysis

Analysis are conduct for all designs of nozzle using software called Javafoil. This JavaFoil is a relatively simple program, which uses several traditional methods for airfoil analysis as shown in Figure 4.

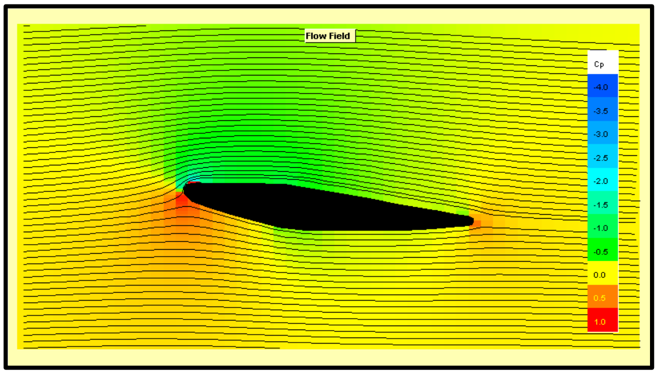


Figure 4 Flow analysis for Nozzle 1

Figure 4 above shows the flow analysis for nozzle 1 profile and reveals that it has a low pressure at the tip of the leading edge as indicated with red in colors of Cp (pressure coefficient), according to the colors of pressure distribution shown at the right side of the nozzle. According to Bernoulli's principle, where the fluid is moving faster when the pressure is lower, and the fluid is moving slower when the pressure is greater. This means that flow velocity towards inlet of nozzle at leading is much greater than the upper surface. It can be expected when the fluid flow velocity through the inlet of nozzle is high, the force or thrust produce at the end of the nozzle would be higher because of the combination with the thrust produce by the propeller itself. The distance of flow separation at high pressure side is small which cause some drag on the smoothness of the flow.

From Javafoil, drag coefficient (C_D) and the flow velocity through the profiles can be known. Results from Javafoil are shown in Table 3 below:

Table 3 Result generated from Javafoil

Nozzle	C_D	Velocity
1	0.0329	1.329
2	0.0556	1.245
3	0.0319	1.257
4	0.0329	1.323
5	0.0520	1.315

A result in Table 3 shows that C_D for Nozzle 2 and 5 in bigger for almost 2 times compared to other nozzles. This indicates that diameter and angle of outer edge plays a part in the contribution of drag force as the flow separation on these nozzles are high.

$$= \frac{\quad}{\frac{1}{2} \quad {}^{2}} \qquad \text{(Equation 1)}$$

From the equation of C_D (Equation 1), the drag force will increase as C_D increase as the values of density, velocity and area are almost the same for all nozzles. Therefore, Nozzle 2 and 5 are rejected as they have a high C_D which will contribute more on drag force. In selecting the best Nozzle out of 3, flow velocity will be considered as the value of C_D for these 3 Nozzle 1,3 and 4 are close. Velocity of flow will give more advantages in the thrust force produce by ducted propeller. Hence, Nozzle 1 is chosen because it has the highest velocity out of those 3 nozzle with a reasonable C_D that only has a small different with Nozzle 3.

5.0 MODEL TEST

The test used in determining the thrust is self propulsion test. In this model test, it is conducted by using stern trawler model MTL038, using the facilities provided by Marine Technology Laboratory towing tank, Universiti Teknologi Malaysia. The model speed of 0.812 m/s is chosen which is equal to 5 knots for actual ship because it is the towing design speed for the trawler model. Test will be carried out at different loading, starting at low rpm to high rpm in order to measure the thrust produce by ducted propeller at lower rpm compared to open propeller. The rpm used are 400, 500, 600 and up to 1000 rpm. Table 4 below shows the particulars of the trawler model.

Table 4 Trawler model particulars

Particulars	Value
Length overall, LOA	2.60 m
Length on Waterline, LWL	2.39 m
Breadth, B	0.60 m
Draught, T	0.24 m
Displacement	133.17 kg
LCG to amidships	0.024 m
Vertical center of gravity, KG	0.246 m
Scale	1 : 10

5.1 Results

Data in Table 5 below shows the results of thrust generated from experiment.

Table 5 Thrust generated from experiment

RPM	V_m (m/s)	Thrust (N)		Thrust increment (%)
		Ducted propeller	Open propeller	
400	0.812	2.788	2.254	23.69
500	0.812	5.508	5.227	5.38
600	0.812	8.917	9.012	-1.05
700	0.812	13.234	13.763	-3.84
800	0.812	16.924	19.196	-11.83
900	0.812	21.565	25.746	-16.24
1000	0.812	26.797	32.845	-18.41

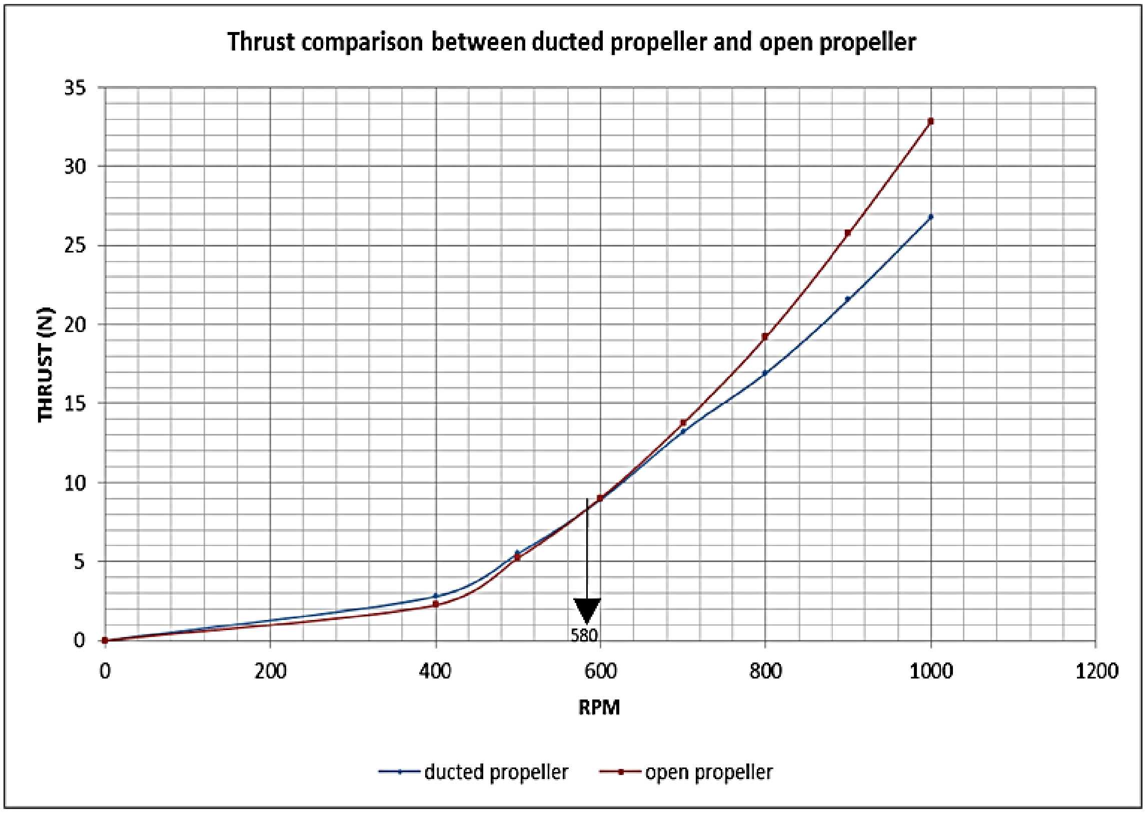


Figure 5 Thrust comparison between ducted propeller and open propeller

Figure 5 illustrates the comparison of thrust between ducted propeller and open propeller. From the test conducted, it was found that the thrust produced by ducted propeller at towing speed is higher than open propeller. However, at the intersection point at 580rpm, the thrust of ducted propeller is starting to drop under the open propeller curve. The result had proved that the installation of ducted propeller is suitable at low rpm speed for trawler or fishing boat with heavily load propeller. For trawlers, if the operating rpm exceeds 580rpm, the efficiency of the propeller will drop.

The highest percentage of thrust increase for the installation of ducted propeller in this model test is 23.69 percent at 400 rpm compared to open propeller. This is a huge amount of thrust produced as it can gave an advantage for catching power with the same rpm produce by open propeller. Thus the cost of operation can be saved as the power supplied is same. Decreased in the percentage of thrust is almost constant as the rpm is increase with the highest value of 18.41 percent of decrease at 1000 rpm. This shows that ducted propeller cannot efficiently operate under high rpm due to frictional drag, cavitation and vibration.

■6.0 CONCLUSION REMARKS

Throughout the research, CFD program can be a useful tool in determining the best designs of nozzle. From the program of javafoil, various of parameter were generated in giving the characteristic result for the design of different nozzles in terms of the flows, velocity and drag coefficient which are vital in selecting the best nozzle.

Through the result obtained from model test, it can be recommended that Malaysian fishing vessel should implement the installation of ducted propeller as it can gave more catching power at lower speed and rpm. Furthermore, the nozzle also can provide a protection to propeller blade from hitting any underwater hazards. The protective ducting around the propeller serves as a protective casing guarding the blades against damage. This can be useful for fishing vessel operating at shallow water as the hazards are high and can protect the propeller from any debris underwater.

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