



# Initial Study of Two-Blade Propeller Design Parameter

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**Abstract.** All manufacturing processes begin with design steps of a product. This study aims to design the main parameters of two-blade propellers for fishing vessels using computer-aided design (CAD), Computer-Aided Engineering (CAE) and Computational Fluid Dynamic (CFD) software simulations. Through simulation, it is hoped that it will be able to reduce a number of physical experiments at the time of making propeller so that it is more efficient in terms of cost and time because it does not repeatedly conduct experiments in making propeller.

**Keywords:** Engineering Design · Two-blade Propeller · CAD-CAE-CFD

## 1 Introduction

The main task of a propeller is to pass on power and torque of a driving engine in the form of rotational motion to produce thrust on a boat/ship. Therefore, a proper propeller design is necessary to ensure the propeller generates propulsion for the boat/vessel in the most effective way [1]. Conversely, if the propeller design is incorrect, it will decrease the propeller performance and fuel efficiency of the ship's propulsion system.

A configuration of the propeller is a special discussion because a selection of the right propeller design depends on specifications of a boat/ship and also affects cost of production. Therefore, hydrodynamic characteristics of propellers are a very prominent aspect to be analyzed in the early stages of design using several methods in the form of propeller model tests. In the world of fishermen and marine, the selection of propellers suitable for a type and size of boats is a very important and difficult undertaking [2].

There has been a lot of software developed that helps designers in the propeller design process ranging from Computer Aided Design (CAD) to Computer Aided Engineering (CAE) including Computational Fluid Dynamics (CFD) which can create a variety of products including propellers computationally in various models and input parameters that can be evaluated continuously and faster [3].

Computational simulation of fluid dynamics is the best alternative with several advantages allowing it to be simulated used actual geometric scales and models under extreme conditions of fluid flow and also found to have close conformity with the experimental data.

## 1.1 Definition Terms

Referring to [4] the following defined several terms related to designing propellers. Diameter (D) – diameter of imaginary circle scratched by the end of a blade when a propeller rotates; Radius – distance from the axis of rotation to the end of blade; Blade face – side of pressure, pitch side. Aft side of blade surface faces the stern; Blade number (Z) – same with the number of blades on a propeller; Blade tip – maximum reach of blades from the center of hub separating front and rear edges; Hub – a solid cylinder located in the center of propeller. The hub shape can be cylindrical, conical, radius and barrel; Blade root – fillet area. Transition region from surface and edge of a blade to peripheral hub where the blades attach to the hub; Pitch (P) – linear distance where propeller will move in one turn without slip; Rake – forward or backward from a blade to a line perpendicular to axis of rotation of propeller; Wake (w) – explains overall disturbances caused by ship's movement as a result of obstacles in hull, streamlined flows passing through the hull and the wave patterns that ship forms on water surface; Developed Area ( $A_D$ ) - is an actual drive face area; Projected area ( $A_P$ ) - is the sum of an area blade projected into a plane perpendicular to the axis of screw; and Expanded area ( $A_E$ ) - is the sum of an area of all blades covered in the frame of expanded blade outside the hub.

After defining the main parameters of propeller blade above, the next step is to design a propeller to produce thrust or absorb the specified power at a certain rpm - under certain conditions. Flow of fluid into propeller varies radially and its purpose is to obtain the geometry of blade as defined above for the load distribution of blade at its radius. The cut cross-section pitch can be selected to match the average wake in each radius (a wake-adjusted propeller) and the shape of blades is selected to minimize cavitations.

## 1.2 Software Based Modeling

Modeling a series-type propeller blade in this paper refers to standard airfoil points of B-series. An outline of airfoil points of propeller was generated using PropCad 2005. Resulting coordinate data were used to model blades of propeller using SolidWorks 2021 program including hub section and corners (fillets) in blade legs. Then using the multipart surfaces option, the blade is modeled into a solid object after going through knit and fill process.

CAE analysis using Finite Element Analysis (FEA) method in this study was carried out by applying torque and pressure to propeller blades of 0.072 Nm and 9500 N/m<sup>2</sup>. Analysis was to obtain maximum performance of blade strength includes stress, strain, and displacement in used scrap aluminum materials.

This study also presents an investigation of performance and hydrodynamic parameters of marine propellers through analysis of Computational Fluid Dynamics (CFD) in order to simulate numerically the propulsion force of a boat, through simulation of flow field around geometry of the blade using numerical methods and algorithm established [5].

## 2 Material and Method

Performance data resulting from MatLab open-source script, manual calculation using formulae (1) to (10), see Table 1, and main size data of propeller, are used as input in Propcad software [6] which is then directly to produce coordinates of 3-D propeller. The next propeller model creation uses Solidwork software based on 3-D coordinate results from previous calculations, then redrawn using Solidworks, see Table 2.

CFD numerical simulation is continued using Solidworks program which is basically the same as other types of CFD-based software [7]. Numerical simulation steps on this solver are divided into several stages, including geometry, mesh, setup, solution and result. Furthermore, optimal results of two-leaf propeller engineering design will be used as a core model formed using 3-D printing.

Creation of a propeller model according to working drawings resulting from the program simulation. Based on this drawing, an offset table and a measurement table can be determined to be used to create a two-blade propeller model, see Table 2.

Design procedure refers to the use of charts and series certified by Society of Naval Architecture and Marine Engineers [SNAME] by establishing characteristics of propeller pitch, pitch speed, pitch ratio, average axial motion speed, propeller diameter (D), blade area, number of blades, blade outline, thickness, shape - the shape of cut cross section is regulated by the need to avoid cavitation, engine power and rotation rate (rpm), effective power ( $P_E$ ) and boat speed ( $V_S$ ).

Furthermore, by using graph, explore the best combination of blade diameter, revolution per minute (rpm) and pitch ratio [6], aiming if speed (n) is determined for each corresponding conductivity ( $P_D$ ) will be estimated on the assumption that a moderate change in loading of  $P_D/n^3$  is constant.

### 2.1 Design Proposed

Propeller design analysis aims to obtain information on minimum power requirements, cavitation, noise, vibration and maximum efficiency conditions at sufficient rotation. Two methods are usually used to design propellers, namely a method that will be adopted in this paper in form of diagram usage obtained from experiments in open water and mathematical methods involving lifting line, lifting surface, vertex lattice, boundary element method.

### 2.2 Formulae Design

Initial design variable requirements of the propeller are delivered power (kW), rotational rate of propeller (rpm), ship speed (m/s), number of blades (Z), Taylor wake friction (w). Forward speed  $V_A$  is obtained from  $V_S$  (boat speed) by model test or by using this formula [8]:

$$V_A = V_S(1 - w) \quad (1)$$

with friction wake,  $w = 0.15$ .

**Table 1.** Two Blade Design Calculation Result

No.	Parameters	Formula	2 Blades		Remarks	
			Given	Calculated	Others	Conver.
1	# blade, <b>Z</b> [Number]		2			
2	Propeler rotation, <b>N</b> [rpm]		1500		157,080	[rad/s]
3	Boat speed (service), <b>V<sub>K</sub></b> [m/det] -> [Knot]		6		3,087	[m/s]
4	Taylor's wake friction, <b>w</b> [W]		0,15			
5	Advanced speed, <b>V<sub>M</sub></b> [m/det.] -> [Knot]	$V_K(1 - w)$		5,10	2,624	[m/s]
6	Engine brake power (Max.), <b>P<sub>B</sub></b> [W] -> [hP]	$P_P/h_p$	5		3,73	[kW]
7	Shaft Efficiency, <b>h<sub>p</sub></b> [%]	$h_p$	0,96			
8	Shaft power, <b>P<sub>P</sub></b> [W] -> [hP]	$P_B * h_p$		4,80		
9	Delivered power, <b>P<sub>H</sub></b> [kW] -> [hP]	$P_P * h_p$		4,61		
10	Power coeffisien Daya, <b>B<sub>P</sub></b> []	$(P_P^{0,5} * N)/V_M^{2,5}$		55,95	Graph	Attach.
11	Optimum efficiency, <b>h<sub>O</sub></b>		0,51		Graph	
12	<i>Pitch - Diameter Propeller ratio,</i> <b>P/D =</b>		0,64			Rotor D
13	<b>d<sub>OPT</sub> =</b>		282			
14	Propeller thrust, <b>F<sub>D</sub></b> [N/m]	$(P_H \cdot h_O)/V_M$		0,46	668,210	[N]
15	Optimum			0,959	[ft]	[m]
16	propeller diameter, <b>D</b>		[*12]	11,506	[inch]	[mm]
17	Pitch Propeller, <b>P</b> [inch]	$(P/D) * D$		7,36		[mm]

(continued)

**Table 1.** (continued)

No.	Parameters	Formula	2 Blades		Remarks	
			Given	Calculated	Others	Conver.
18	Blade area ratio, <b>RLS</b> []	$(A_E/A_0)$	0,55		Table	
19	Blade thickness fraction, <b>h<sub>t</sub></b> []		0,05			
20	Blade area (disk area), <b>A<sub>0</sub></b> [inch <sup>2</sup> ]	$(\phi * D^2)/4$		103,97		
21	Blade expanded area, <b>A<sub>E</sub></b> [Inch <sup>2</sup> ]	$(A_E/A_0 * A_0)$		31,191		
22	Maximum blade, <b>t<sub>0</sub></b> [inch]	$D * h_t$		0,575		
23	Hub diameter, <b>d</b> [inch]	$0,18 * D$		2,071	0,053	[m]
24	Projected area, <b>A<sub>P</sub></b> = [inch <sup>2</sup> ]	$A_D * (1,067 - 0,229 * (P/D))$		52,634		
25	Developed area blade section, <b>A<sub>D</sub></b> = [inch <sup>2</sup> ]	$RLS * A_0$		31,191		
26	Expanded area, <b>A<sub>E</sub></b> = [inch <sup>2</sup> ]	$(A_E/A_0) * A_D$		31,191	$A_D = A_E$	
27	Blade material density of bronze alloy (g) [N/m <sup>3</sup> ]	$\rho_{NAB} \cdot g$	7590	74457,9	$B_{tf} = 0,05$	$z = 0,5$
28	Total blade weight, <b>W</b> [N]	$1,982 * B_{tf} * z * g * R^3$		23,021		
29	Blade polar moment of inertia, <b>I<sub>P</sub></b> [Nm <sup>2</sup> ]	$0,2745 * W * R^2$		0,135		
30	Total stress on blades, <b>s</b> [N/m <sup>2</sup> ]	$W/A_0$		343,2		

In initial design stage,  $P_B$  as brake power, boat speed, and graphs are used to track the best efficiency combination of  $D$  (inch),  $n$  (rpm) and  $(P/D)$ .  $P_B$  is power transmitted to engine clutch or flywheel while  $P_S$  as shaft power is power available to gearbox output clutch. The relationship between  $P_B$  and  $P_S$  is as follows.

$$P_B = P_S / \eta_S \quad (2)$$

Where  $\eta_S$  is shaft efficiency of 0.98 for a boat with an engine located aft and 0.97 for a boat with an engine located in the middle of boat.

**Table 2.** Research Design

Activity	Method/Activity	Remarks
Two-blade propeller engineering design	- Primary Data: ship speed, rpm, propeller diameter, number of blades and others - 3-D coordinates of matlab <i>open source</i> script results - Usage of engineering design performance data forms CAD	Open source Matlab, PropCad and Solidworks
Numerical Simulation CAE	- CAE: <i>Simulation</i> , Geometry, <i>meshing</i> , etc.	Solidworks

For analysis of design and performance of propeller using Wageningen B series, the power delivered is

$$P_D = P_S \eta_S \quad (3)$$

Choice at the final design stage can be influenced by limitations of blade diameter and by engine characteristics of available propeller. Rpm corresponding to a certain power can be estimated with the assumption that for a moderate change of constant load  $P_D/n^3$  so that  $B_P$  and are obtained because  $P_D$ ,  $D$ ,  $V_A$  and  $n$  are known,  $B_P$  can be calculated by the formula:

$$B_P = \frac{P_D^{0,5} n}{V_A^{2,5}} \quad (4)$$

Values of  $\eta_0$  and  $(P/D)$  can be tracked using the graph corresponding to  $B_P$  value. Therefore, an optimal diameter is obtained as.

$$D = \frac{\delta_{opt} V_A}{n} \quad (5)$$

If for reasons of draft restriction and maintaining a sufficient amount of water over fluid thread,  $D$  is limited to a few values less than that indicated for efficiency reasons, with the same  $B_P$  value but a new value of corresponding to the new  $D$ , the graph is again used to determine and  $(P/D)$ . Knowing  $\eta_0$ , assumed propulsive coefficient can be calculated using this equation.

$$\eta_D = \frac{1 - t}{1 - W} \eta_0 \eta_R \quad (6)$$

Where  $t$ ,  $w$  and  $\eta_R$  are known from a model test or have been estimated  $P_D$ , otherwise new propulsive efficiency is used; this calculation is repeated more than once, if necessary, until a substantial value is obtained. Then, propeller thrust is expressed as follows.

$$T = \frac{P_D \eta_0}{V_A} \quad (7)$$

Propeller blade thickness ratio,  $\eta_t = \frac{t_0}{D}$  where  $t_0$  is the maximum blade thickness and  $D$  is propeller diameter.

To estimate the weight of all ( $W$ ) blades and the polar moment of blade inertia using approximate formula as follows.

$$W = 1.982 B_{tf} \zeta \gamma R^3 \quad (8)$$

$$I_P = 0.2745 W R^2 \quad (9)$$

with  $I_P$  = polar moments of all blades  
 $B_{tf}$  = blade thickness fraction  
 $V$  = blade area fraction  
 $\gamma$  = specific gravity of blade material  
 $R$  = blade end radius (tip)

Thus stress ( $\sigma$ ) on the blade is obtained from this equation.

$$\sigma = \frac{\text{Force on Blade}}{\text{Area of Blade Disk}} = \frac{F}{A_0} = \frac{M g}{A_0} \quad (10)$$

### 3 Result and Discussion

Using formulas above, initial parameters of two-blade design are then calculated with initial design data of the propeller blade as follows. Brake power (maximum power),  $P_B = 5$  [hp] = 3.73 [kW], planned propeller speed = 1500 [rpm], planned boat speed = 6 [knots] = 3.087 [m/s], number of propeller blade,  $Z = 2$ , Taylor's wake friction,  $w = 0.15$ .

#### 3.1 Simulation Steps

*Geometry:* build a two- or three-dimensional representation of the object to be modeled and tested using Solidworks working plane coordinate system.

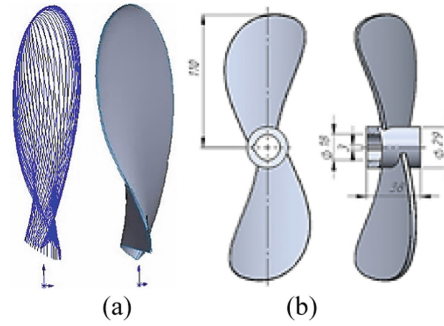
*Create Material Properties:* determine a custom material arrangement of used aluminum or brass materials from various research sources required including thermal and mechanical properties.

*Generate Mesh:* Solidworks understands the arrangement of elements i.e., determines how modeled system should be broken down into finite elements.

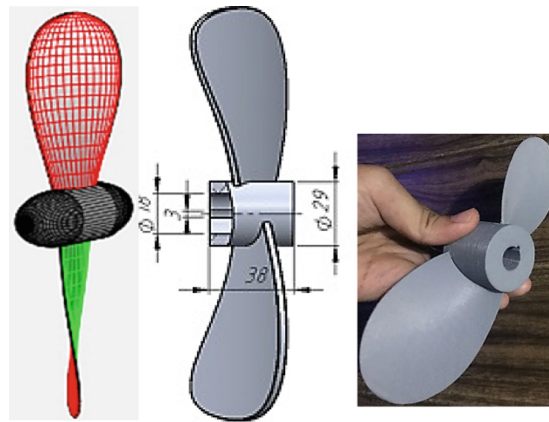
*Apply Load:* next is to overload the system with constraints, such as physical loads or limit conditions.

*Solve Solution:* is actually a simulation step with Solidworks needing to understand the desired simulation conditions problem must be solved (linear or non-linear conditions, dynamic or static, etc.).

*Present Results:* once a solution is obtained, there are many ways to present the simulation results, choosing from many options such as tables, graphs, and contour plots.



**Fig. 1.** (a) Transformation CAD. Blades: Surface to Solid (b) Two-blade Propeller



**Fig. 2.** 3-D coordinate, CAD and 3-D Printing Result

### 3.2 CAE Analysis

After setting some of main parameters of the propeller such as type, power, propeller diameter and others using OpenProp or PropCad obtained some propeller performance data such as *advance ratio* ( $J$ ), thrust coefficient ( $K_T$ ), torque coefficient ( $K_q$ ) and so on as well as the coordinates of the 3-D propeller and CAD solid propeller two-blade, see Fig. 1 and 2, after being exported to the Solidworks program. Solid modeling is generally useful because Solidworks programs can calculate dimensions and volumetric magnitudes of successfully designed propellers.

Property material for non-linear CAE analysis in Solidworks is a custom-made material referring to scrap aluminum casting materials [9–11] with density of  $2700 \text{ kg/m}^3$ , maximum and yield stresses of 167 and 115 MPa with torque and pressure, as design parameters, experienced on two-blade propeller surfaces of  $0.072 \text{ Nm}$  and  $9500 \text{ N/m}^2$  so that Von Mises stress results are obtained the maximum is at a point of contact between propeller blade and hub of  $9.324 \cdot 10^6 \text{ Pa}$  and minimum safety factor at the hub and propeller blade contact point is 5.12 and the maximum is at the end (tip) of the blade of  $1.672 \cdot 10^5$ , see Fig. 3 and 4.



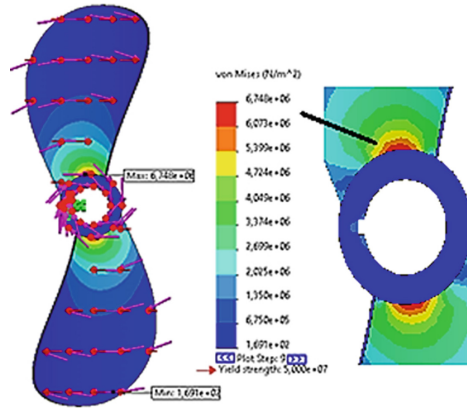


Fig. 3. Von Mises simulation results

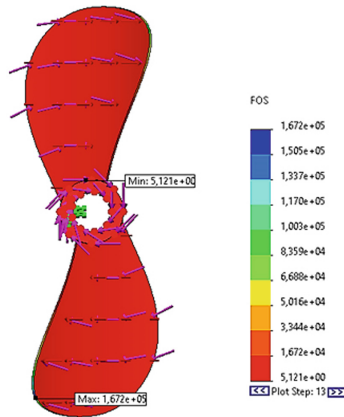


Fig. 4. Safety factor simulation result

### 4 Conclusion

Performance of a propeller really needs to be checked to find out whether the propeller is able to propel the boat at a desired speed. From simulation results, the stress plot is observed that stress experienced on the used aluminum propeller blades is far below the yield strength limit for isotropic materials ( $115 \text{ N/mm}^2$ ), thus this propeller will not experience elastic failure. This paper is limited to presenting only non-linear structural static analysis presented by Von Mises stress and factor of safety results which can then be followed by dynamic analysis such as frequency spectrum to determine noise reduction from used aluminum alloy materials.

**Acknowledgments.** This article and research was funded by State Polytechnic of Sriwijaya PNPB funds through Applied Research (Penelitian Terapan Unggulan) - Number: 5747/PL6.2.1/LT/2022.

**Authors' Contributions.** Conceptualization: I. M, Methodology: I. M, and S.E Validation: I. M, S. W., and M. T.

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