

THE DEVELOPMENT OF UNIKL MIMET FIXED PITCH PROPELLER SERIES – PART 1 – THE GEOMETRY DEVELOPMENT OF THE FP SERIES

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ABSTRACT

The need for new propeller series is required for a new generation of medium-speed vessel ranging from 18 to 30 knots. Currently a naval architect and boat designers are still depending on old propeller series such as Wageningen B series, KCA series, Newton Rader series, but most of this propeller series are either suited for low speed vessels or high speed vessels. Therefore, there is a requirement for a propeller series for medium-speed vessels. The existing propeller series as mentioned above i.e. B series, KCA series, and Gawn series are already outdated and need some improvement to be suited to a modern medium speed hull form. These old propeller series are not efficient as what a modern propeller required. Nowa days, more ships are using the state-of-the-art propeller, therefore a new modern propeller series is needed for modern medium speed vessel with moderate to a high skew for less noise and vibration. This is the main reason on why we need for our own new up to date propeller series with a high skew blade profile. This propeller are fixed-pitch propellers which have a moderate blade skew and camber. The aim for this project is to develop the 3D model and the CAD drawing for 4, 5, 6 and 7 bladed propellers with blade area ratio from 0.4 to 0.758. The series have a range of pitch diameter ratio from 0.40 to 1.2. Before any modelling can be done in PropCAD, the blade thickness of the propeller need to be defined earlier. This estimation of the blade thickness was based on Bureau Veritas Class rules on Propeller, NR 467. The blade thickness calculations were done in Matlab. Once, the blade thickness was defined using the BV rules, the modelling of the FP series propeller was done in PropCAD. The FP series propeller which consisted of 62 propellers then were varied in its pitch diameter ratio, expanded area ratio, skew tip angle and rake angle. The 3D model in PropCAD were enhanced in Rhinoceros in order to make the propeller as in a solid form. In the PropCAD, the offset tables and the 2D CAD drawings were produced and printed out. Once the solid propeller modelling was completed, the 3D printing of a sample of propeller was printed. A sample of 6 bladed propellers was 3D printed using PLA or Polylactic Acid plastic material. The sample is 250 mm in diameter. Overall there were 62 propellers were modelled in Rhinoceros where all the 62 propellers were varied in its expanded area ratio and its pitch diameter ratio.

Keywords: propeller, design, geometry

INTRODUCTION

In the preliminary design of ships and propellers, it is common to choose propellers using a standard propeller series. A propeller series, is a range of a propeller which were varied in its pitch diameter ratio, expanded blade area ratio, number of blades and rake angle. Then this propeller series was open water tested either in a towing tank or in a cavitation tunnel. From this open water test, the open water characteristics can be found where the KT-KQ-J chart were plotted. To find the optimum propeller for the specific design is by using propeller this open water diagram for the said propeller series. Some of the existing propeller series are Wageningen B series, Gawn series, KCA series, AU series and Newton-Rader series. All the propeller series mentioned above were developed somewhere around 1940 – 1962. But somehow, these propeller series are still being used in the preliminary design of ships and propellers.

The need for new propeller series is required for a new generation of medium-speed vessel ranging from 18 to 30 knots. Currently a naval architect and boat designers are still depending on old propeller series such as Wageningen B series, KCA series, Newton Rader series, but most of this propeller series are either suited for low speed vessels or high speed vessels. Therefore, there is a requirement for a propeller series for medium-speed vessels.

The existing propeller series as mentioned above i.e. B series, KCA series, and Gawn series are already outdated and need some improvement to be suited to a modern medium speed hull form. These old propeller series are not efficient as what a modern propeller required. Nowa days, more ships are using the state-of-the-art propeller,

therefore a new modern propeller series is needed for modern medium speed vessel with moderate to a high skew for less noise and vibration. This is the main reason on why we need for our own new up to date propeller series with a high skew blade profile. This propeller is a fixed-pitch propeller which have a moderate blade skew and camber. The aim for this project is to develop the 3D model and the CAD drawing for 4, 5, 6 and 7 bladed propellers with blade area ratio from 0.4 to 0.758. The series will have a range of pitch diameter ratio from 0.40 to 1.2.

A sample of 6 bladed propellers was 3D printed using PLA or Polylactic Acid plastic material. The sample is at 250 mm in diameter.

In a preliminary design of ships and propellers, it is common to choose propellers using a standard propeller series. A propeller series, is a range of a propeller which were varied in its pitch diameter ratio, expanded blade area ratio, number of blades and rake angle. To find the optimum propeller for the specific design is by using propeller open water diagram for the said propeller series.

This Wageningen B series is the most extensive and widely used propeller series as reported by Carlton (2018). The extent of the propeller series is shown in Table 1. The B series are from 2 bladed to 7 bladed propellers. The blade area ratios are from 0.30 to 1.05. The pitch diameter ratios are from 0.5 to 1.4.

Table 1 The range of the Wageningen B series

No of blade	BLADE AREA RATIO AE/AO													
	0.30													
2	0.30													
3		0.35			0.50			0.65			0.80			
4			0.40			0.55			0.70			0.85	1.00	
5				0.45			0.60			0.75				1.05
6					0.50			0.65			0.80			
7						0.55			0.70			0.85		

Propeller B-Series, or best known as Wageningen, is a propeller often used specifically for the form of ship merchant. The B-Series propeller's shape is very basic. The B series propeller blade section consist of aerofoil and segmental section. The aerofoils blade section starts from 0.2R at ends at radius fraction 0.5R. The segmental section starts from 0.6R to 1.0R. This can be seen in the general plan of B5-screw series showing the blade section profile for B5.45, B5.60, B5.75 and B5.105 in Figure 1. The newly developed FP series propeller was based on the Wageningen B series propeller and BB series section profiles.

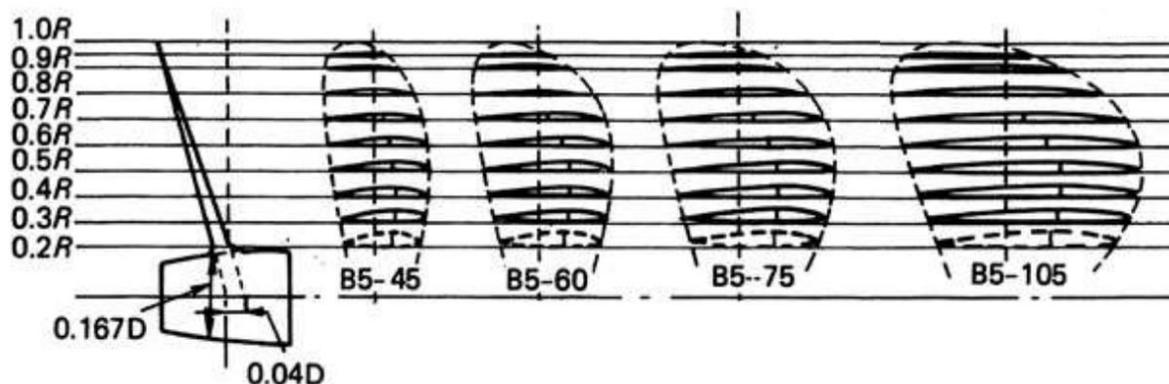


Figure 1 The general plan of B5-screw propeller series (Carlton, 2018)

The Wageningen B-series has a moderate skew of 13.7 degree. In the FP series, this skew angle was increased to 41 to 45.1 degrees. Therefore, making the FP series as a high skew propeller series. The pitch distribution of the B series is at full pitch from 0.60R to 1.0R, but only 80% pitch for radius fraction 0.2R to 0.5R. The FP series pitch distribution followed exactly as the B series propeller. The hub ratio of the B series is at 0.169.

The AU series was developed in Japan by Yazaki (1962). This propeller series is almost similar to the Wageningen B-series. The development of this Au-outline type propeller is the result of "AU type Aerofoil". This

propeller series is complementary to the Wageningen B-series in several ways, but it has not achieved the universal success of the B-series outside of Japan.

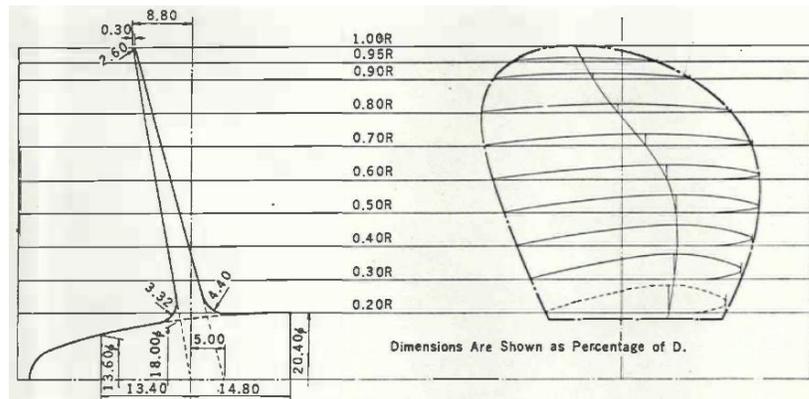


Figure 2 The section and profile of the AU 4-70 series (Yazaki and Takahashi, 1969)

The propeller blade varied from 4 blades to 7 blades. The expanded blade area ratio extended from 0.40 to 0.758. The pitch diameter ratios were varied from 0.4 to 1.2. The rake angle is set at 0 degree and 10 degrees. The hub ratio is at 0.180. The newly developed FP series followed the range of the AU series except for the 5 bladed propeller where the expanded area ratio is changed from 0.65 to 0.75. The section profile of the AU series is shown in Figure 2. The section used aerofoil section from 0.2R to 0.5R. The segmental section is used at radius fraction 0.6R to 1.0R. The Au series also has a moderate skew at 13.8 degree similar to the Wageningen B series. The details of the AU series, can be found in Carlton (2018).

The Gawn series was developed by Gawn (1952). Gawn (1952) tested a series of 37 three bladed propellers covering range of pitch diameter ratios from 0.4 to 2.0. The blade area ratios cover a range from 0.2 to 1.1. The Gawn propeller was tested at 503 mm in diameter. The illustration of the Gawn series propeller is shown in Figure 3. The Gawn series has a uniform face pitch, segmental blade parts, constant blade thickness ratio, namely 0.060, and a boss diameter of 0.2D for each of the propellers. The propeller did not have any skew and did not have any rake. The blade section is segmental as described earlier. The maximum thickness location is at 50% of the chord length.

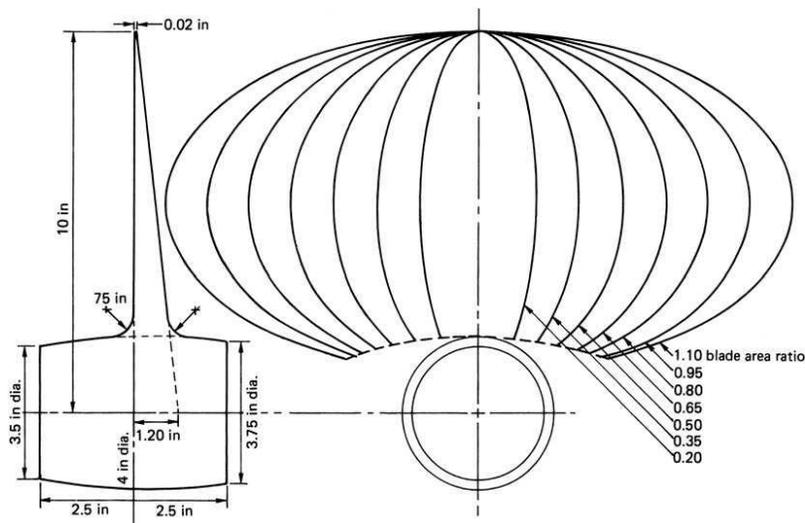


Figure 3 Blade outline of the Gawn series (Carlton, 2018)

The details of this Gawn series can be found in Carlton (2018). As this propeller is outdated and suitable for high speed vessel, none of the geometry of the Gawn series is chosen for the FP series propeller.

The KCA series was developed by Gawn and Burrill (1957). Gawn and Burrill (1957) tested a series of 30 three bladed propellers covering range of pitch diameter ratios from 0.6 to 2.0. From 1950 to 1955, the detailed

research period consisted of over 3000 propeller measurements and some 1600 photos in patterns of cavitation. At the University of Newcastle upon Tyne, England, this propeller sequence was tested in the cavitation tunnel. As the cavitation tunnel was used and subsequently, the propeller array, rather than the towing tank, was a variety of different cavitation numbers have been tested. The blade area ratios cover a range from 0.5 to 1.1. The KCA series propeller was tested at 406 mm or 16 inches in diameter. The illustration of the KCA series propeller is shown in Figure 4.

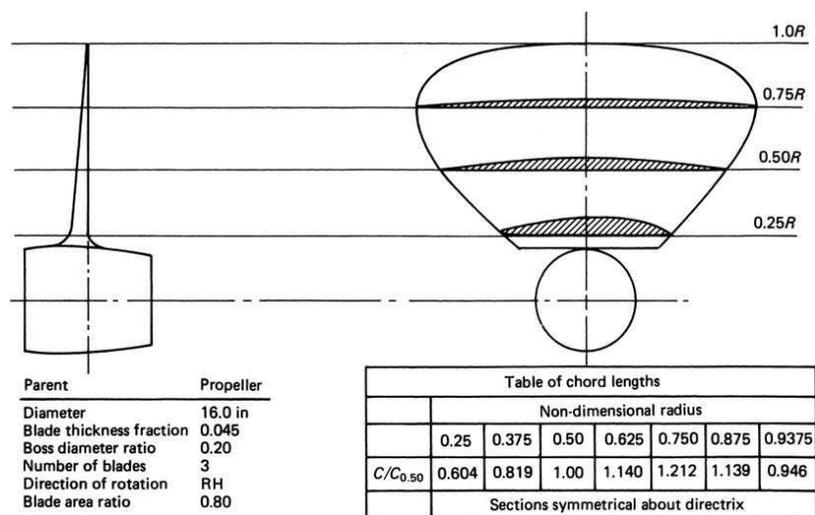


Figure 4 KCA blade outline (Carlton, 2018)

The KCA series has segmental section at each radius fraction. This series did not have any skew. This series had a uniform face pitch, segmental sections over the outer half of the blade, and in the inner half. The flat faces of the segmental sections were lifted at the leading and trailing edges. The KCA series did not have any rake. The hub ratio is at 0.20. As this propeller design is more suited for a high-speed or naval craft, the profile and the section shape are not chosen for the FP series. The details of this KCA series can be found in Carlton (2018).

The Newton-Rader propeller series was developed by Newton and Rader (1961). They tested the propeller series in a cavitation tunnel. The series was tested in a comparatively small collection of 12, three-bladed propellers designed for high-speed craft propulsion. The Newton-Rader propeller series was designed to have pitch ratios between 1.04 and 2.08 and blade area ratios between 0.48 and 0.95. The extent of this propeller series are listed in Table 2. The profile, the transverse view and the section of the Newton-Rader series propeller is shown in Figure 5.

Table 2 Extent of the Newton Rader series

BAR	FACE PITCH RATIO			
0.48	1.05	1.26	1.67	2.08
0.71	1.05	1.25	1.66	2.06
0.95	1.04	1.24	1.65	2.04

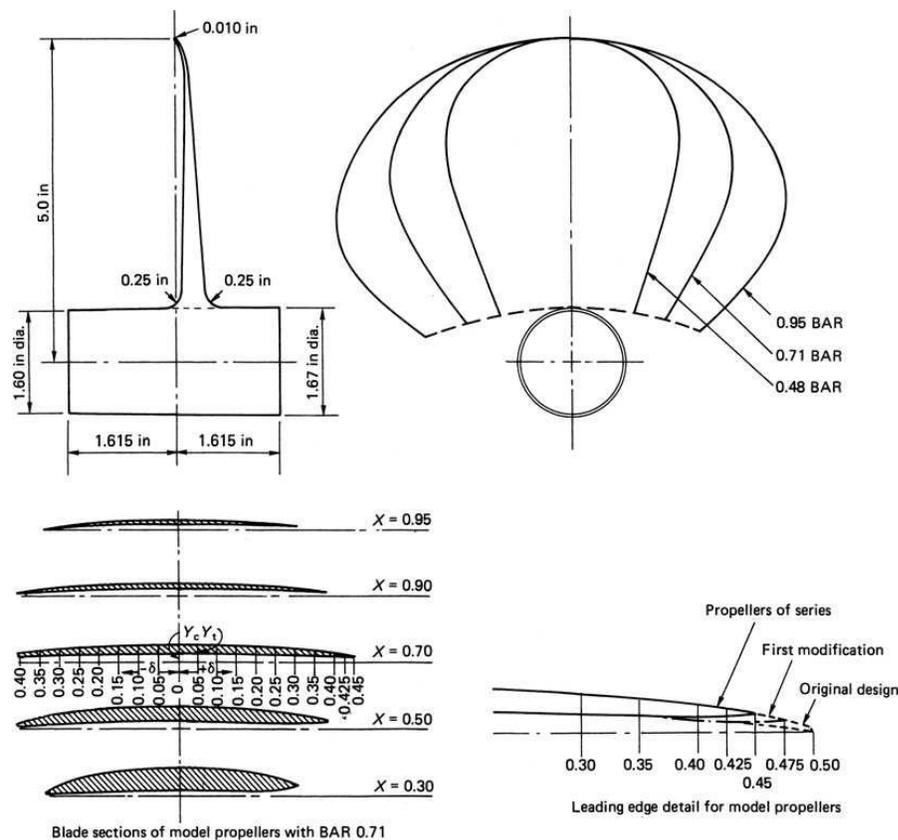


Figure 5 Newton Rader series blade form

The propeller series, had a diameter of 254 mm (10 in.). The propeller series has a constant face pitch ratio of 1.2 and a blade area ratio of 0.750. This propeller has a non-linear blade thickness distribution with a blade thickness fraction of 0.06. The blade sector structure was based on a $a = 1.0$ mean line of the NACA with a superimposed quasi-elliptic thickness form. The series was constructed in such a way that the series propellers could have the same distribution of camber ratio as the parent propeller. As this propeller design is more suited for a high-speed or naval craft similar to the Gawn and KCA series, the profile and the section shape are not chosen for the FP series. The details of this Newton-Rader propeller series can be found in Carlton (2018) and Newton and Rader (1961).

PROBLEM STATEMENT

The existing propeller series are already outdated and need some improvement for modern medium speed hull-form. The Wageningen B series, Gawn series, KCA series are old series that maybe not that efficient as what the modern propeller required. With the introduction of the energy efficient design index or EEDI, an improvement of the propeller design in reducing fuel consumption is required. Thus, this is a driving force for the development of new propeller series. A new modern propeller series is needed for modern medium speed vessel with moderate to high skew (for less noise and vibration). Therefore, a new modern propeller series is needed for modern medium speed vessel. In this project, the geometry of the newly designed propeller is developed.

General, EEDI is the Energy Efficiency Design Index for new ships has indeed been made mandatory. EEDI is a rule made for all newly designed ships by the International Maritime Organisation or the IMO, which must meet the EEDI index, otherwise the ship would not be authorised. EEDI is a measure of how much engine power is used by each emitted pollutant gas.

One measure in getting the EEDI improved is by getting an efficient propeller. Therefore, in this project, it is the aim is to develop an up-to-date propeller to cater the needs for modern vessels.

RESEARCH METHODOLOGY

Before any modelling can be done in PropCAD, the blade thickness of the propeller need to be defined earlier. This estimation of the blade thickness was based on Bureau Veritas Class rules on Propeller, NR 467 (Bureau Veritas, 2020). Once, the blade thickness is defined using the BV rules, the modelling of the FP series propeller can be done in PropCAD. The FP series propeller which consisted of 62 propellers then were varied in its pitch diameter ratio, expanded area ratio, skew tip angle and rake angle.

The 3D model in PropCAD were enhanced in Rhinoceros in order to make the propeller as in a solid form. In the PropCAD, the offset tables and the 2D CAD drawings were produced and printed out. Once the solid propeller modelling was completed, the 3D printing of a sample of propeller was printed.

Development of FP series propeller

The range of the newly developed MIMET FP series were based on the AU series range (Carlton, 2012) which consist of 4 to 7 blades propeller. The pitch diameter ratios were varied for 0.4 to 1.2. The expanded area ratios were varied from 0.4 to 0.758. The skew at the tip was set at 0.15. The boss ratio was set at 0.15. The rake angle is also varied at two positive rake at 0 degree and 10 degrees. The details of the FP series range are listed in Table 3. These variations were used in the modeling of the surface in PropCAD. These values will be the input in the editing the section data. The identification of the FP propeller series is designated as XZ_BARXX_PDXX, where the first term is the number of blade, the second is the expanded area ratio, and the third is the pitch diameter ratio.

Table 3 The range of MIMET FP series.

NUMBER BLADES	4	5		6	7	
PITCH RATIO	0.5, 0.6, 0.8, 1.0, 1.2	0.4, 0.6, 0.8, 1.0, 1.2	0.4, 0.6, 0.8, 1.0, 1.2	0.5, 0.7, 0.9, 1.1	0.8	0.8
DIAMETER (m)	0.250	0.250	0.250	0.250	0.250	0.250
EXPANDED AREA RATIO	0.40, 0.55	0.50	0.75	0.55, 0.70	0.55	0.65, 0.758
SKEW TIP	0.15	0.15	0.18	0.18	0.15	0.18
BOSS RATIO	0.180	0.180	0.180	0.180	0.180	0.180
RAKE ANGLE	10, 0	10, 0	10, 0	10, 0	10, 0	10, 0

Modelling the FP series in PropCAD

The steps for modelling the FP series in PropCAD is shown in a flow chart as in Figure 7. The steps in modelling the surface of the propeller blade, starts with editing the section data. The first input data to be keyed-in is the diameter of the propeller. Then the expanded area ratios of the propeller were keyed-in in the section data according to Table 3. Then the rake angle and the expanded skew at the tip over D were keyed-in in the section data. Once all the data were keyed-in, all these changes are accepted by clicking the 'build' button and also the 'refresh' button.

The next step is to edit the hub data. The key-in values that are needed in the hub data are (1) the hub length (2) the forward hub diameter (3) mid hub diameter (4) Aft hub diameter (5) Shaft diameter (6) Shaft taper (7) the root radius and (8) the location of the propeller axis.

The principal data for instance (1) the diameter (2) nominal pitch and (3) number of blades were keyed-in in the prop summary table at the main menu screen. To add thickness to the blade section which were pre-calculated using BV rules on propeller, were added in the 'Prop Builder' where the thickness rule was selected as 'User'. The radius fraction r/R was change to 0.25 with the correct thickness. More explanation on how the blade thickness was calculated is explained in section 4.2. An example of a complete propeller built in PropCAD is shown in Figure 8.

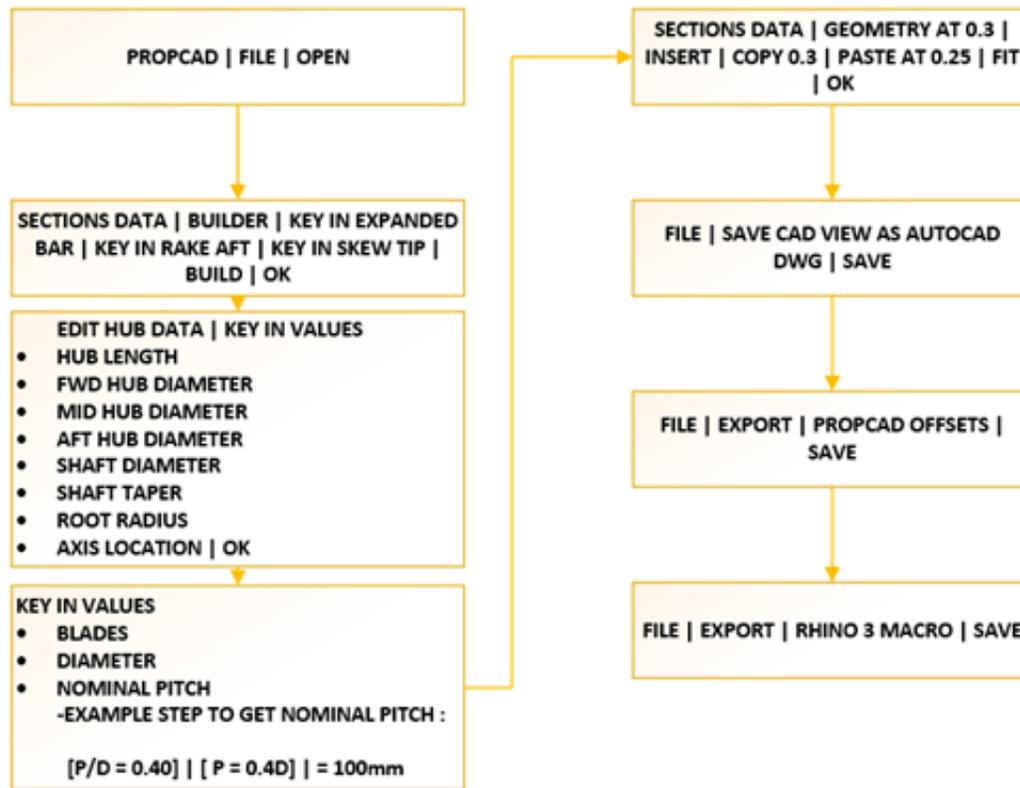


Figure 7 The flowchart of the modelling the 3D model in PropCAD

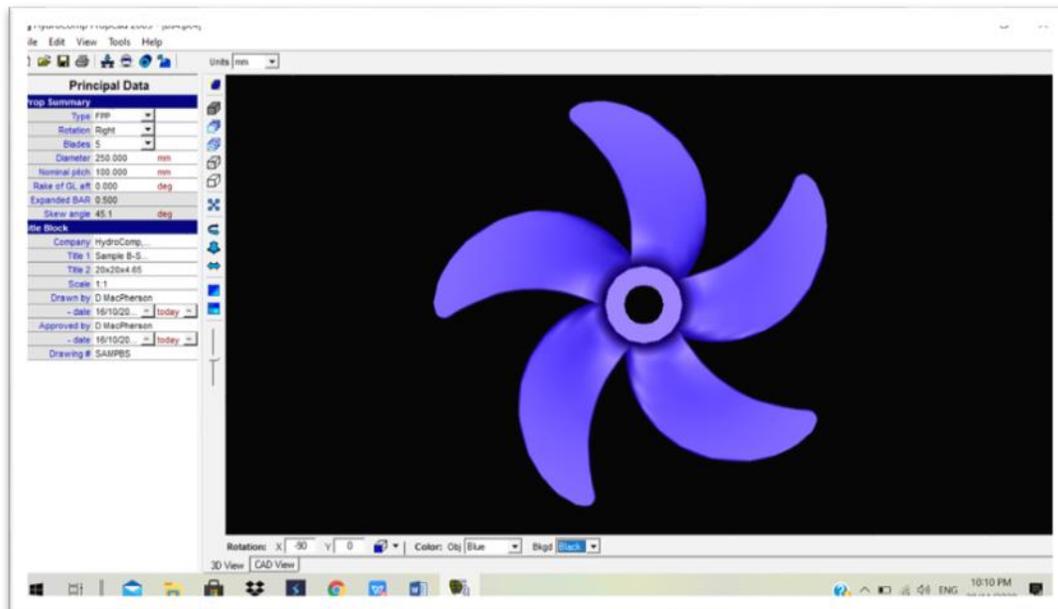


Figure 8 3D view FP series propeller in Propcad software

RESULTS AND DISCUSSION

Blade thickness calculation using Bureau Veritas Classification Rules.

The blade thickness is required to be at a certain thickness as to provide some structural strength to the propeller blade. The blade thickness for the FP series propeller were determined using the NR467 classification rules from Bureau Veritas (2020). There are six calculations that are described in Bureau Veritas (2020) which are (1) blade thickness at 0.25R (2) blade thickness at 0.60R (3) blade thickness at 0.25R for propeller having skew more than 25 degrees but less than 50 degrees. (4) blade thickness at 0.60R for propeller having skew more than 25 degrees but less than 50 degrees (5) blade thickness at 0.9R for propeller having skew more than 25 degrees but less than 50 degrees. (6) the radius at the blade root.

The maximum thickness at 0.25 R in mm for a solid propeller is not to be less than what is obtained in Equation 1.

$$t_{0.25} = 3.2 \left[f \cdot \frac{1.5 \times 10^6 \cdot \rho \cdot M_T + 51.8 \left(\frac{D}{100} \right)^3 B I N^2 h}{I \cdot z R_m} \right]^{\frac{1}{2}} \quad (\text{Equation 1})$$

The equation 1 is taken from NR467 classification rules, Bureau Veritas (2020) (pg. 183), where:

F is the material factor as indicated in Table 4.

P is $\rho = D/H$.

H is the mean pitch of propeller, in m. When H is not known, the pitch at 0.7 radius from the propeller axis $H_{0.7}$ may be used instead of H .

D is the propeller diameter, in m.

MT is the continuous transmitted torque, in kN.m; where not indicated, the value given by the following formula may be assumed for MT : $MT = 9.5 (P/N)$.

P is the maximum continuous power of propulsion machinery, in kW.

N is the rotational speed of the propeller, in rev/min.

δ is the density of blade material, in kg/dm^3 , as indicated in Table 4.

B is the developed area ratio.

H is the rake, in mm.

L is the expanded width of blade section at 0.25 radius from propeller axis, in mm.

The maximum thickness at 0.6 R in mm for a solid propeller is not to be less than what is obtained in Equation 2.

$$t_{0.6} = 1.9 \left[f \cdot \frac{1.5 \times 10^6 \cdot \rho_{0.6} \cdot M_T + 18.4 \left(\frac{D}{100} \right)^3 B I N^2 h}{I_{0.6} \cdot z R_m} \right]^{0.5} \quad (\text{Equation 2})$$

where:

$\rho_{0.6}$ is $D/H_{0.6}$

$H_{0.6}$ is the pitch at 0.6 radius from the propeller axis, in m

$l_{0.6}$ is the expanded width of blade section at 0.6 radius from propeller axis, in mm.

The maximum thickness at 0.25 R in mm for a solid propeller having skew angles between 25o and 50o, is not to be less than what is obtained in Equation 3.

$$t_{s-0.25} = t_{0.25}(0.92 + 0.0032\nu) \quad (\text{Equation 3})$$

The maximum thickness at 0.6 R in mm for a solid propeller having skew angles between 25° and 50° is not to be less than what is obtained in Equation 4.

$$t_{s-0.6} = t_{0.6}(0.74 + 0.0129\nu - 0.0001\nu^2) \quad (\text{Equation 4})$$

The maximum thickness at 0.9 R in mm for a solid propeller having skew angles between 25° and 50° is not to be less than what is obtained in Equation 5.

$$t_{s-0.9} = t_{0.6}(0.35 + 0.0015\nu) \quad (\text{Equation 5})$$

The radius at the blade root can be calculated using the formula as obtained in Equation 6.

$$\text{Radius of blade root} = \frac{3}{4} \times t_{0.25} \quad (\text{Equation 6})$$

where:

$t_{s-0.25}$ is the maximum thickness, in mm, of skewed propeller blade at the section at 0.25 is the radius from the propeller axis.

$t_{0.25}$ is the maximum thickness, in mm, of normal shape propeller blade at the section at 0.25 radius from the propeller axis.

$t_{s-0.6}$ is the maximum thickness, in mm, of skewed propeller blade at the section at 0.6 radius from the propeller axis.

$t_{0.6}$ is the maximum thickness, in mm, of normal shape propeller blade at the section at 0.6 radius from the propeller axis, obtained by the formula in [2.2.1]

$t_{s-0.9}$ is the maximum thickness, in mm, of skewed propeller blade at the section at 0.9 radius from the propeller axis.

ν is the skew angle.

The values for the maximum torque m_t and the shaft speed N were obtained from Mustaffa Kamal (2016). These values were based on the powering of a medium-speed wave-piercing catamaran. These input data are listed in Appendix 1. All the input data listed in Appendix 1 are in full scale. The scale ratio is 1:13.6. The propeller diameter D , mean pitch of propeller H , rake angle h were varied in 62 propellers. The expanded width of blade section at 0.6 radius from propeller axis $I_{0.6}$, the expanded width of blade section at 0.25 I, and the pitch radius from the propeller axis at 0.6 $H_{0.6}$ need to be taken to be calculated for the results in this project. The skew angle ν for the propeller was taken from PropCAD.

The data to be include in a blade thickness calculation is the material factor f , the minimum tensile strength of blade material R_m , density of blade material δ , where Nickel-Manganese Bronze was chosen for the FP series propeller to fulfil the suitable strength for the modern speed vessels. All the values mentioned above is shown in Table 4.

Table 4 Normally used materials for propeller blades and hub (Bureau Veritas, 2020).

Material	R_m	δ	f
Common Bronze	400	8.3	7.6
Manganese Bronze	440	8.3	7.6
Nickel-Manganese Bronze	440	8.3	7.9
Aluminium Bronze	590	7.6	8.3
Steel	440	7.9	9.0

Calculation of Blade Thickness using Matlab

The calculations of the blade thickness as mentioned earlier were programmed in Matlab. All the programming was done using the editor in Matlab using the m file format. This is to make the repetitive calculation easier and without any human error in the calculation. From the propeller diameter in full scale must be converted into model scale by using the formula $\lambda = D_S/D_M$. Second, calculate the mean pitch of the propeller and with the design speed of the catamaran for the modern speed vessel.

The transmitted torque and the shaft speed of propeller were taken from Mustaffa Kamal (2016) (pg.100) (pg.119) for the calculation of the maximum thickness of blade. The values from the thickness at 0.25R in full scale must be converted back into model scale. There blade thickness was then calculated according to equation 1 to equation 6 as shown earlier. The expanded width of blade section at 0.6R was taken from PropCAD. The code of the Matlab programme is shown as the followings:

```

clc
clear
%% input data - All the inputs shall be in full scale

f          = 7.9;          % Material factor as indicated in Table 4
D          = 3.4;          % Propeller diameter in m
H          = 3.4;          % Mean pitch of propeller, in m. When H is not known, the pitch at 0,7 radius
                                % from the propeller axis H0,7 may be used instead of H
Mt         = 80;          % Continuous transmitted torque, in kN.m;
delta      = 8.3;          % Density of blade material, in kg/dm3, as indicated in Tab 3
B          = 0.40;         % Developed area ratio
l          = 581.264;      % Expanded width of blade section at 0,25 radius from propeller axis, in mm
N          = 150;          % Rotational speed of the propeller, in rev/min
h          = 299;          % Rake, in mm
z          = 5;            % Number of blades
Rm         = 440;          % Minimum tensile strength of blade material, in N/mm2.
v          = 45.1;         % Skew angle in degree
lamda     = 13.6;         % Scale ratio, Ds / Dm
H_06      = 3.4;          % Pitch at 0,6 radius from the propeller axis, in m
l_06      = 758.472;      % Expanded width of blade section at 0,6 radius from propeller axis, in mm.

%% Rules Calculation for max blade thickness at radius fraction r0.25, r0.6 and r0.9

P_D_070   = H / D;
P_D_060   = H_06 / D;
rho        = D / H;
rho_06    = D / H_06;

t_025    = 3.2*(f*(((1.5*10^6*rho*Mt) + (51*delta*(D/100)^3*B*I*N^2*h))/(l*z*Rm)))^0.5;
ts_025   = t_025 * (0.92 + (0.0032*v));
t_06     = 1.9*(f*(((1.5*10^6*rho_06*Mt) + (18.4*delta*(D/100)^3*B*I*N^2*h))/(l_06*z*Rm)))^0.5;
ts_06    = t_06 * (0.74 + (0.0129*v)-(0.0001*v^2));
ts_09    = t_06 * (0.35 + (0.0015*v));

%% Converting to model scale
ts_025_model = ts_025 / lamda;
ts_06_model  = ts_06 / lamda;
ts_09_model  = ts_09 / lamda;
min_radius_root = (3/4)* ts_025_model

```

```

% Displaying the results
fprintf('Thickness at 0.25R (in mm, model scale) =')
disp(ts_025_model)
fprintf('Thickness at 0.60R (in mm, model scale) =')
disp(ts_06_model)
fprintf('Thickness at 0.90R (in mm, model scale) =')
disp(ts_09_model)
fprintf('Min. root radius (in mm, model scale) =')
disp(min_radius_root)

```

The Matlab programme starts with clearing the data and screen by using the command 'clc' and 'clear'. The second step is the defining the input data as defined and shown in Appendix 1. The third major step is the calculation using the BV rules as defined in Equation 1 until Equation 6.

The next step in the programme is the conversion of full-scale blade thickness to model scale blade thickness. Therefore, the scale ratio is needed as an input at the beginning of the programme. Then the final step is to print all the results in the command window. The results of the blade thickness calculation using Matlab are shown in Appendix 2. Even though the blade thickness at 0.25R varied from 7.4 mm to 14 mm, only one blade thickness was chosen for the building of the 62 FP series propellers. The chosen thickness at 0.25R is at 14.88 mm.

The 2D CAD drawing

The 2D CAD drawing was obtained from the PropCAD software. This was achieved by saving the current PropCAD file to an AutoCAD drawing file in a .dwg format. Initially the PropCAD 2D view is available in the PropCAD software itself as shown in Figure 9, but for further documentation, the file is needed to be converted to an AutoCAD file. The 2D drawing consists of three views which are (1) the profile view (2) the transverse view and (3) the expanded view. Apart from that the radius fraction r/R from 0.2R to 1.0R, the maximum blade thickness t at each radius fraction, the local pitch p at each radius fraction, the local radius r , local skew at each radius fraction and expanded width or section chord length at each radius fraction.

The propeller particulars were also included in the 2D CAD drawing such as rotation direction, number of blades, full diameter, nominal pitch, expanded area ratio, rake aft, skew, material type, density, design power, design RPM and the thickness rules used.

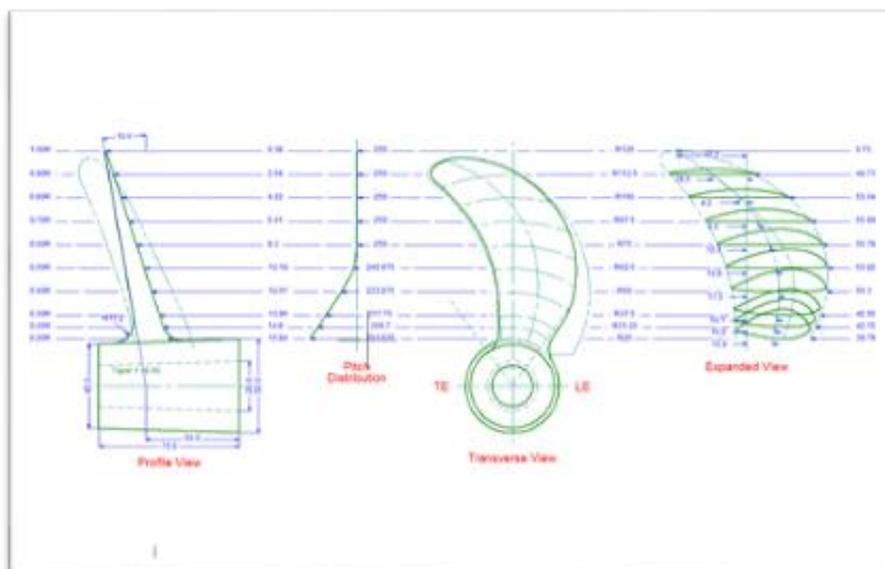


Figure 9 CAD view of FP series propeller

The offset table of the FP series.

The offset table was obtained from the PropCAD software. This was achieved by exporting the current PropCAD file to a PropCAD offset file in a off format. In the beginning of the offset table, the particulars such as the chord, the maximum thickness, the skew, the pitch, the pitch angle and the rake angle at each radius fraction are listed as in Table 5. Then, the offsets are shown in three ways, (1) 2D offsets (2) 3D XYZ offsets, (3) 3D radial offsets. In the beginning of the table of offsets, the particulars of the section data are shown as listed in Table 5. The columns in table 5 are (1) the radius fraction, (2) the local radius, (3) the chord or the expanded width, (4) the maximum thickness (5) the skew length (6) pitch (7) the pitch angle and (8) the rake angle.

In the 2D offsets table, the coordinates x, y at the back and the coordinate x, y at the face are listed from the leading edge LE to the trailing edge TE. In between the LE and TE, there are stations from 2.5, 5, 10 to 95 as shown in Figure 10.

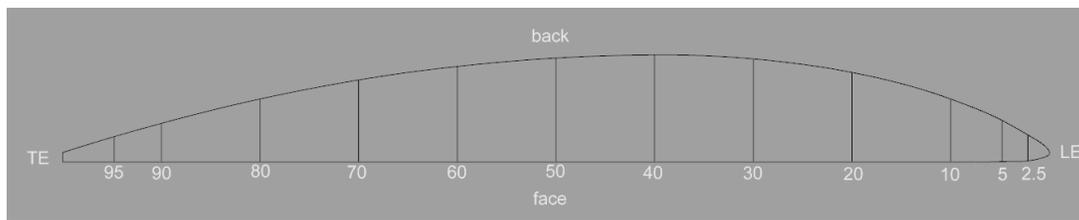


Figure 10 Blade Section Stations

In the 3D XYZ offsets table, the coordinates of x, y and z for radius fraction 0.2R to 1.0R are listed. This coordinate system is using the three dimensional cartesian coordinates system. In the 3D radial offsets table, the cylindrical coordinates of r, θ, ϕ were used to represent the coordinates of the blade surface. The illustration of the Cartesian coordinate system is shown in Figure 11 (a) and the illustration of the cylindrical coordinate system is shown in Figure 11 (b). An example of the coordinated being applied to a propeller blade is shown in Figure 12. The examples are shown for FP propeller 4Z_BAR040_PD10 to 7Z_BAR055_PD080_RA0 in Figure 17.

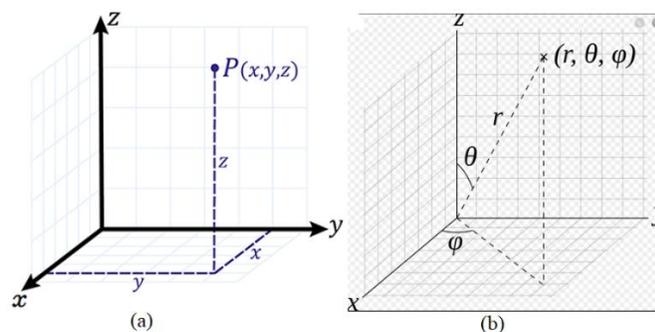


Figure 11 (a) The Cartesian coordinate system and (b) the cylindrical coordinate system

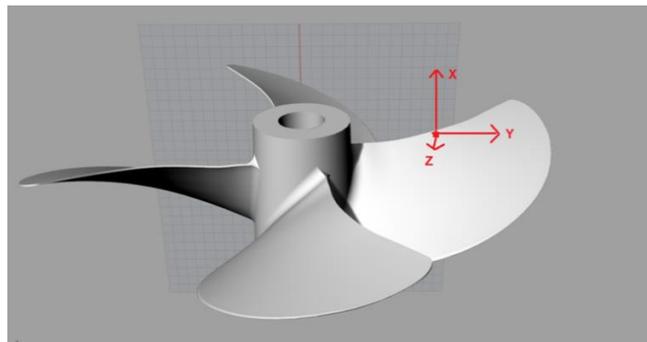


Figure 12 The 3D XYZ coordinates at a propeller blade.

Table 5 Table of section particulars

r/R	r	C	MT	SK	P	PA°	RL
0.2000	25.000	39.790	17.950	-13.770	241.950	57.01	0.0
0.2500	31.250	42.750	16.880	-15.040	251.640	52.04	0.0
0.3000	37.500	45.550	15.800	-16.150	261.300	47.96	0.0
0.4000	50.000	50.300	13.650	-17.220	280.650	41.78	0.0
0.5000	62.500	53.820	11.500	-15.910	295.170	36.93	0.0
0.6000	75.000	55.780	9.350	-12.350	300.000	32.48	0.0
0.7000	87.500	55.890	7.200	-6.030	300.000	28.62	0.0
0.8000	100.000	53.040	5.050	4.230	300.000	25.52	0.0
0.9000	112.500	44.710	2.900	18.500	300.000	23.00	0.0
0.9500	118.750	35.660	1.830	28.000	300.000	21.90	0.0
0.9800	121.880	26.220	1.290	32.810	300.000	21.39	0.0
0.9900	123.440	19.100	1.020	35.160	300.000	21.15	0.0
1.0000	125.000	0.750	0.380	37.500	300.000	20.91	0.0

Modelling the FP series in Rhinoceros.

To make the propeller is solid form, further modelling is needed in order to close all the gaps in between the propeller blade surfaces. The improvements to be made are (1) closing the trailing edge gaps (2) closing the tip gaps (3) making radius fillet at blade root (4) arraying the number of blades (5) trimming the inner surface of the blade palm in the hub and (6) joining all surfaces. The details of the steps in making a solid propeller in Rhinoceros is shown in Figure 13.

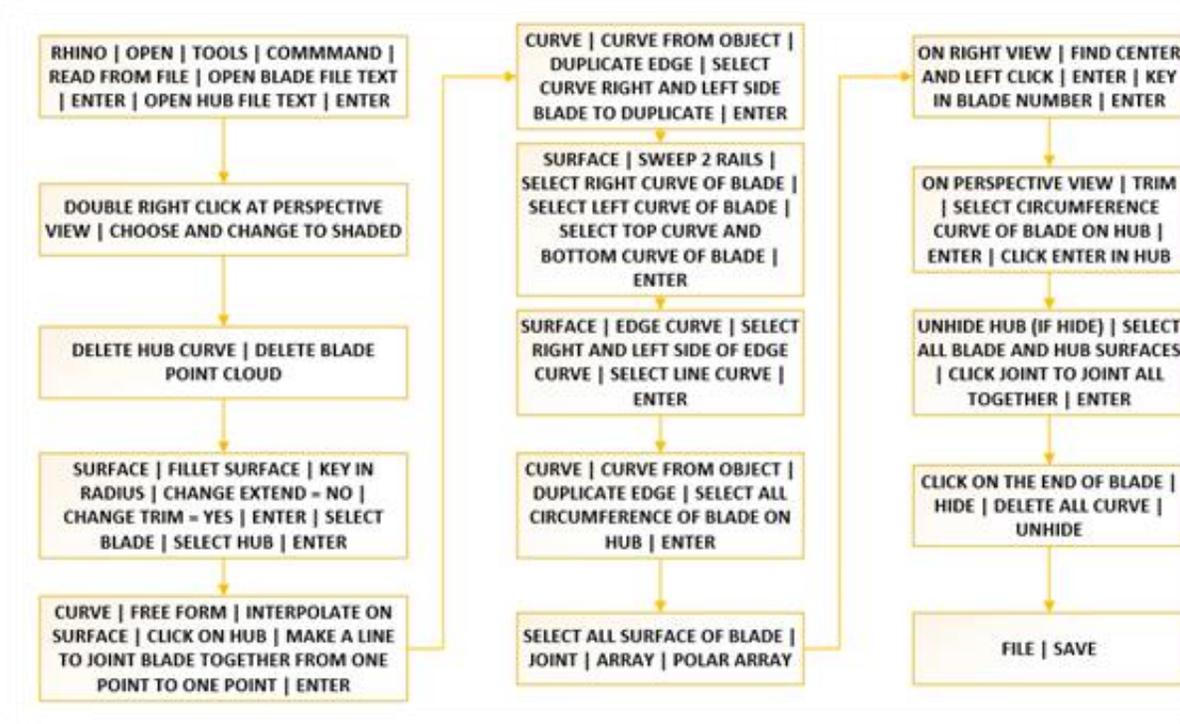


Figure 13 Modelling FP Series in Rhinoceros 3D

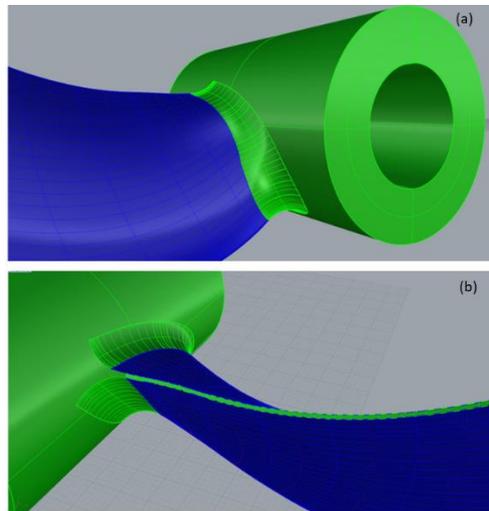


Figure 14 (a) The making of root fillet and (b) the closing of the trailing edge of the blade in Rhinoceros

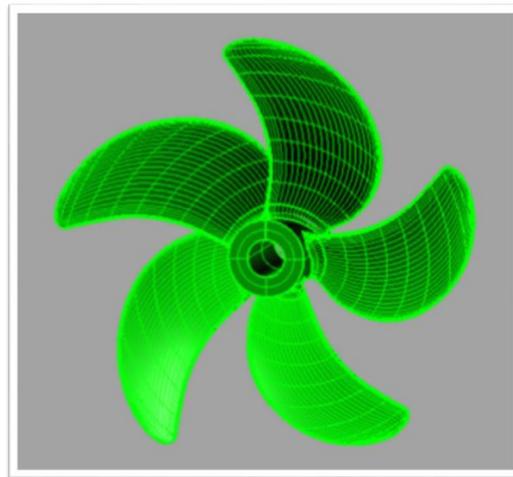


Figure 15 The completed solid propeller after polar arraying and joining all the blade surface and hub together.

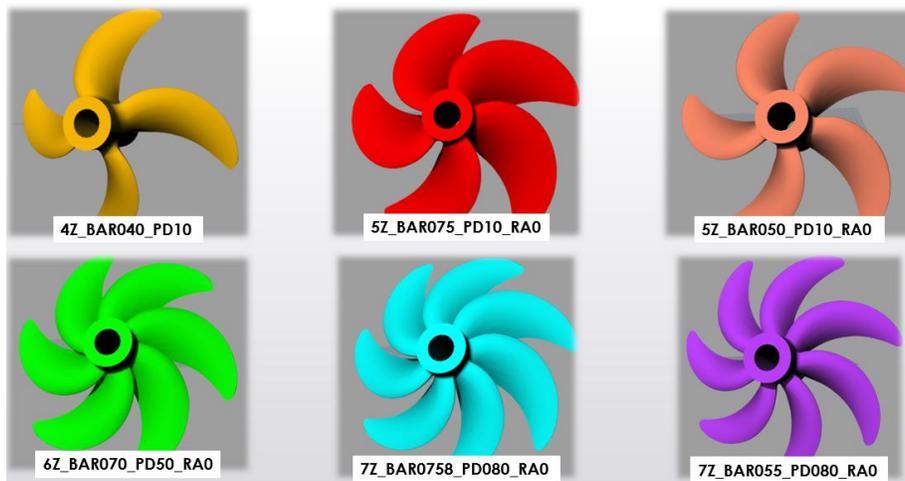


Figure 16 The examples of completed FP series

An example of making the root fillet and closing the trailing edge in Rhinoceros is shown in Figure 14 (a) and (b). The completed solid 3D propeller is shown in Figure 15. The complete solid file is then saved in a 3dm format. Six examples of a completed and rendered FP propeller series for 4Z_BAR040_PD10, 5Z_BAR075_PD10_RA0, 5Z_BAR050_PD10_RA0, 6Z_BAR070_PD050_RA0, 7Z_BAR0758_PD080_RA0 and 7Z_BAR055_PD080_RA0 are shown in Figure 16.

3D printing of the FP series propeller.

A sample for display was made using 3D printer. The printing was outsourced to LZ 3D Printing Malaysia. The cost of the printing is at RM59 where the rate is at RM0.20 per gram. The total weight of the propeller is 210 grams without the base support. This was cheaper than other 3D printing company, where AA3D Printing & Engineering rate is at RM0.70 per gram where the total cost is at RM210.00. The 3D printer is the 'Fused Deposition Modelling (FDM) type printer. The material used for the propeller 3D printing is Polylactic Acid Plastic or PLA. The PLA material chosen is PLA Black. The propeller was printed in model scale where the diameter of the model scale propeller is at 250 mm.

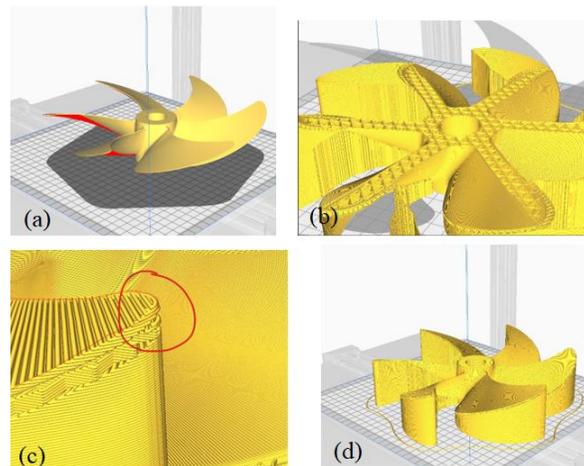


Figure 17 (a) Setting of 3D printing using STL file (b) infill ratio (c) The layer thickness of 0.2 mm (d) complete printed propeller

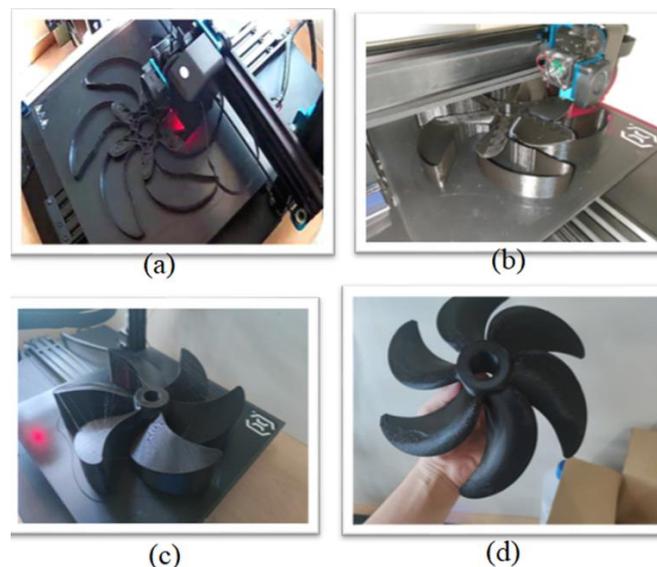


Figure 18 The 3D printing process (a) the support base is printed (b) printing in progress (c) completed printed propeller (d) propeller removed from the support base.

The setting of the 3D printer is with 20% infill and 0.2 mm layer height. The 20% infill layer means that in the solid propeller, contained 20% PLA material and the rest of 80% are air cavity. The source file for the 3D printer is in STL format, therefore in Rhinoceros the 3dm file format need to be converted into STL file format before the printing process. This can be achieved by saving as the 3dm file into a STL file. The setting using the STL file is shown in Figure 17 (a), where the infill ratio can be seen in Figure 17 (b). The layer thickness of 0.2 mm can be seen in Figure 17 (c). Then complete printed propeller can be seen in Figure 17 (d). The actual printing is shown in Figure 18, where in Figure 18 (a) the base is printed, in Figure 18 (b) and (c) the propeller is printed on the base that was printed earlier. In Figure 18 (d) the complete printed propeller is shown. The whole printing was done in 28 hours. A further polishing and finishing are required to smoothen the propeller surface to an acceptable level for display purposes.

CONCLUSION AND RECOMMENDATION

The development of the MIMETFP series is presented. As a result of that, a new propeller series for medium speed vessel were developed in this project.

This report presents the 3D model and the CAD drawing development for 4, 5, 6 and 7 bladed propellers with blade area ratio from 0.4 to 0.758 which range from 0.4 to 1.2 of pitch diameter ratio. This project existed, because the existing propeller series such as Wageningen B series, Gawn series, KCA series and Newton-Rader series are already outdated. This project is meant for the development of propeller series for the modern medium speed vessels. With the old series propeller, there are maybe not efficient as what the modern propeller needed. Therefore, in this project the FP series is designed to minimize noise and vibration by using moderate to high skew angle. This project has developed the geometry of the new propeller series with high skew was discussed earlier in chapter 4. This project has achieved its objectives by building a modelling of surface in PropCAD and making the propeller into a solid form in Rhinoceros. The offsets data was also produced using PropCAD. Later this table offsets can be used for 3D manufacturing. The offset tables include the chord, pitch diameter ratio, maximum thickness for the propeller series. But prior to that, the blade thickness was calculated according to NR467 classification rules from Bureau Veritas, 2020 for strength purposes. A sample of a 3D printed model propeller with a diameter of 250 mm is printed. However, the propeller need to be sanded and polished for a high quality finish. Finally, the outcomes of the FP series propeller have been achieved to fulfil the need of the requirements for highly skewed propeller. Overall there were 62 propellers were modelled in Rhinoceros where all the 62 propellers were varied in its expanded area ratio and its pitch diameter ratio.

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APPENDIX

Appendix 1: Input Data for BV Rules Blade Thickness Calculation

PROPELLER	f	D (m)	H (m)	mt kNm	δ kg/dm ³	B	l mm	N rev/min	h mm	z	Rm N/mm ²	ν deg	λ	H_06 m	l_06 mm
4Z_BAR040_PD050	7.9	3.4	1.7	80	8.3	0.4	581.264	150	299.2	4	440	43.5	13.6	1.7	758.472
4Z_BAR040_PD060	7.9	3.4	2.04	80	8.3	0.4	581.264	150	299.2	4	440	41.9	13.6	2.04	758.472
4Z_BAR040_PD080	7.9	3.4	2.72	80	8.3	0.4	581.264	150	299.2	4	440	38.7	13.6	2.72	758.472
4Z_BAR040_PD10	7.9	3.4	3.4	80	8.3	0.4	581.264	150	299.2	4	440	35.8	13.6	3.4	758.472
4Z_BAR040_PD12	7.9	3.4	4.08	335	8.3	0.4	581.264	252	299.2	4	440	33.2	13.6	4.08	758.472
4Z_BAR040_PD050_RA0	7.9	3.4	1.7	80	8.3	0.4	581.264	150	0	4	440	43.5	13.6	1.7	758.472
4Z_BAR040_PD060_RA0	7.9	3.4	2.04	80	8.3	0.4	581.264	150	0	4	440	41.9	13.6	2.04	758.472
4Z_BAR040_PD080_RA0	7.9	3.4	2.72	80	8.3	0.4	581.264	150	0	4	440	38.7	13.6	2.72	758.472
4Z_BAR040_PD10_RA0	7.9	3.4	3.4	80	8.3	0.4	581.264	150	0	4	440	35.8	13.6	3.4	758.472
4Z_BAR040_PD12_RA0	7.9	3.4	4.08	335	8.3	0.4	581.264	252	0	4	440	33.2	13.6	4.08	758.472
4Z_BAR055_PD050	7.9	3.4	1.7	80	8.3	0.55	799.272	150	299.2	4	440	43.5	13.6	1.7	1042.984
4Z_BAR055_PD060	7.9	3.4	2.04	80	8.3	0.55	799.272	150	299.2	4	440	41.9	13.6	2.04	1042.984
4Z_BAR055_PD080	7.9	3.4	2.72	80	8.3	0.55	799.272	150	299.2	4	440	38.7	13.6	2.72	1042.984
4Z_BAR055_PD10	7.9	3.4	3.4	80	8.3	0.55	799.272	150	299.2	4	440	35.8	13.6	3.4	1042.984
4Z_BAR055_PD12	7.9	3.4	4.08	335	8.3	0.55	799.272	252	299.2	4	440	33.2	13.6	4.08	1042.984
4Z_BAR055_PD050_RA0	7.9	3.4	1.7	80	8.3	0.55	799.272	150	0	4	440	43.5	13.6	1.7	1042.984
4Z_BAR055_PD060_RA0	7.9	3.4	2.04	80	8.3	0.55	799.272	150	0	4	440	41.9	13.6	2.04	1042.984
4Z_BAR055_PD080_RA0	7.9	3.4	2.72	80	8.3	0.55	799.272	150	0	4	440	38.7	13.6	2.72	1042.984
4Z_BAR055_PD10_RA0	7.9	3.4	3.4	80	8.3	0.55	799.272	150	0	4	440	35.8	13.6	3.4	1042.984
4Z_BAR055_PD12_RA0	7.9	3.4	4.08	335	8.3	0.55	799.272	252	0	4	440	33.2	13.6	4.08	1042.984
5Z_BAR050_PD040	7.9	3.4	1.36	80	8.3	0.5	581.264	150	299.2	5	440	45.1	13.6	1.36	758.472
5Z_BAR050_PD060	7.9	3.4	2.04	80	8.3	0.5	581.264	150	299.2	5	440	41.9	13.6	2.04	758.472
5Z_BAR050_PD080	7.9	3.4	2.72	80	8.3	0.5	581.264	150	299.2	5	440	38.7	13.6	2.72	758.472
5Z_BAR050_PD10	7.9	3.4	3.4	80	8.3	0.5	581.264	150	299.2	5	440	35.8	13.6	3.4	758.472
5Z_BAR050_PD12	7.9	3.4	4.08	335	8.3	0.5	581.264	252	299.2	5	440	33.2	13.6	4.08	758.472
5Z_BAR050_PD040_RA0	7.9	3.4	1.36	80	8.3	0.5	581.264	150	0	5	440	45.1	13.6	1.36	758.472

	f	D	H	mt	δ	B	l	N	h	z	Rm	v	λ	H_06	I_06
5Z_BAR050_PD060_RAO	7.9	3.4	2.04	80	8.3	0.5	581.264	150	0	5	440	41.9	13.6	2.04	758.472
5Z_BAR050_PD080_RAO	7.9	3.4	2.72	80	8.3	0.5	581.264	150	0	5	440	38.7	13.6	2.72	758.472
5Z_BAR050_PD10_RAO	7.9	3.4	3.4	80	8.3	0.5	581.264	150	0	5	440	35.8	13.6	3.4	758.472
5Z_BAR050_PD12_RAO	7.9	3.4	4.08	335	8.3	0.5	581.264	252	0	5	440	33.2	13.6	4.08	758.472
5Z_BAR075_PD040	7.9	3.4	1.36	80	8.3	0.75	872.032	150	299.2	5	440	54.2	13.6	1.36	1137.776
5Z_BAR075_PD060	7.9	3.4	2.04	80	8.3	0.75	872.032	150	299.2	5	440	50.3	13.6	2.04	1137.776
5Z_BAR075_PD080	7.9	3.4	2.72	80	8.3	0.75	872.032	150	299.2	5	440	46.4	13.6	2.72	1137.776
5Z_BAR075_PD10	7.9	3.4	3.4	80	8.3	0.75	872.032	150	299.2	5	440	42.9	13.6	3.4	1137.776
5Z_BAR075_PD12	7.9	3.4	4.08	335	8.3	0.75	872.032	252	299.2	5	440	39.9	13.6	4.08	1137.776
5Z_BAR075_PD040_RAO	7.9	3.4	1.36	80	8.3	0.75	872.032	150	0	5	440	54.2	13.6	1.36	1137.776
5Z_BAR075_PD060_RAO	7.9	3.4	2.04	80	8.3	0.75	872.032	150	0	5	440	50.3	13.6	2.04	1137.776
5Z_BAR075_PD080_RAO	7.9	3.4	2.72	80	8.3	0.75	872.032	150	0	5	440	46.4	13.6	2.72	1137.776
5Z_BAR075_PD10_RAO	7.9	3.4	3.4	80	8.3	0.75	872.032	150	0	5	440	42.9	13.6	3.4	1137.776
5Z_BAR075_PD12_RAO	7.9	3.4	4.08	335	8.3	0.75	872.032	252	0	5	440	39.9	13.6	4.08	1137.776
6Z_BAR055_PD050	7.9	3.4	1.7	80	8.3	0.55	532.848	150	299.2	6	440	52.3	13.6	1.7	695.232
6Z_BAR055_PD070	7.9	3.4	2.38	80	8.3	0.55	532.848	150	299.2	6	440	48.3	13.6	2.38	695.232
6Z_BAR055_PD090	7.9	3.4	3.06	80	8.3	0.55	532.848	150	299.2	6	440	44.6	13.6	3.06	695.232
6Z_BAR055_PD11	7.9	3.4	3.74	80	8.3	0.55	532.848	150	299.2	6	440	41.4	13.6	3.74	695.232
6Z_BAR055_PD050_RAO	7.9	3.4	1.7	80	8.3	0.55	532.848	150	0	6	440	52.3	13.6	1.7	695.232
6Z_BAR055_PD070_RAO	7.9	3.4	2.38	80	8.3	0.55	532.848	150	0	6	440	48.3	13.6	2.38	695.232
6Z_BAR055_PD090_RAO	7.9	3.4	3.06	80	8.3	0.55	532.848	150	0	6	440	44.6	13.6	3.06	695.232
6Z_BAR055_PD11_RAO	7.9	3.4	3.74	80	8.3	0.55	532.848	150	0	6	440	41.4	13.6	3.74	695.232
6Z_BAR070_PD050	7.9	3.4	1.7	80	8.3	0.7	678.232	150	299.2	6	440	52.3	13.6	1.7	884.952
6Z_BAR070_PD070	7.9	3.4	2.38	80	8.3	0.7	678.232	150	299.2	6	440	48.3	13.6	2.38	884.952
6Z_BAR070_PD090	7.9	3.4	3.06	80	8.3	0.7	678.232	150	299.2	6	440	44.6	13.6	3.06	884.952
6Z_BAR070_PD11	7.9	3.4	3.74	80	8.3	0.7	678.232	150	299.2	6	440	41.4	13.6	3.74	884.952
6Z_BAR070_PD050_RAO	7.9	3.4	1.7	80	8.3	0.7	678.232	150	0	6	440	52.3	13.6	1.7	884.952
6Z_BAR070_PD070_RAO	7.9	3.4	2.38	80	8.3	0.7	678.232	150	0	6	440	48.3	13.6	2.38	884.952

Appendix 1: Cont..Input Data for BV Rules Blade Thickness Calculation

	f	D	H	mt	δ	B	l	N	h	z	Rm	v	λ	H_06	I_06
6Z_BAR070_PD090_RAO	7.9	3.4	3.06	80	8.3	0.7	678.232	150	0	6	440	44.6	13.6	3.06	884.952
6Z_BAR070_PD11_RAO	7.9	3.4	3.74	80	8.3	0.7	678.232	150	0	6	440	41.4	13.6	3.74	884.952
7Z_BAR055_PD080_RAO	7.9	3.4	2.72	80	8.3	0.55	456.688	150	299.2	7	440	38.7	13.6	2.72	595.952
7Z_BAR055_PD080_RAO	7.9	3.4	2.72	80	8.3	0.55	456.688	150	0	7	440	38.7	13.6	2.72	595.952
7Z_BAR065_PD080_RAO	7.9	3.4	2.72	80	8.3	0.65	539.784	150	299.2	7	440	46.4	13.6	2.72	704.344
7Z_BAR065_PD080_RAO	7.9	3.4	2.72	80	8.3	0.65	539.784	150	0	7	440	46.4	13.6	2.72	704.344
7Z_BAR0758_PD080_RAO	7.9	3.4	2.72	80	8.3	0.758	629.544	150	299.2	7	440	46.4	13.6	2.72	821.304
7Z_BAR0758_PD080_RAO	7.9	3.4	2.72	80	8.3	0.758	629.544	150	0	7	440	46.4	13.6	2.72	821.304

Appendix2 Blade Thickness Calculation Results

PROPELLER SERIES NO	ts 0.25	ts 0.6	ts 0.9	radius	RAKE ANGLE
4Z_BAR040_PD050	11.2962	5.9679	2.2287	8.4722	10
4Z_BAR040_PD060	10.3621	5.4341	2.0304	7.7716	10
4Z_BAR040_PD080	9.0557	4.6747	1.7509	6.7918	10
4Z_BAR040_PD10	8.1748	4.1507	1.5607	6.1311	10
4Z_BAR040_PD12	14.8875	7.5879	2.8672	11.1657	10
4Z_BAR040_PD050	10.7291	5.8544	2.1863	8.0469	0
4Z_BAR040_PD060	9.747	5.3108	1.9843	7.3102	0
4Z_BAR040_PD080	8.3591	4.5348	1.6985	6.2693	0
4Z_BAR040_PD10	7.4102	3.9972	1.503	5.5576	0
4Z_BAR040_PD12	13.7312	7.3585	2.7805	10.2984	0
4Z_BAR055_PD050	10.0444	5.1739	1.9322	7.5333	10
4Z_BAR055_PD060	9.279	4.7257	1.7657	6.9592	10
4Z_BAR055_PD080	8.2156	4.0897	1.5318	6.1617	10
4Z_BAR055_PD10	7.5045	3.6523	1.3733	5.6284	10
4Z_BAR055_PD12	13.5138	6.6401	2.5091	10.1353	10
4Z_BAR055_PD050	9.1497	4.9925	1.8644	6.8622	0
4Z_BAR055_PD060	8.3121	4.5289	1.6922	6.2341	0
4Z_BAR055_PD080	7.1285	3.8671	1.4484	5.3464	0
4Z_BAR055_PD10	6.3193	3.4087	1.2817	4.7395	0
4Z_BAR055_PD12	11.7097	6.2751	2.3711	8.7823	0
5Z_BAR050_PD040	11.3508	6.0026	2.2416	8.5131	10
5Z_BAR050_PD060	9.4007	4.8876	1.8262	7.0505	10
5Z_BAR050_PD080	8.2481	4.2119	1.5775	6.1861	10
5Z_BAR050_PD10	7.4729	3.7461	1.4085	5.6047	10
5Z_BAR050_PD012	13.5621	6.8372	2.5835	10.1716	10
5Z_BAR050_PD040	10.7810	5.8884	2.1990	8.0858	0
5Z_BAR050_PD060	8.7180	4.7501	1.7748	6.5385	0
5Z_BAR050_PD080	7.4766	4.0561	1.5192	5.6075	0
5Z_BAR050_PD10	6.6279	3.5752	1.3443	4.9709	0

Appendix2 cont., Blade Thickness Calculation Results

PROPELLER SERIES NO	ts 0.25	ts 0.6	ts 0.9	radius	RAKE ANGLE
5Z_BAR050_PD12	12.2815	6.5816	2.4870	9.2112	0
5Z_BAR075_PD040	10.0866	5.1362	1.934	7.5649	10
5Z_BAR075_PD060	8.5318	4.2421	1.5889	6.3988	10
5Z_BAR075_PD080	7.6228	3.703	1.3833	5.7171	10
5Z_BAR075_PD10	7.0178	3.3318	1.2444	5.2633	10
5Z_BAR075_PD12	12.5109	6.0392	2.2594	9.3832	10
5Z_BAR075_PD040	9.0428	4.9239	1.8541	6.7821	0
5Z_BAR075_PD060	7.2991	3.9868	1.4933	5.4744	0
5Z_BAR075_PD080	6.2483	3.4144	1.2755	4.6862	0
5Z_BAR075_PD10	5.5300	3.0162	1.1265	4.1475	0
5Z_BAR075_PD12	10.2365	5.5639	2.0816	7.6774	0
6Z_BAR055_PD050	10.0147	5.2489	1.9707	7.511	10
6Z_BAR055_PD070	8.5632	4.433	1.6576	6.4224	10
6Z_BAR055_PD090	7.6384	3.8989	1.4559	5.7288	10
6Z_BAR055_PD11	6.9912	3.5146	1.3135	5.2434	10
6Z_BAR055_PD050	9.3929	5.124	1.9238	7.0447	0
6Z_BAR055_PD070	7.8450	4.2874	1.6032	5.8838	0
6Z_BAR055_PD090	6.8424	3.7365	1.3953	5.1318	0
6Z_BAR055_PD11	6.1296	3.3381	1.2476	4.5972	0
6Z_BAR070_PD050	9.2017	4.7197	1.772	6.9013	10
6Z_BAR070_PD070	7.9593	4.0072	1.4984	5.9694	10
6Z_BAR070_PD090	7.173	3.5421	1.3227	5.3798	10
6Z_BAR070_PD11	6.6261	3.2083	1.1991	4.9696	10
6Z_BAR070_PD050	8.3255	4.5416	1.7052	6.2442	0
6Z_BAR070_PD070	6.9535	3.8002	1.4210	5.2152	0
6Z_BAR070_PD090	6.0649	3.3118	1.2367	4.5487	0
6Z_BAR070_PD11	5.4330	2.9587	1.1058	4.0748	0
7Z_BAR055_PD080	7.7686	3.996	1.4967	5.8265	10
7Z_BAR055_PD080	7.1288	3.8673	1.4485	5.3466	0
7Z_BAR065_PD080	7.5401	3.8371	1.4334	5.6551	10
7Z_BAR065_PD080	6.712	3.6677	1.3701	5.034	0
7Z_BAR0758_PD080	7.2382	3.6082	1.3479	5.4286	10
7Z_BAR0758_PD080	6.2151	3.3965	1.2688	4.6613	0