Design Procedure of 4-Bladed Propeller

Ishiodu Anthony[1], Williams Ekwere[1], Ezenwa Ogbonnaya[2] and Kuvie Ejabefio[3]
email:aishiodu@yahoo.com
[1]Department of Marine Engineering, Maritime Academy of Nigeria, Oron, Akwa Ibom State, Nigeria.
[2]Department of Mechanical/Marine Engineering, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria.
[3]Department of Marine Engineering, Rivers State University of Science and Technology, Port Harcourt, Rivers State Nigeria.

Abstract

Marine propellers, although submerged in water aft of the ship, form an integral part of a ship and play a vital role in ship propulsion. Much has been said and published on the development of the marine propeller from the time of antiquity to the present age, but there is more to be done. Therefore, this paper focuses on the design procedure of four bladed marine propellers with specific interest on engines with 85Bhp and ship speed of 30knots for the design of the fixed pitch propeller. This work covers the basic principles underlying the design from the beginning to the end. Thus, this work used the B_p *standard chart using the optimum design line to carry out the design analysis of propellers for a ship with a detailed calculation of the various stages involved in the derivation of the basic propeller. The result of the work thus shows that for a propeller with Blade area ratio of 0.55, the open water efficiency is 73%. This means that irrespective of the initial cost of designs and manufacturing this type of propeller, the development of maximum efficiency should be the pursuit of the designer, the manufacturer and the user.*

Keywords: *4-Bladed propeller, efficiency, pitch ratio, expanded area, developed area, projected area*

1.0 Introduction

The movement of a ship through water is achieved by the power so developed in the engine via the propeller shaft to the propeller in water. The distance or forward motion depends mainly on the propeller pitch which is defined as how far the propeller can travel for one revolution of the shaft.

According to [1], propeller is a type of a fan that transmits power by converting rotational motion into thrust. A pressure difference is produced between the forward and the rear surfaces of the air foil-shaped blade, and a fluid (such as air or water) is accelerated behind the blade. Propeller dynamics can be modeled by both Bernoulli's principle and Newton's third law. A propeller is sometimes colloquially known as screw.

In sculling, a single blade is moved through an arc; from side to side taking care to keep presenting the blade to the water at effective angle [1]. The innovation introduced with the screw propeller was the extension of that arc more than 360° by attaching the blade to a rotating shaft. Propellers can have a single blade, but in practice there is nearly always more than one so as to balance the forces involved.

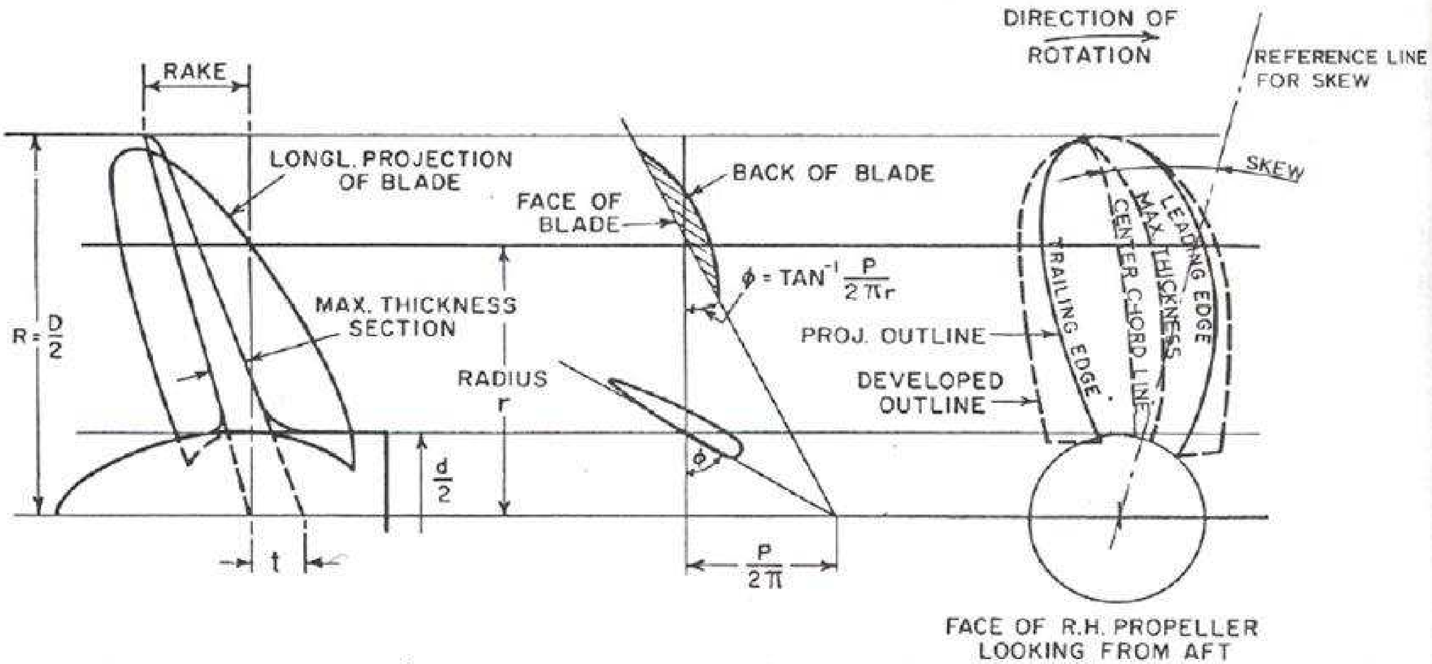
Typical propeller geometry is shown in Fig. 1 which outlines some of the terms used in designing a propeller for a ship. The drawing starts with the elevation view, which shows the side view, including the blade thickness and the rake angle. Rake takes advantage of the fact that the flow into the propeller is slightly inwards. It also increases the clearance between the blade and the hull. The blade thickness reduces away from the shaft center, so the nominal thickness is the thickness projected as if the blade went all the way to the centerline.

The elevation view, which shows the sections and skew. Skew makes the propeller enter a given flow area less suddenly as it spins than if all of the sections were aligned. This reduces noise and change the loading along the blade [2].

It is noticed that in [3], the fundamental theory of screw propeller is applicable to all forms of marine propellers. In its present form a screw propeller consist of a stream lined hub attached outboard to a rotating engine shaft on which are mounted two to seven blades. The blades are either solid which the hub detachable or movable. The screw propeller which has the characteristics motion of a screw revolves about the axis along which it advances; the blades are approximately elliptical in outline.

The screw propeller is divided into the fixed pitch and controllable pitch propellers which are of the two types mainly used in the marine sector. The fixed screw propeller has a constant pitch with an increasing thickness from blade tip to the boss. The pitch of the propeller at any point is constant so that the value of the pitch will be ideal for calculation purposes.

Controllable pitch propeller has a variable pitch; where the blades are rotated normally to the drive shaft by additional machinery usually hydraulic, the hub and control linkages running down the shaft. This allows the drive machinery to operate at a constant speed while the propeller loading is changed to match operating conditions. It also eliminates the need for a reversing gear and allows for more rapid change to thrust, as the revolutions are constant. This type of propeller is most common on ships such as tugs where there can be enormous differences in propeller loading when towing. This is comparable to running free, a change which could cause conventional propellers to lock up as insufficient torque is generated



Developed area ratio = $DAR = \frac{A_D}{A_0}$

Projected area of blades (on transverse plane) outside hub = A_P

Projected area ratio = $PAR = \frac{A_P}{A_0}$

Blade width ratio = $BWR = \frac{\text{Max. blade width}}{D}$

Mean width ratio = $MWR = \frac{A_D/\text{length of blades (outside hub)}}{D}$

Diameter D Pitch ratio = $\frac{P}{D}$

Pitch P Blade thickness ratio = $\frac{t}{D}$

No. of blades 4 Pitch angle = ϕ

Disk area = area of tip circle = $\frac{\pi}{4}D^2 = A_0$

Developed area of blades, outside hub = A_D

Fig 1: *Typical Propeller Drawing* [4]

1.1 Definition of Terms Relating to Propeller Design [5]

a. **Diameter –** The diameter of the imaginary cycle scribed by the blade tips as the propeller rotates.

b. **Radius** – The distance from the axis of rotation to the blade tip. The radius multiplied by two is equal to the diameter.

c. **Blade face** – The pressure side, pitch side. Aft side of the blade surface facing the stern.

d. **Blade number** – Equal to the number of blades on the propeller.

e. **Blade tip** – Maximum reach of the blade from the center of the hub separates the leading and trailing edges.

f. **Hub** – Solid cylinder located at the center of the propeller. Bored to accommodate the engine shaft. Hub shapes include cylindrical, conical, radius and barreled.

g. **Blade root** – Fillet area. The region of transition from the blade surfaces and edges to the hub periphery. The area where the blade attaches to the hub.

h. **Pitch (*P*)** – The linear distance that a propeller would move in one revolution with no slippage.

i. **Rake** – The fore or aft slant of a blade with respect to a line perpendicular to the propeller axis of rotation.

j. **wake (*w*)** – this explains the overall disturbances created by the motion of the ship as a result of the drag of the hull, the streamline flow past the hull and the wave patterns formed by the ship on the surface water.

k. **Developed Area (** A_D) - This is the actual area of driving faces.

l. **Projected Area (** A_P)-. This is the sum of the blade areas projected into a plane which is perpendicular to the axis of the screw

m. **Expanded Area (** A_E)-. This is the sum of area of all blades enclosed in an expanded blade outline outside the hub.

2.0 Materials and Methods

To aid in propeller design, open water experiments with small–scale propeller mode were made in towing tanks were also carried out using existing classification society rules. The experiments were used to verify the design calculations like the thrust, torque and revolution per minute (*rpm*). In vibration analysis, a specialized dynamometer is used to measure the blade frequency, force generated by the propeller [6].

The design procedure was restricted to the use of charts and series certified by the Society of Naval Architecture and Marine Engineers [SNAME]. These took into considerations certain propeller chart characteristics like propeller pitch, pitch velocity, pitch ratio, mean axial speed of advance, propeller diameter (D), blade area, number of blades, blade outline, thickness, section shapes which are governed by the need to avoid cavitations, Engine power and rated *rpm*, effective power (P_E) and the ship speed (V_s) were fixed. This is also possible by the use of the charts to explore the best combination of diameter, revolution per minute (*rpm*) and pitch ratio gives the best efficiency. [6], postulates that once the speed (n) is determined to any corresponding delivered power (P_D), it can be estimated on the assumption that moderate changes of loading P_D/n^3 would be constant.

The completed propeller depends for its success on the satisfactory integration of scientific discipline such as hydrodynamics, stress analysis and metallurgy. Other aspect of its success would include manufacturing technology with supportive inputs from mathematics, dynamics and thermodynamics. It is therefore not surprising that several of the requirements of the principles for the design are in partial agreement to a greater extent, in their aim to satisfy a particular set of requirement and constraints.

In this work, our basis is directed on engineering principles for operation at high propeller efficiency. This took into consideration high damage resistance, reduction of cavitations, adequate strength to prevent defection and distortion of the propeller blades under very high stresses to which it is subjected to. The material selection procedure shown in Appendix A also helps to achieve the above.

2.1 Design Analysis

Propeller design analysis aimed at obtaining minimum power requirements, cavitation, noise, vibration and maximum efficiency conditions at an adequate revolution. Two methods are usually used in propeller design:

a. Use of diagrams obtained from open water propeller experiments for systematic propeller series.

b. The use of mathematical methods (Lifting line, lifting surface, vertex lattice, boundary element method) based on circulation theory. This work covers the first design method only.

2.2 Systematic Propeller Series

In the open water experiment, diagrams of systematic model propeller series were used. The series consist of propeller whose number of blade (Z), blade area ratio $\left(A_E/A_0\right)$, pitch ratio$\left(P/D\right)$, blade section shape and blade section thickness were varied systematically. The mostly used propeller series is the Wageningen B series.

In this design, calculations considered were scaled effects in the velocity field where the propeller is to operate. A practical design approach is presented using the Wageningen B series propeller for a case where the P_D, V_A and the n are known. The set of propeller consists of four bladed propellers and is developed in such a manner that the whole range of $\left(A_E/A_0\right)$ and $\left(P/D\right)$ of the Wageningen B series propeller are included.

The Wageningen B propeller series is a general purpose series. This series is expressed with open water diagram obtained from model tests of K_T - K_Q - J curves for propeller with constant blade number (Z), $\left(A_E/A_0\right)$ and $\left(P/D\right)$[7]. Since the open water experiments are made in fresh water, this must be considered in the design calculations. The Wageningen B series propellers are extensively used for the design and analysis of fixed pitch propeller.

2.3 Practical Design Approach for 4-Blade Propeller [8]

The initial design variable requirements of the propeller are given below:

1. Delivered power (*KW*)
2. Propeller rate of rotation (rpm)
3. Speed of ship (m/s)
4. Number of blades
5. Taylor's wake friction (*w*).

The speed of ship (V_s), the number of propeller revolution (n), the blade number (Z) and the blade area ratio $\left(A_E/A_0\right)$ are known while pitch ratio $\left(P/D\right)$, diameter (D) and the performance characteristics (J, K_T, K_Q, η_0) are investigated among probable solutions. The speed of advance V_A is obtained from V_s by model test or by using the formula:

$$V_A = V_s(1 - w) \qquad (1)$$

Where w is the Wake friction (w=0.15).

In the preliminary design stage, only the brake power P_B and the speed of ship are fixed, and it is possible using charts to explore the best combination of D (ins), n (*rpm*) and $\left(P/D\right)$ to give the best efficiency. Brake power P_B is the power delivered at engine coupling or flywheel while shaft power P_s is the power available at the output coupling of the gearbox. The relationship between P_B and P_s is stated below:

$$P_B = \frac{P_s}{\eta_S} \qquad (2)$$

The shaft power P_s is therefore given as:

$$P_s = P_B\eta_S \qquad (3)$$

Where η_s is the shaft efficiency and have value of 0.98 for ships with engine located aft and 0.97 for ships with engine located amidships. For the purpose of this work 0.98 was used.

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

$$P_D = P_s\eta_s \qquad (4)$$

From [6], the choice in the final design stage may be affected by limitations on propeller diameter and by characteristics of propeller machinery available. the rpm corresponding to the particular delivered power can be estimated on the assumption that for moderate change of loading P_D/n^3 constant therefore can B_p and δ be calculated since P_D , D,

V_A and n are known, the values of B_p can be calculated as:

$$B_p = \frac{P_D^{0.5} n}{V_A^{2.5}} \qquad (5)$$

The values of η_0 and $\left(P/D\right)$ can be traced using charts (Appendix B) corresponding to this values of B_p. The optimum diameter is therefore given as

$$D = \frac{\delta_{opt} V_A}{n} \qquad (6)$$

In some cases, it may not be possible to use the value of D because of restrictions of draft or other reasons, such as the maintenance of adequate water over the screw, the need for adequate tip clearance. If for these reasons, D is limited to some value less than that indicated on the efficiency grounds, with the same value of B_p but a new value of δ corresponding to the new D, the chart is again, used to determine η_0 and $\left(P/D\right)$. Knowing η_0, the assumed propulsive coefficient can be checked from the expression.

$$\eta_D = \frac{1-t}{1-W}\eta_0\eta_R \qquad (7)$$

Where t, w and η_R are known from model test or have been estimated P_D if not, the new propulsive efficiency is used; the calculation is repeated more than once, if necessary until substantial value is obtained. Then, the propeller thrust is given as:

$$T = \frac{P_D \eta_0}{V_A} \qquad (8)$$

The maximum blade thickness (produced to shaft axis),

Blade thickness ratio $= \frac{t_0}{D}$

Where t_o = *Maximum blade thickness*

D = *Propeller diameter*

To estimate the weight of all blades and the polar moment of inertia of a blade, the approximate formula given by [8] was adopted.

$$Weight, W = 1.982 B_{tf} \varsigma Y R^3 \qquad (9)$$

$$I_p = 0.2745 W R^2 \qquad (10)$$

Where

I_P = *Polar moment of inertia of all blades*

B_{tf} = *Blade Thickness fraction*

ς = *Blade area fraction*

Y = *Specific weight of blade material*

R = *Propeller tip radius*

Weight W = Mg = Force

Hence, we assume that the force acting on the propeller blade therefore is $F = N = Mg$.
Hence, the stress (σ) on the propeller is therefore given as:

$$\sigma = \frac{Force\ on\ propeller\ blade}{Disk\ Area\ of\ propeller\ blade}$$

$$\sigma = \frac{F}{A_0} \qquad (11)$$

3. Analysis and Discussion of Results

Having stated the propeller design basis, there is need to calculate for the parameters needed to achieve the design. The initial design variables of the propeller are given below:

$$Break\ Power\ P_B = 85Hp$$

$$Ship\ speed\ V_s = 30\ Knots\ (in\ service)$$

The speed of advance V_A of the propeller is calculated using equation (1)

$$V_A = V_s(1-w)$$
$$= 30(1-0.15)$$
$$= 25.5 knots$$

Brake power P_B from equation 2 is calculated as follow:

$P_s = P_B \eta_S$

$P_s = 85 \times 0.96$

$P_s = 81.6\, Hp$

Then,

$P_D = P_s \eta_s$

$P_D = 81.6 \times 0.98 = 79.768$

$P_D = 80\ Hp$

The power coefficient B_p can be calculated using

$$B_p = \frac{P_D^{0.5} n}{V_A^{2.5}}$$

$$= \frac{80^{0.5} \times 3000}{25.5^{2.5}}$$

$$= \frac{80^{0.5} \times 3000}{25.5^{2.5}}$$

$$= \frac{26832}{3283.601} = 8.172 \approx 8.0$$

From the chart of type B series of 4-bladed shown in Appendix B, the value of $B_p = 8.0$ is read. The point of intersection between the B_p line and optimum line (in red line) was traced to get $(P/D) = 1.15$, $\eta_0 = 0.73$ and $\delta_{opt} = 113$

Propeller thrust can be calculated using equation 8

$$T = \frac{P_D \eta_0}{V_A}$$

$$= \frac{80 \times 0.73}{25.5}$$

$$T = 2.290\ N / m$$

The optimum diameter of the propeller is given as

$$D = \frac{\delta_{opt} V_A}{n}$$

$$D = \frac{113 \times 25.5}{3000}$$

$$D = \frac{3264}{3000}$$

$$= 0.9605\ ft$$

$$= 11.5 ins$$

Since $P/D = 1.15$

$$P = 1.15 \times D$$

$$= 1.15 \times 11.5$$

$$= 13.2 ins$$

Having determined the pitch, diameter and delivered horse power of the propeller, the thickness Blade, the blade area and hub (boss) diameter from the ratios stated for these in the type B series chart for 4 blade design are as follows:

Number of blades (Z) = *4*

Blade area ratio (A_E / A_0) = *0.55*

Blade thickness ratio = *0.05*

Hub (Boss) diameter (D) = *11.5 ins*

Therefore,

Blade area (Disk area) $A_0 = \frac{\pi D^2}{4}$

$$A_0 = \frac{3.142\,(11.5)^2}{4}$$

$$A_0 = 103.88\ ins^2$$

Since,

Blade area ratio, $A_E / A_0 = 0.55$

$A_E = A_0 \times 0.55$

where A_E

(Expanded Area of all blades outside hub)

$A_E = 103.88 \times 0.55$

$A_E = 57.13\, ins^2$

To find the maximum blade thickness (produced to shaft axis),

blade thickness ratio $= \frac{t_0}{D}$

Where t_o = *Maximum blade thickness*

D = *Propeller diameter*

From chart, blade thickness fraction = 0.05

$$0.05 = \frac{t_0}{D}$$

$$t_0 = 0.05 \times D$$

$$t_0 = 0.05 \times 11.5$$

$$= 0.58\ ins$$

Hence, the maximum blade thickness is approximately 0.6ins.

To determine the hub (Boss) diameter of the propeller, the relation Boss (hub) diameter ratio $d = 0.18D$

$$0.18 = \frac{d}{D}$$

Where

d = *hub (boss) diameter*

D = *propeller diameter*

$$d = 0.18 \times D$$

$$= 0.18 \times 11.5$$

$$= 2.1\ ins$$

Hence, the hub boss diameter (d) is approximately *2.1 ins*. To determine the developed and projected area and their ratios, using the following relations given by [9].

Projected Area ration, $\frac{A_p}{A_0} = \frac{4A_P}{\pi D^2}$

Developed Area Ratio, $\frac{A_D}{A_0} = \frac{4A_D}{\pi D^2}$

Expanded Area Ratio $\frac{A_E}{A_0} = \frac{4A_E}{\pi D^2}$

Where $D = 11.5ins$, then the value of A_D (Developed area of the blades) can be found by

$$\frac{A_E}{A_0} = \frac{4A_D}{\pi D^2}$$

$$A_D = \frac{A_E}{A_0} \times \frac{\pi D^2}{4}$$

Recall that $\frac{A_E}{A_0} = 0.55$ and $\frac{\pi D^2}{4} = 103.88ins^2$

$$\therefore A_D = 0.55 \times 103.88$$

$$= 57.13ins^2$$

This shows that $A_D = A_E = 57.13inches^2$. It can be concluded that the developed area can be taken as being equal to the expanded area of the blade section of the propeller. The projected area of the blade (A_p) can also be found by using the relationship, proposed by [10]for non-skewed forms. Thus, this is given as:

$$A_D = \frac{A_P}{1.067 - 0.229P/D}$$

But Pitch ratio $P/D = 1.15$

$$A_p = A_D \times (1.067 - 0.229P/D)$$

$$A_p = 57.13 \times (1.067 - 0.229 \times 1.15)$$

$$A_p = 45.91ins^2$$

It therefore follows from the foregoing that Developed Area Ratio

$$\frac{A_D}{A_0} = \frac{57.13}{103.88} = 0.55$$

Projected Area Ratio

$$\frac{A_p}{A_0} = \frac{45.91}{103.88} = 0.44$$

Expanded Area Ratio A_E

$$\frac{A_E}{A_0} = 0.55$$

To determine the pitch along the length or radius of the propeller blade, the Pitch at 25%, 50%, 60%, 70%, 80%, 90% radius representing $P_{0.25}, P_{0.5}, P_{0.6}, P_{0.7}, P_{0.8}, P_{0.9}$, respectively was calculated.

$$\frac{D}{2} = \frac{11.5}{2} = 5.75\ ins$$

i. $P_{0.25} = pitch\ 25\%\ or\ R$

pitch $P = P_0 \times (D)(P/D)$

$$P_{0.25} = 25/100 \times 5.75 \times 1.15$$

$$P_{0.25} = 1.65ins$$

ii. $P_{0.5} = Pitch\ at\ 50\%\ of\ R$

$$= 50/100 \times 5.75 \times 1.15$$

$$= 3.30ins$$

iii. $P_{0.6} = Pitch\ at\ 60\%\ of\ R$

$$P_{0.6} = {}^{60}\!\!/_{100} \times 5.75 \times 1.15$$
$$P_{0.6} = 3.97 ins$$

iv. $P_{0.7} = Pitch\ at\ 70\%\ of\ R$
$$= {}^{70}\!\!/_{100} \times 5.75 \times 1.15$$
$$= 4.63 ins$$

v. $P_{0.8} = Pitch\ at\ 80\%\ of\ R$
$$= {}^{80}\!\!/_{100} \times 5.75 \times 1.15$$
$$= 5.9 ins$$

vi. $P_{0.9} = Pitch\ at\ 90\%\ of\ R$
$$= {}^{90}\!\!/_{100} \times 5.75 \times 1.15$$
$$= 5.95 ins$$

vii. $P_{1.0} = Pitch\ at\ 100\%\ of\ R$
$$= 1 \times 5.75 \times 1.15$$
$$= 6.61 ins$$

The above shows the pitch distribution along the blades of the propeller at various calculated radii. In the same way, the thickness of the blade section could be found for the radii, using the blade thickness fraction= $\frac{t_0}{D} = 0.05$; so that $t_0 = 0.05\, D$

Hence, t_0 estimate the thickness along the radius of the propeller.

$$t_0 = 0.05 \times (\ R\ percentage\ )$$

$t_{0.1} = thickness\ at\ 10\%\ of\ the\ blade\ section\ of$ $expanded\ cylindrical\ section$

$$\therefore t_{0.1} = (10\%\ of\ R) \times 0.05 = 0.1 \times R \times 0.05\ \therefore$$
$$Where\ \ R = 5.75 inches$$
$$t_{0.1} = 0.1 \times 5.75 \times 0.05 = 0.03 ins$$
$$t_{0.2} = 0.2 \times 5.75 \times 0.05 = 0.08 ins$$
$$t_{0.3} = 0.3 \times 5.75 \times 0.05 = 0.09 ins$$
$$t_{0.4} = 0.4 \times 5.75 \times 0.05 = 0.12 ins$$
$$t_{0.5} = 0.5 \times 5.75 \times 0.05 = 0.14 ins$$
$$t_{0.6} = 0.6 \times 5.75 \times 0.05 = 0.17 ins$$
$$t_{0.7} = 0.7 \times 5.75 \times 0.05 = 0.20 ins$$
$$t_{0.8} = 0.8 \times 5.75 \times 0.05 = 0.23 ins$$
$$t_{0.9} = 0.9 \times 5.75 \times 0.05 = 0.26 ins$$
$$t_{1.0} = 1.0 \times 5.75 \times 0.05 = 0.29 ins$$

From the model propeller used, Table 1 was obtained for the blade width along its length from the tip to the root. These are spaced at 20 mm interval to each other.

From this, the mean width of the propeller blade was calculated as follows:

$$Mean\ width\ of\ \ propeller\ blade$$
$$= \frac{Sum\ of\ \ all\ the\ blade\ width}{Number\ of\ \ intervals} = \frac{\sum x}{N}$$
$$= \frac{755}{8} = 94.38 mm$$

Table.1: *Values of length from the tip to the root.*

S/No	***From tip to root (****Ins)*	***Blade width x*** *(Ins)*
1	*0.79*	*1.97*
2	*1.57*	*3.15*
3	*2.36*	*3.74*
4	*3.15*	*4.33*
5	*3.94*	*4.92*
6	*4.72*	*5.31*
7	*5.51*	*4.33*
8	*6.30*	*1.97*

Mean width of propeller blade = 3.7ins approximately. Hence, the mean width ratio of the propeller is calculated as:

$$Mean\ width\ ratio = \frac{Mean\ dveloped\ width}{Diameter}$$

$$= \frac{3.715 ins}{11.5 ins} = 0.323$$

From this, the length of the blades can be determined using:

$$Mean\,width\,ratio = \frac{A_0\ /\ Length\,of\ \ blade(outside\,hub)}{Diameter\,D}$$

$$Mean\,width\,ratio \times D = \frac{A_D}{Length\,of\ blade}$$

$$Length\,of\ blade = \frac{A_D}{Mean\,width\,ratio \times D}$$

$$Length\,of\ blade = \frac{57.13}{0.323 \times 11.5}$$

$$= 15.38 ins$$

The tip radius of the propeller is approximately the same as the radius of the propeller diameter measured from the top of the blade to the center of the propeller boss. The weight of all blades can be calculated using equation 10.

$$Weight, W = 1.982 B_{tf}\, \varsigma\, YR^3$$

B_{tf} = 0.05

ς = 0.50

R =167.64 mm = 0.168m

From fluid mechanics:

Specific weight (W) of substance = specific gravity of the material (NAB) ×specific weight of water.

NAB = Nikel Aluminum Bronze

From Appendix A, properties of propeller materials, *specific gravity of NAB = 7.6*

Also, *specific weight of water = 9.8 KNm*^{3} *= 9800 Nm*$^{3.}$Therefore, the specific weight of the propeller blade material is:

Y propeller blade material = S × specific weight of water

$$= 7.6 \times 9600 = 74480\ Nm^{-3} = 74.48\ KNm^3$$

Hence, the weight of the blade becomes:

$$W = 1.982\, B_{tf}\ \varsigma YR^3$$

$$= 1.982 \times 0.05 \times 0.50 \times 74480 \times (0.168)^3$$

$$= 17.5N$$

To estimate the polar moment of inertia, I_P of all blades, we use the relation:

$$I_P = 0.2745WR^2$$

$$= 0.2745 \times 17.5 \times (0.168)^2$$

$$= 0.136Nm^2$$

Stress on the propeller blade, from the relation *stress = Force per unit area.*

Total stress on propeller blade = Force acting per unit area of the blades. Recall that *blade (Disk) area =* A_0 *= 136.85 ins*^{2}

= 0.0876m^2

Since weight of all blades, *W = 17.5N*

$$F = N = Mg = 17.5N$$

Hence, σ from equation 11 is therefore given as:

$$\sigma = \frac{17.5}{0.0876}$$

$$= 199.77\,N/m^2$$

The total stress acting on the propeller

σ = 199.77N/m^2

The procedures of propeller design with detailed calculation of the dimensions have been accomplished and the parameters and data are shown in table 2. The drawing and design characteristics of the propeller is shown in Appendix C.

Table 2: *Design Parameters and Data*

S/N	*PARAMETERS*	*METRIC UNIT*
1	*Engine Brake Power (* P_B *)*	*85 Hp*
2	*Ship Speed (*V_S*)*	*30Knots*
4	*Delivered Power of propeller*	*80Hp*
5	*Propeller speed of advance (*V_A*)*	*25.5Knots*

6	*Power coefficient (B_p)*	*8.0*
7	*Propeller open water efficiency (η_0)*	*0.73*
8	*Propeller diameter (D)*	*11.5ins*
9	*Pitch (P)*	*13.2ins*
10	*Pitch ratio (P/D)*	*1.15*
11	*Number of blades (Z)*	*4*
12	*Blade area ratio (A_E/A_o)*	*0.55*
13	*Blade thickness fraction (t_0/D)*	*0.05*
14	*Hub (Boss) diameter ratio (d/D)*	*0.18*
15	*Blade area (A_o)*	*103.88ins^2*
16	*Expanded area of blade (A_E)*	*57.13ins^2*
17	*Developed area blade section (A_p)*	*68.42ins^2*
18	*Projected area of blade section (A_D)*	*57.13ins^2*
19	*Developed area ratio (A_D/A_o)*	*0.55*
20	*Expanded area ratio (A_E/A_o)*	*0.55*
21	*Projected area ration (A_p/A_o)*	*0.44*
22	*Maximum blade thickness (t_o)*	*0.58 ins*
23	*Boss (Hub) diameter*	*2.1ins*
31	*Maximum blade width*	*5.3ins*
34	*Mean width ratio*	*0.323*
35	*Length of blade*	*15.38ins*
37	*Weight of propeller blades (W)*	-
38	*Polar moment of inertia of propeller blade*	-
39	*Taylor's wake fraction (F)*	*0.15*
40	*Force on propeller*	-
41	*Total stress on propeller blades*	-

Conclusion

A step by step design procedure for a 4-bladed propeller have been outlined in this work. This took bearing from what are available for the design of one bladed to 3-bladed propellers. Also consideration was taken from existing charts, materials classifications and characteristics of already designed one to three bladed propellers to come with what would obtain for 4-bladed propellers which is not common.

Recommendation

Propeller design procedure is a very versatile, although approximate dwells more on the simplified approach to the design propeller by making use of the methodical series which are charts developed from tested basin experiments.

It is therefore recommended that B_p chats series 4.55 should be adopted for the design of 4-bladed propellers. Furthermore, the designed propeller drawing and characteristics that this work propounded with the Lloyd's Register of Shipping Standard materials classification should continue to be adopted also for 4-bladed propellers.

_-

References

[1] Wikipedia (2013), Propeller (Marine), en.wikipedia.org/wiki/propeller (marine).

[2] Chris Barry (2005), *Propeller Selection for Boats and Small Ships*, E Marine Training - Prop Matching, the U.S. Coast Guard.

[3] Breslin P. John and Anderson Poul, 1996 *Hydrodynamics of Ship Propellers*, Technology & Engineering, Cambridge University Press, p. 559

[4] Techet A.H., (2004), *13.012 Hydrodynamics for Ocean Engineers Reading*: Propellers Version 1.0, aht

[5] Ejabefio, K.A (2010), *Design Analysis of a Propeller for a Container Ship*, Final Year Project, Department of Marine Engineering, Rivers State University of Science and Technology, Port Harcourt Nigeria.

[6] Carica P.M, Castrol A.M and Stern F (2010), Self Propulsion Computations Using a Speed Controller and a Discretized Propeller With Dynamic Overset Grids, *Journal Of Marine Science and Technology*, 15(4), 316-330

[7] *Serkan Ekinci*, (2011), A Practical Approach For Design of Marine Propellers with Systematic Propeller Series, *Znanost, Science, Brodogradnja – Shipbuilding* 2 Lipanj, June 2011, Članak, Paper 714

[8] Schoenherr, K.E (1963), *Formulation of Propeller Blade Strength*, SNAME Spring Meeting, April 1963.

[9] Charlton, J. S. (1994): The Design and Performance of Super Cavitating propellers.

[10] Vladmir, K. J., Jiaying, S., Karl, H. H. (2009). *“CFD Investigation in Scale Effect on Propeller with Different Magnitude of Skew in Turbulent Flow*, First International Symposium on Marine Propulsors

.

APPENDIX A

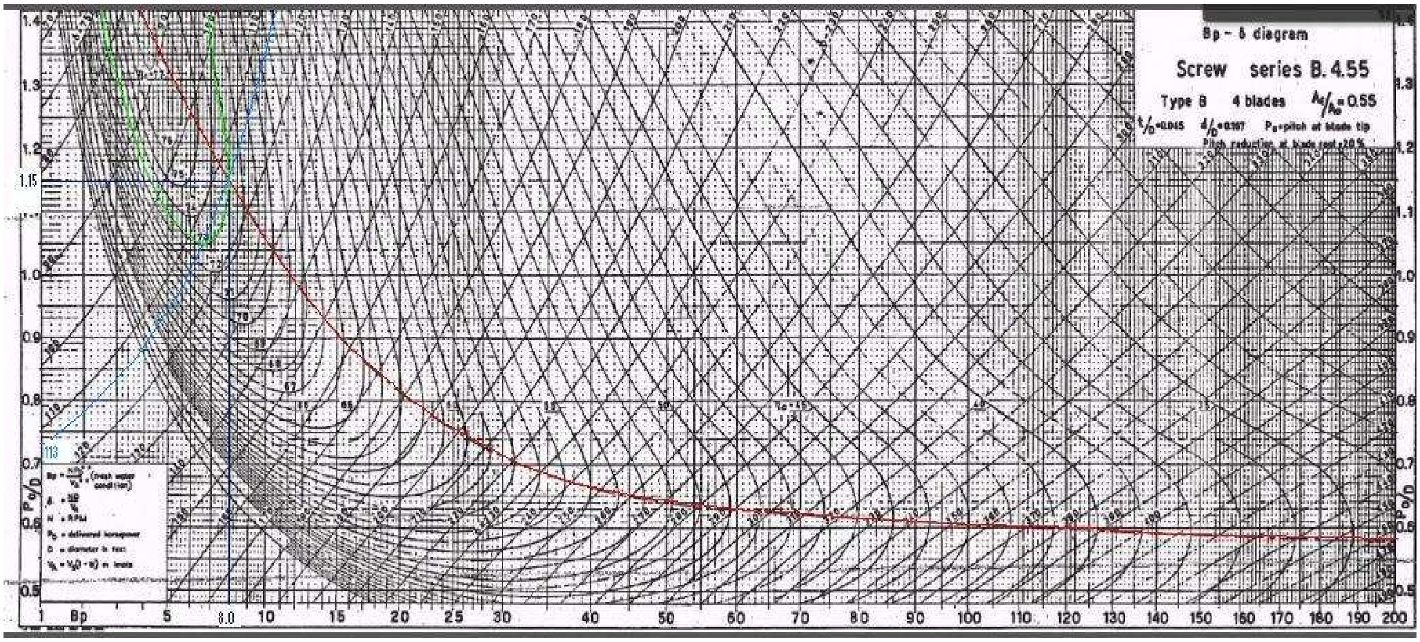
Standard Materials Classified by Lloyd’s Register of Shipping.

MATERIALS	**S.T UNITS**			**METRIC UNITS**		
	Specified Minimum Tensile Strength	G Density	U Allowable Stress	Specified Minimum Tensile Strength	G Density	U Allowable Stress
Gray cast iron	250	7.2	17.2	25	7.2	17.5
Spherical or modular graphite cast iron	400	7.3	20.6	41	7.3	2.1
log alloy steels	400	7.9	20.6	45	7.9	2.1
carbon steels	400	7.9	20.6	41	7.9	2.1
13% chromium stainless steels	540	7.7	41	55	7.7	42
Chromium-Nickel authentic stainless steel	540	7.6	41	46	7.9	4.2

Grade Cu1, manganese Bonze (higher tensile brass)	440	8.3	39	45	8.3	4
Grade Cu3 Nickel, Aluminum Bronze	590	7.6	56	60	7.6	5.7
Grade Cu4, Manganese Aluminum Bronze	630	7.5	4.6	64	7.5	4.7

APPENDIX B

B_p Chart series 4.55



APPENDIX C

Designed Propeller Drawing and Characteristics