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Optimization of Ducted Propeller Design for the ROV (Remotely Operated Vehicle) Using CFD

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Abstract

The development of underwater robot technology is growing rapidly. For reaching the best performance, it is important that the innovation on ROV should be focused on the thruster and propeller.

In this research, the ducted propeller thruster is used while three types of SHUSKHIN nozzle are selected. The design is compared in accordance with the thruster that has been made as the propulsion device of underwater robots. Each type of the thruster model indicates different force and torque. For the analysis, each model is built in Computer Aided Design (Rhinoceros) program packages and Computational Fluid Dynamics (CFD) to find the most optimal model which can produce the highest thrust. Among the entire model, the Kaplan series (Ka5-75) with the type C of nozzle has the highest thrust which is 2.53 *N* or 25.24% of extra thrust.

For the optimization of thrust, genetic Algorithms (GA) is used. The GA can search for parameters in large multi-dimensional design space. Thus, the principle can be applied for determining the initial propeller that produces optimum thrust of ROV. The GA has successfully shown able to obtain an optimal set parameters for propeller characteristics with the best performance.

Keywords: Remotely Operated Vehicle (ROV), ducted propeller, CFD, genetic algorithms

Nomenclature

A_E	propeller expanded area
A_0	propeller disk area
C_{Tn}	regression coefficient of thrust coefficient
C_{Qn}	regression coefficient of torque coefficient
D	diameter propeller
J	advance coefficient
K_T	thrust coefficient
K_Q	torque coefficient
N	propeller blade pitch
P/D	pitch diameter ratio
Q	torque (Nm)
S_n	exponent of J
T	thrust
t_n	exponent of P/D
U_n	exponent of A_E/A_0
V_n	exponent of Z
Z	number of blades
P	density of water

1. Introduction

Remotely Operated Vehicle (ROV) is an instrument formed mini-sized submission vehicle. ROV is usually used to explore underwater photography, military operation and underwater pipeline repairing. ROV is used for activities small cave. ROV is designed to have abilities of seabed rescue operations and repairing of seabed objects from the surface [1].

Underwater robot is designed and manufactured absolutely requires many supporting components to improve the operation to perform a variety missions. Thruster is one component that has function as locomotor of underwater robot to maneuver horizontally when it moves forward and backward and also to maneuver vertically to moves up and down [2].

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The first proposal to use a screw propeller appears to have been made in England by Hooke in 1680, and its first actual use is generally attributed to Colonel Stevens in a stream-driven boat at New York in 1804. In 1828 a vessel 18 m (60 feet) long was successfully propeller by a screw propeller designed by Ressel. The screw propeller has reigned supreme in the realm of marine propulsion. It has proved extraordinarily adaptable in meeting the incessant quest for propellers to deliver more and more thrust under increasingly arduous conditions [3].

The Genetic Algorithms is one of method that has tool for optimization for many difficult optimization problem with multiple objectives. GA methods were shown to be able to replace the traditional computation method and design charts. In this case, for determining the initial propeller that optimum for ROV thruster is difficult. For selecting the initial propeller, used optim tools in Genetic Algorithms, the result will be found directly and efficiently.

However, the traditional design charts method and previous GA methods were limited in considering or maximum hydrodynamic aspect alone, such as hydrodynamic efficiency, and the thrust coefficient, etc. Hence, the goals of the present research are: to determine the optimum value of thrust for ROV thruster using 3 parameters are pitch diameter ratio, expanded blade area ratio, and rotational speed of propeller. Applying GA methods to propeller design with consideration of thrust for reaching the best performance of propeller.

2. Method

The Computational Fluid Dynamics (CFD) [4], is one branch of fluid mechanics that uses numerical methods and algorithms to solve and analyse problems related to fluid flow the purpose of CFD is to predict accurately on fluid flow, heat transfer, and chemical reactions in complex systems, which involve one or all the above phenomena.

2.1. ROV Design

In this research, ROV project in Fig. 1 has been designed and which has dimension as shown as the Table 1.

Table 1 Principle dimensions of ROV

Item	Unit
Length	601.87 *mm*
Beam	409.20 *mm*
Height	290.00 *mm*
Mass (on air)	13.70 *mm*
Weight	5.00 *N*

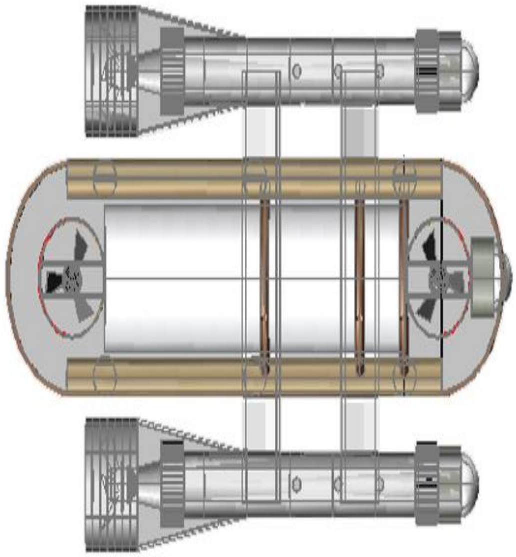


Fig. 1 ROV Project design

2.2. Propeller Design

The propeller dimension and geometry design are listed in the Table 2.

Table 2 Principle dimensions of Propeller

Item	Unit
Diameter	130.00 mm
Pitch	78.00 mm
Amount of blade	5 blades
Expanded BAR	0.75
Rake of angle (B5-75)	10.00 degree
Rake of angle (Ka5-75)	15.00 degree
Rotational speed	300.00 rpm
Density of water	1.025 kg/m3

In this case, the propeller dimension was chosen by the product sold in the market. And using this dimension, propeller was designing in CAD model. For the design used 2 types of design, B-Series (B5-75) as shown in Fig. 2 and Kaplan-Series (Ka5-75) as shown in Fig. 3.

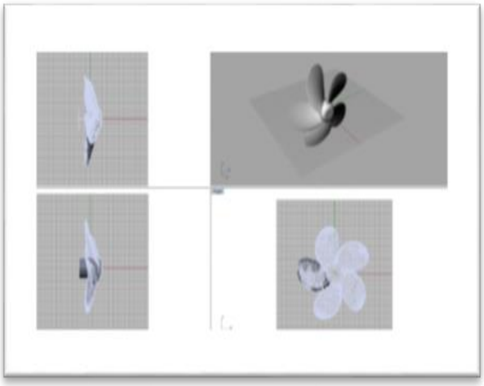


Fig. 2 B-Series (B5-75)

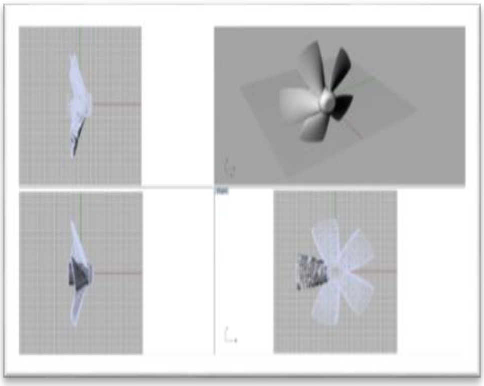


Fig. 3 Kaplan-Series (B5-75)

2.3. Numerical Method and Bboundary Conditions

In this steps, for the numerical on analysis was using Computational Fluid Dynamics Method. Several steps for calculations such as: geometry, mesh, setup, solution, and result.

Boundary condition was calculating for the open water propeller [5]. The boundary condition can be shown in Fig. 4.

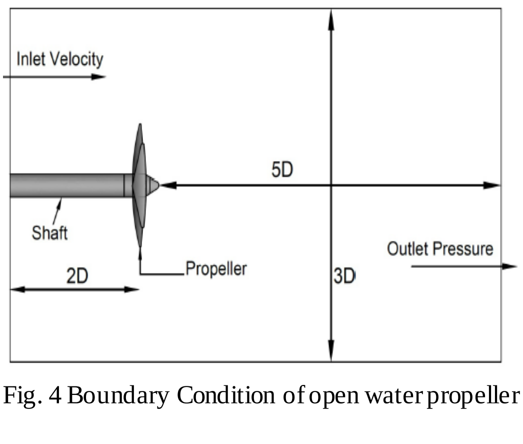


Fig. 4 Boundary Condition of open water propeller

2.4. Validation of Thruster

In this research to validate the result of the test model, used the software test result that already exist and was conducted by Mulyowidodo, K. et al in Bandung Technology Institute - Indonesia. Validation of underwater thruster for SHRIMP ROV-ITB is used to determine the exact boundary condition for using on the boundary condition when analyzing 3 models for ROV thruster using CFD-based software. Reference is taken from the validated model for the testing thruster. Used propeller type of Ka5-75 series and based on the theory of wageningen [6], the open water propeller characteristics conventionally were presented in form of the thrust and torque coefficient K_T and K_Q in term of the advance coefficient J, where

$$K_T = \frac{T}{\rho n^2 D^4} \tag{1}$$

$$K_Q = \frac{T}{\rho n^2 D^5} \tag{2}$$

$$J = \frac{V_A}{nD} \tag{3}$$

The characteristics of the ship's propeller for open water test condition are as represented in KT-KQ-J Chart. Type of each propeller is having the characteristic curves of different performance. It can be shown in Fig. 5.

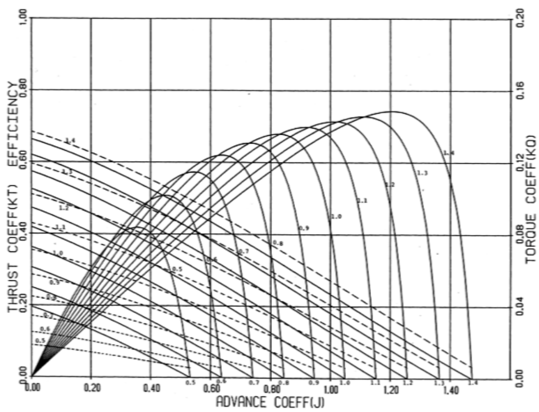


Fig. 5 K_T-K_Q-J Chart

2.5. Geometry Design of Nozzle

For the calculation of nozzle, SHUSHKIN nozzle has been chosen which developed (Prof.Dr.-Ing. H. Heuser, 1982). The nozzle design is shown in Fig. 6.

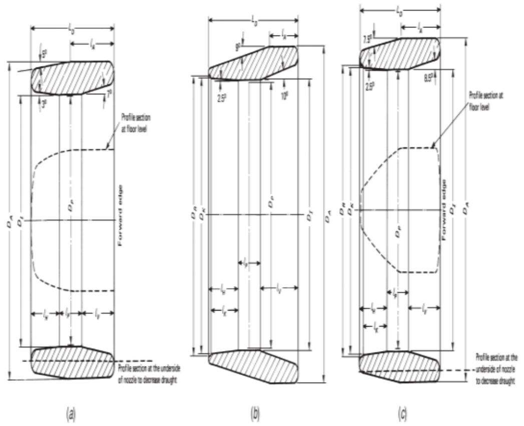


Fig. 6 Pressure process and flow contraction at the nozzle propeller compared

The Size of kort nozzle tipe A:

LD/DP =0,75; DI /DP = 1.015; limits: 20mm <(DI –DP) < 60 mm; DA/DI = 1,25; LA/LD = 0,53; LP/LD = 0,27, LV/LD = 0,40; LH/LD = 0:33

The size of kort nozzle tipe B:

LD/DP = 0,75; DI/DP = 1,015; limits: 20mm < (DI –DP) < 60 mm; DA/DI = 1,25; DK/DI = 1,02; DR/DI = 1,035; LA/LD = 0,32; LP/LD = 0,25, LV/LD = 0,425; LH/LD = 0,325; LK/LH = 0,925

The size of kort nozzle tipe C :

LD/DP = 0,75; DI/DP = 1,015; limits: 20mm < (DI –DP) < 60 mm; DA/DI = 1:20; DK/DI = 1,015; DR/DI = 1,030; LA=LD = 0,50; LP/LD = 0,50; LV/LD = 0,40; LH/LD = 0,35; LK/LH = 0,880

2.6. Preliminary Propeller Design

The preliminary propeller design problem is described in detail in the Principles of Naval Architecture [3]. Here is the basic design or initial design of propeller with the principal dimension as:

(Dependent variables)

Diameter : 130.00 mm

Amount of blades (z) : 5 blades

Rake of Angle : 15.00 degree

Material : Mn.Bronze (2)

Density of water : 1.025 kg/m3

(Independent variables)

P/D : 0.60; 0.65; 0.70

AE/A0 : 0.75; 0.80; 0.85

Rotational speed (n) : 5 *rps*; 10 *rps*; 15 *rps*

2.7. Performance of Computation

Selecting from a propeller series is a simple method to design a propeller. Among the series propeller is one of the most often used and studied. And selection of the blade was improved later. The thrust and torque coefficient can be expressed as the Table 3.

Table 3 Regression coefficients and exponents of KT-KQ

n	C_{Tn}	s_n	t_n	u_n	v_n	**n**	C_{Qn}	s_n	t_n	u_n	v_n
1	0.00880496	0	0	0	0	1	0.00379368	0	0	0	0
2	−0.204554	1	0	0	0	2	0.00886523	2	0	0	0
3	0.166351	0	1	0	0	3	−0.032241	1	1	0	0
4	0.158114	0	2	0	0	4	0.00344778	0	2	0	0
5	−0.147581	2	0	1	0	5	−0.0408811	0	1	1	0
6	−0.481497	1	1	1	0	6	−0.108009	1	1	1	0
7	0.415437	0	2	1	0	7	−0.0885381	2	1	1	0
8	0.0144043	0	0	0	1	8	0.188561	0	2	1	0
9	−0.0530054	2	0	0	1	9	−0.00370871	1	0	0	1
10	0.0143481	0	1	0	1	10	0.00513696	0	1	0	1
11	0.0606826	1	1	0	1	11	0.0209449	1	1	0	1
12	−0.0125894	0	0	1	1	12	0.00474319	2	1	0	1
13	0.0109689	1	0	1	1	13	−0.00723408	2	0	1	1
14	−0.133698	0	3	0	0	14	0.00438388	1	1	1	1
15	0.00638407	0	6	0	0	15	−0.0269403	0	2	1	1
16	−0.00132718	2	6	0	0	16	0.0558082	3	0	1	0
17	0.168496	3	0	1	0	17	0.0161886	0	3	1	0
18	−0.0507214	0	0	2	0	18	0.00318086	1	3	1	0
19	0.0854559	2	0	2	0	19	0.015896	0	0	2	0
20	−0.0504475	3	0	2	0	20	0.0471729	1	0	2	0
21	0.010465	1	6	2	0	21	0.0196283	3	0	2	0
22	−0.00648272	2	6	2	0	22	−0.0502782	0	1	2	0

Table 3 Regression coefficients and exponents of KT-KQ (continued)

n	C_{Tn}	s_n	t_n	u_n	v_n	n	C_{Qn}	s_n	t_n	u_n	v_n
23	−0.00841728	0	3	0	1	23	−0.030055	3	1	2	0
24	0.0168424	1	3	0	1	24	0.0417122	2	2	2	0
25	−0.00102296	3	3	0	1	25	−0.0397722	0	3	2	0
26	−0.0317791	0	3	1	1	26	−0.00350024	0	6	2	0
27	0.018604	1	0	2	1	27	−0.0106854	3	0	0	1
28	−0.00410798	0	2	2	1	28	0.00110903	3	3	0	1
29	−0.000606848	0	0	0	2	29	−0.000313912	0	6	0	1
30	−0.0049819	1	0	0	2	30	0.0035985	3	0	1	1
31	0.0025983	2	0	0	2	31	−0.00142121	0	6	1	1
32	−0.000560528	3	0	0	2	32	−0.00383637	1	0	2	1
33	−0.00163652	1	2	0	2	33	0.0126803	0	2	2	1
34	−0.000328787	1	6	0	2	34	−0.00318278	2	3	2	1
35	0.000116502	2	6	0	2	35	0.00334268	0	6	2	1
36	0.000690904	0	0	1	2	36	−0.00183491	1	1	0	2
37	0.00421749	0	3	1	2	37	0.000112451	3	2	0	2
38	5.65229E−05	3	6	1	2	38	−2.97228E−05	3	6	0	2
39	−0.00146564	0	3	2	2	39	0.000269551	1	0	1	2
						40	0.00083265	2	0	1	2
						41	0.00155334	0	2	1	2
						42	0.000302683	0	6	1	2
						43	−0.0001843	0	0	2	2
						44	−0.000425399	0	3	2	2
						45	8.69243E−05	3	3	2	2
						46	−0.0004659	0	6	2	2
						47	5.54194E−05	1	6	2	2

As the functions of the blade number, blade area ratio, pitch ratio and advance coefficient [4]:

$$K_T = \sum_{n=1}^{39} C_{Tn} J^{Sn} \left(\frac{P}{D}\right)^{tn} \left(\frac{A_E}{A_0}\right)^{Un} Z^{vn} \qquad (4)$$

$$K_Q = \sum_{n=1}^{47} C_{Qn} J^{Sn} \left(\frac{P}{D}\right)^{tn} \left(\frac{A_E}{A_0}\right)^{Un} Z^{vn} \qquad (5)$$

where C_{Tn} and C_{Qn} are the regression coefficients of the thrust and torque coeffficients, repectively; *Sn*, *tn*, *Un*, and vn are the exponents of *J, P/D, AE/A0, and Z*, respectively.

2.8. Genetic Algorithms (GA)

The basic theory, Genetic Algorithms are search algorithms based on the mechanics of natural selection and natural genetics.

They combine survival of the fittest among string structure with structured yet randomized information exchange to inform a structure algorithms with some of the innovative flair of human search.

In every generation, a new set of artificial creatures (strings) is created using bits and pieces of the fittest of the old man; an occasional new part is tried for good measure. While randomized, genetic algorithms are no simple random walk. They efficiently exploit historical information to speculate on new search points with expected improved performance. Genetic algorithms have been developed by John Holland [7].

Based on the theory, the research was conducted with the set of parameters dependent and independent variables. For the first steps were identifying variables and functions, the propeller of remotely operated vehicle (ROV) , there are three variable that we could change randomly as like as P/D (pitch ratio), AE/A0 (expanded blade area ratio), and n (rotational speed). Using the three variables, we would get the value of KT and KQ. Thus, the thrust (T) and torque (Q) can be expressed as:

Function:

$$T = K_T \left(\rho n^2 D^4\right) \qquad (6)$$

$$Q = K_Q \left(\rho n^2 D^5\right) \qquad (7)$$

The fitness function we can select the Eqs. (6) and (7), then used the regression Table (3) to produce the thrust and torque coefficients.

Fitness function:

$$K_T = \sum_{n=1}^{39} C_{Tn} J^{Sn} \left(\frac{P}{D}\right)^{tn} \left(\frac{A_E}{A_0}\right)^{Un} Z^{vn} \qquad (8)$$

$$K_Q = \sum_{n=1}^{47} C_{Qn} J^{Sn} \left(\frac{P}{D}\right)^{tn} \left(\frac{A_E}{A_0}\right)^{Un} Z^{vn} \qquad (9)$$

The constraint function, used three variables (P/D, A_E/A_0, n) can be created as:

Constraint function:

$$0.60 \leq \frac{P}{D} \leq 0.70 \qquad (10)$$

$$5 \leq n \leq 15 \qquad (11)$$

2.9. Optimization

For the process of optimization shown in Fig. 7, used optimization tools that supported by Matlab program for the solution of Genetic Algorithms method. In this case, GA apply to know how is the optimum thrust for the initial propeller using the parameters and all parameters setup for GA is shown in Table 4.

Table 4 Setting up the GA parameters

GA parameters	Population size = 20
	Number of generations = 80
	Selection: Stochastic uniform
	Crossover rate = 0.8
	Crossover function: Scattered
	Mutation rate = 0.2

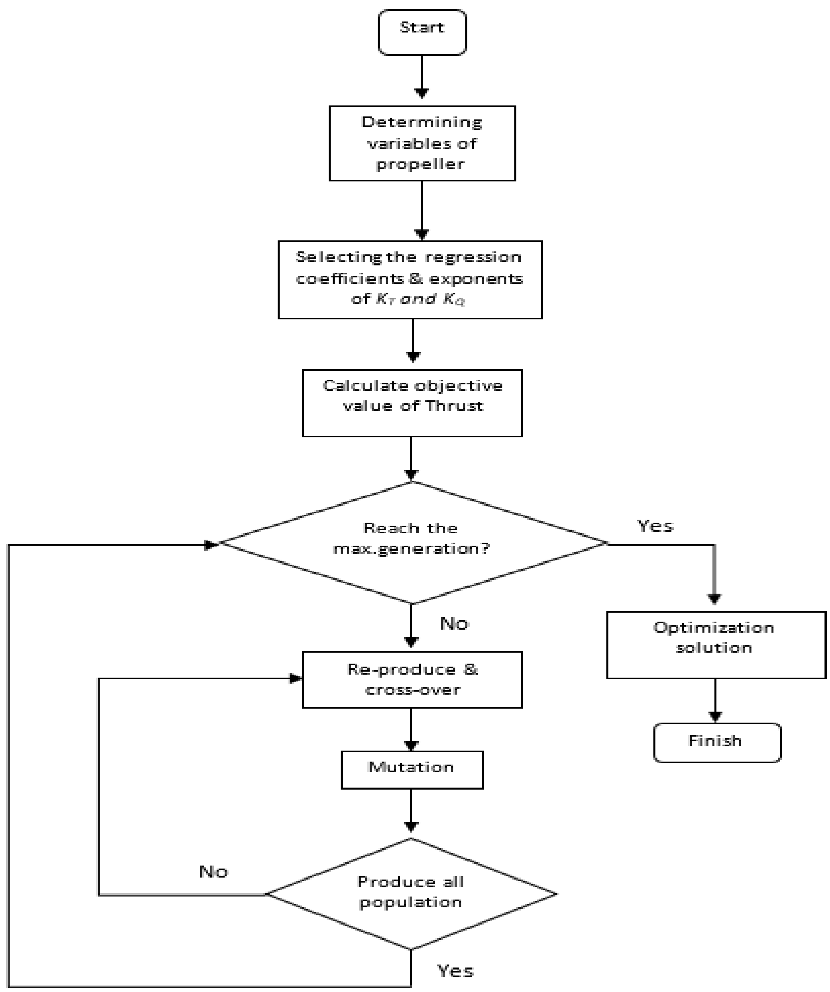
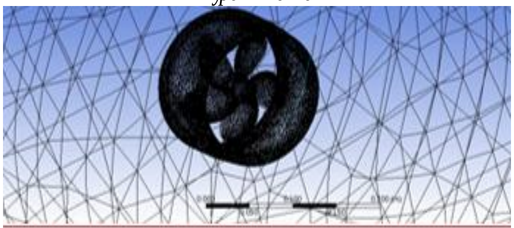


Fig. 7 Flowchart of genetic algorithms

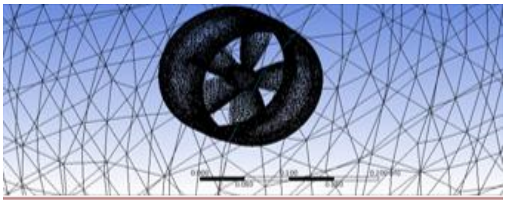
2.10. CFD Analysis

Type A nozzle



Domain	Nodes	Elements
Default Domain	151053	845769

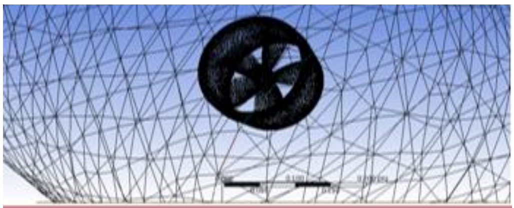
Fig. 8 Meshing of type A for B-Series (B5-75)



Domain	Nodes	Elements
Default Domain	125480	702840

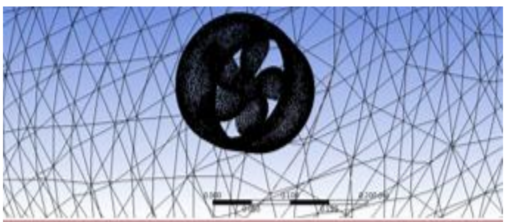
Fig. 9 Meshing of type A for Kaplan-Series (Ka5-75)

Type B nozzle



Domain	Nodes	Elements
Default Domain	204080	1146817

Fig. 10 Meshing of type B for B-Series (B5-75)

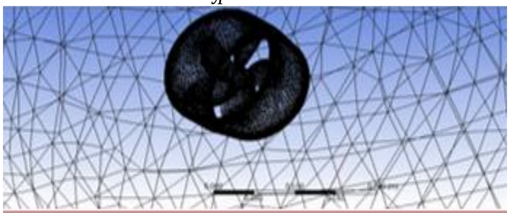


Domain	Nodes	Elements
Default Domain	179164	1007934

Fig. 11 Meshing of type B for Kaplan-Series (Ka5-75)

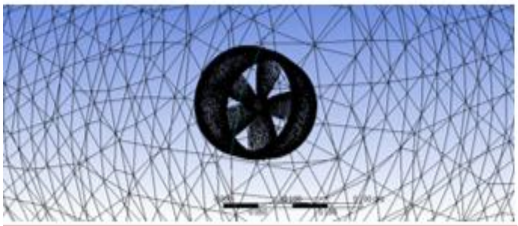
The process of analysis for the nozzle design has been conducted. There were some different results for the meshing process of all nozzle's type. For the type A for B-Series (B5-75) shown in Fig. 8, it has 845,769 *nodes* and Kaplan-Series (K5-75) shown in Fig.9 has 702,840 *nodes*. The type B for B-Series (B5-75) shown in Fig.10, it has 1,146,817 *nodes* and Kaplan-Series (K5-75) shown in Fig.11 has 1,007,934 *nodes*. The type C for B-Series (B5-75) shown in Fig.12, it has 1,343,789 *nodes* and Kaplan-Series (K5-75) shown in Fig.13 has 1,206,703 *nodes*.

Type C nozzle



Domain	Nodes	Elements
Default Domain	239314	1343789

Fig. 12 Meshing of type C for B-Series (B5-75)



Domain	Nodes	Elements
Default Domain	214573	1206703

Fig. 13 Meshing of type C for Kaplan-Series (Ka5-75)

Streamline simulation

For the simulation of streamline, the input for all types were same, and the rotational speed was 300rpm. The results of streamline from type A nozzle for B-series (B5-75) shown in Fig.14, type A nozzle for Kaplan-series (Ka5-75) shown in Fig.15, type B nozzle for B-series (B5-75) shown in Fig.16, type B nozzle for Kaplan-series (Ka5-75) shown in Fig.17, type C nozzle for B-series (B5-75) shown in Fig.18, type A nozzle for Kaplan-series (Ka5-75) shown in Fig. 19.

Type A nozzle

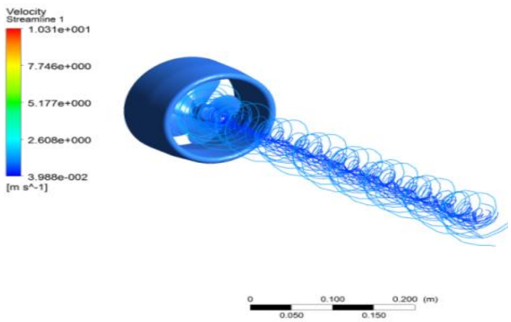


Fig. 14 Streamline of type A for B-Series (B5-75)

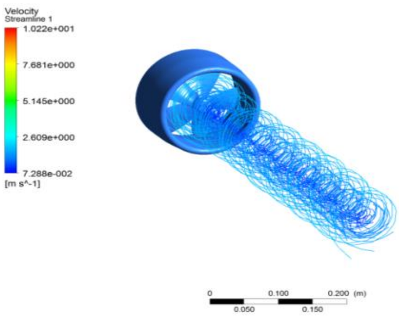


Fig. 15 Streamline of type A for Kaplan-Series (Ka5-75)

Type B nozzle

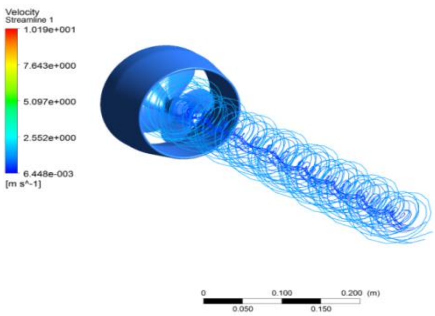


Fig. 16 Streamline of type B for B-Series (B5-75)

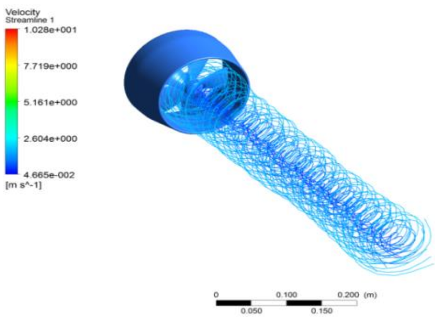


Fig. 17 Streamline of type B for Kaplan-Series (Ka5-75)

Type C nozzle

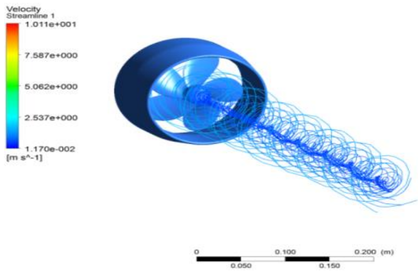


Fig. 18 Streamline of type C for B-Series (B5-75)

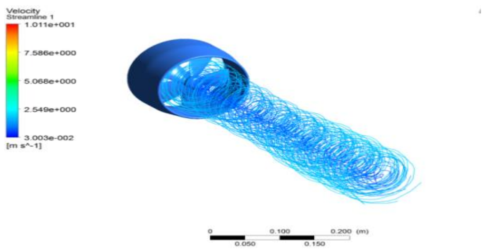


Fig. 19 Streamline of type C for Kaplan-Series (Ka5-75)

From all the figures, it can be seen that the type C of nozzle was the highest of thrust than type A or type B.

Pressure contour

Type A nozzle

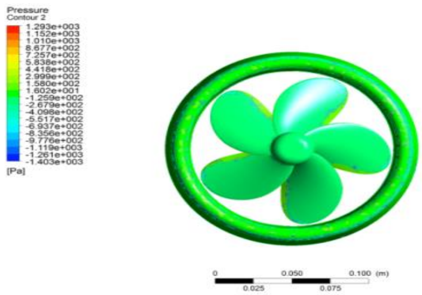


Fig. 20 Pressure contour of type A for B-Series (B5-75)

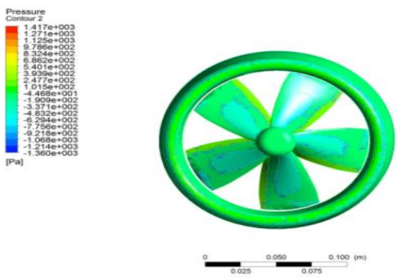


Fig. 21 Pressure contour of type A for Kaplan-Series (Ka5-75)

Type B nozzle

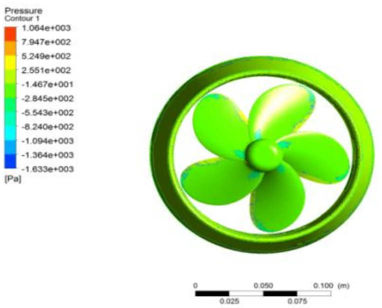


Fig. 22 Pressure contour of type B for B-Series (B5-75)

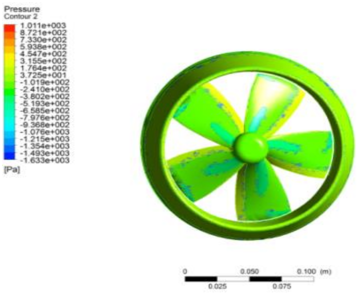


Fig. 23 Pressure contour of type B for Kaplan-Series (Ka5-75)

Type C nozzle

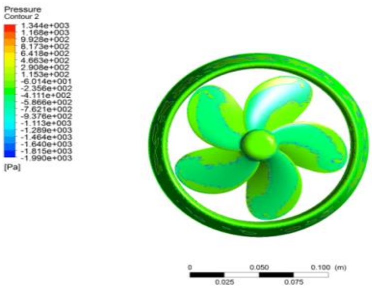


Fig. 24 Pressure contour of type C for B-Series (B5-75)

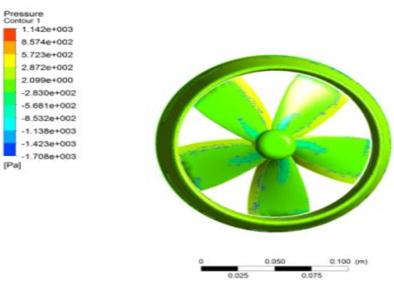


Fig. 25 Pressure contour of type C for Kaplan-Series (Ka5-75)

This process was indicating the pressure distribution on the blade area. The results of pressure contour from type A nozzle for B-series (B5-75) shown in Fig. 20, type A nozzle for Kaplan-series (Ka5-75) shown in Fig. 21, type B nozzle for B-series (B5-75) shown in Fig. 22, type B nozzle for Kaplan-series (Ka5-75) shown in Fig. 23, type C nozzle for B-series (B5-75) shown in Fig. 24, type A nozzle for Kaplan-series (Ka5-75) shown in Fig. 25.

3. Results and Discussion

From the analysis of CFD method, it can be seen on the Table 5. For the changes of the force as clearly shown in Fig. 26, and the changes of the torque shown in Fig. 27.

Table 5 Results of Force (T) and Torque (Q)

Type of models		Force (T) (N)	Torque (Q) (Nm)
B-Series (B5-75)	Propeller without nozzle	1.67	0.016
	Nozzle A	2.06	0.020
	Nozzle B	2.12	0.021
	Nozzle C	2.26	0.023
Kaplan (Ka5-75)	Propeller without nozzle	2.02	0.020
	Nozzle A	2.34	0.022
	Nozzle B	2.50	0.023
	Nozzle C	2.53	0.024

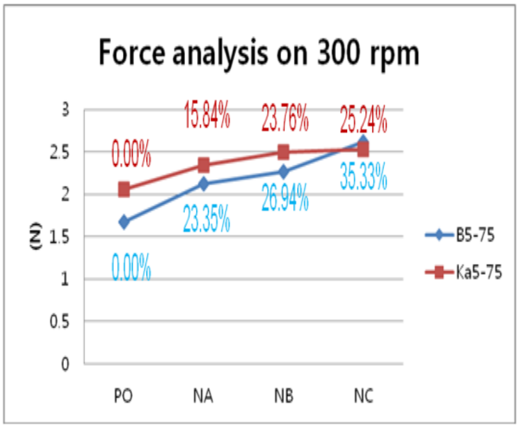


Fig. 26 Chart of Force (T) analysis on 300*rpm*

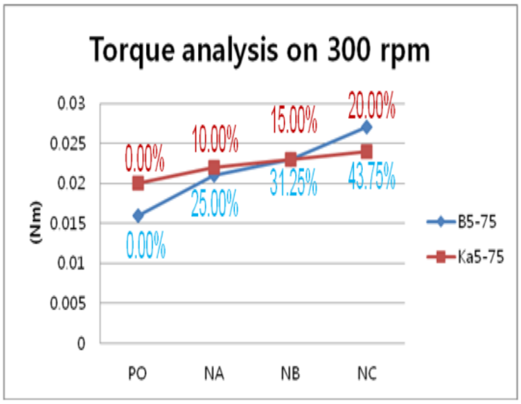


Fig. 27 Chart of Torque (Q) analysis on 300*rpm*

In this paper, we have described the specification and the design concepts of ducted propeller as the thruster of ROV (Remotely Operated Vehicle). There were several designs of the ducted propeller. Total of models were 6 models, B-Series (B5-75) and Kaplan-Series (Ka5-75) with nozzle's type A, B, and C.

Based on the simulations which were conducted, can be concluded that the highest of force (T) was model of Kaplan-Series (Ka5-75) with type C of nozzle. The model could produce 2.53 N, or 25.24% of extra thrust. The lowest of torque (Q) was model of B-Series (B5-75) with type A of nozzle. Thus the best model will be used for ROV thruster is model of Kaplan-Series (Ka5-75) with type C of nozzle.

In other hand, the model also was conducted for analysis using other software, was used Star CCM+ for checking the value of the force (T) and the torque (Q). The geometry shown in Fig. 28, The mesh scene as shown in Fig. 29, and the results could be seen in Fig. 30 for the streamline simulation and for the pressure contour shown in Fig. 31.

Geometry

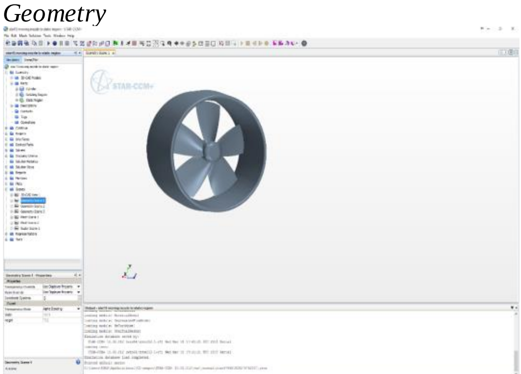


Fig. 28 Geometry of ducted propeller in Star CCM+

Generating Mesh

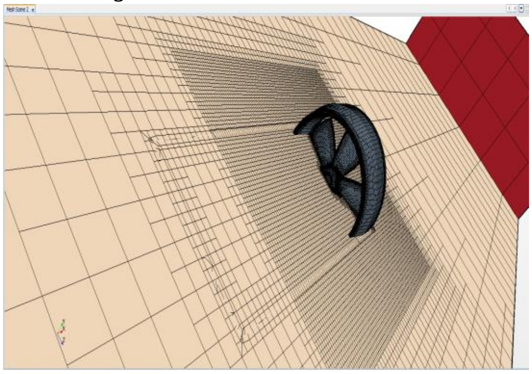


Fig. 29 Mesh Scene in Star CCM+

Streamline simulation

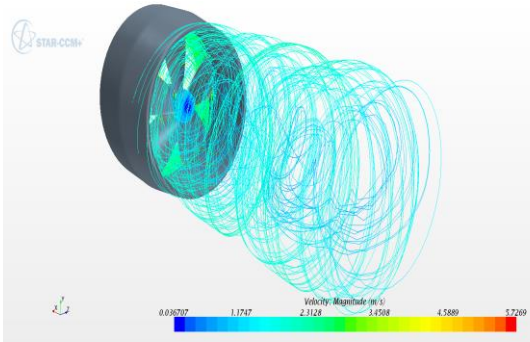


Fig. 30 Streamline simulation in Star CCM+

Pressure Contour

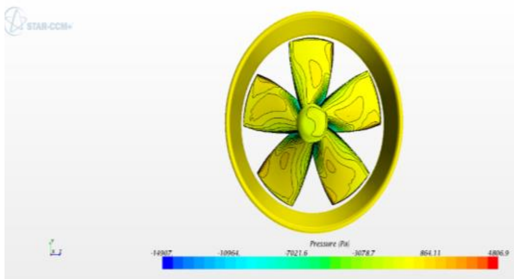


Fig. 31 Pressure contour in Star CCM+

Based on the simulation results both of ANSYS CFX and Star CCM+ is almost same value, the difference of the force (thrust) is around 5%. It means, the analysis of ducted propeller is enough satisfied and accurate. It can be seen on the Table 6.

Table 6 Comparison Results

Results	ANSYSCFX	STAR CCM+
Force (T)	2.53	2.66
Torque (Q)	0.024	0.033

Optimization

In the previous chapter has been obtained the model that will be used for the ROV (Remotely Operated Vehicle). The model is the Kaplan-series with type C nozzle. Further, the optimization analysis can be applied to get the optimal of thrust for this case.

With the fitness function and constraints from the Table 7, the results can be exported by Genetic Algorithms as shown in Fig. 32.

Table 7 Output of Optimum Thrust

Iteration	P/D	A_E/A_0	n(*rev/s*)
51	0.60	0.79	5.00

At the 51 iteration using GA, the thrust will be optimum when the value of P/D (pitch ratio) is 0.60, AE/A0 is 0.79 and the value of rotational speed is 5 rev/s.

Based on the results from the Table 8, the thrust is increasing 27.43% from 2.530 N to 3.224 N. And it means the optimization of the thrust for the ducted propeller of ROV is reached and satisfied.

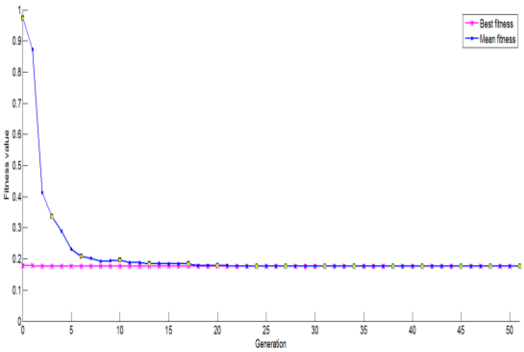


Fig. 32 Fitness value through the generations

Final Results

Table 8 Comparison the final results

Result	Original	New	Differences
Force (*N*)	2.530	3.224	+27.43%
Torque (*Nm*)	0.024	0.032	+33.33%

4. Conclusions

In this paper, about a study on development of the propulsion device for the ROV (Remotely Operated Vehicle). The CFD method has been demonstrated to be more effective as the problem solver for determining the optimum thrust of ROV.

The nozzle can produce the extra thrust for the propeller. CFD model shows these results.

The comparison of propeller types such as B-Series (B5-75) and Kaplan-series (Ka5-75) shows that Kaplan-series (Ka5-75) has stronger thrust than B-series (B5-75) and the streamline simulation shows these results also.

The highest thrust (T) is from the model Kaplan-series (K5-75) with type C of nozzle. The model can produce 2.53 N or 25.24% of extra thrust.

The GA is applied for optimization design of the initial propeller dimension and the results show that it is good for this kind of the problems.

The optimization method GA is easy to use as optimum solution in multi-dimensional using three variables such as P/D (pitch ratio), AE/A0 (expanded blade area ratio), and n (rotational speed) are affecting to the result of the thrust.

From the results of optimization, the thrust is optimum when the value of P/D is 0.60, AE/A0 is 0.79 and the value of rotational speed is 5 rev/s or 300 rpm.

In this research, for the optimization of the ducted propeller for ROV has been proposed and provides the solution to the problem of ROV thruster. Therefore, CFD method and GA optimization can be employed due to its ability to solve the problem and its performance mentioned above especially for the best performance of ducted propeller.

Acknowledgement

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