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Marine Propeller Geometry Characterization

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Abstract: This study describes a non-contact methodology of characterizing marine propeller geometric properties using 3-D scanning and computer aided design application tool. The process develops a solid virtual propeller model by converting the physical model through 3-D scanning. An outboard marine propeller of '9.25×8J1' has been utilized for the purpose of demonstrating the feasibility of this method. Studies showed that the geometric properties can be successfully characterized. The virtual modelling found a propeller nominal pitch distance value of 203.26 mm has an insignificant variance of 0.03% from that of the manufacturer's design value. An average variance of 0.83% of the pitch distance across each sectional radius is also found to be insignificant as compared to the physical model.

Key words: Outboard marine propeller, 3-D scanning, propeller blade, geometry characterization

INTRODUCTION

The geometric properties are crucial elements for the development of marine propeller, in particular the cavitation phenomenon study. The propeller blade physical profile has always been challenging due to difficulties to achieve accurate measurement of the complex and helicoidal surface geometry (Carlton, 2012). Two applicable methods for characterizing propeller geometry can be categorized as contact or non-contact methods. Contact method involves physical contact between the measuring devices and the propeller physical profile such as the pitch meter measuring system, the precision caliper system by Lee *et al.* (2002), the Computer Numerical Control Coordinate Measuring Machine (CNC-CMM) and others. In non-contact method, electronic visual or optic systems can be utilized to convert the propeller physical model into 3-D coordinate points and pre-process into a 3-D virtual model. The applicable non-contact methods included the 3-D scanner, binocular stereo machine vision application by Zhang and Lu (2011), digital photogrammetric procedure by Ackermann *et al.* (2008), profilometer by Gollini (1991) and others. However, the non-contact methods on propeller geometry characterization are preferable as 3-D data or output model could be preserved for further development and as well as cost effective compared to the contact methods.

In the propeller development, propeller geometric properties are in 2-D data (existing data) forms are converted into 3-D coordinates data and subsequently into 3-D solid virtual model (as an output data). In this study, the characterization process is reversed, where virtual model being the existing data and the 2-D data such as the propeller pitch value, skew angle, rake angle, pitch angle, blade thickness and hydrofoil detail of each radius distribution are extracted as the output data. The conversion of physical to virtual propeller model is carried out using 3-D scanning system and model reconstruction.

9.25×8.5-J1 OUTBOARD MARINE PROPELLER

An outboard marine propeller '9.25×8.5-J1' manufactured by Yamaha Motor Corporation has been adopted in this study. The propeller is a three blades aluminium alloy propeller type for low horsepower outboard marine engine (9.9-20 HP) applications. Generally, the propeller is a low skew type propeller with the outer diameter of 235 mm and nominal pitch distance of 203 mm (Fig. 1).

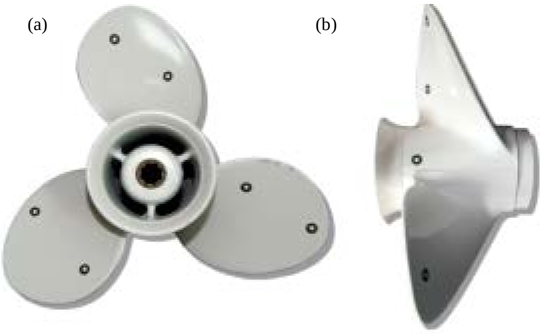

Fig. 1(a-b): J1 series outboard marine propeller

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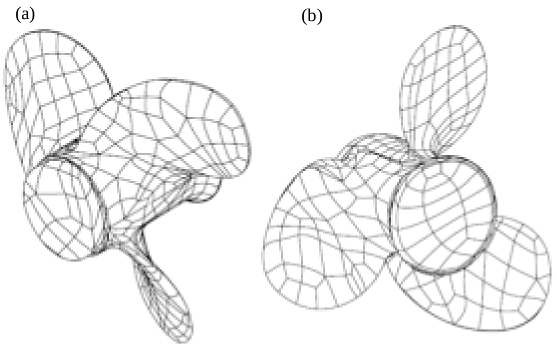

Fig. 2(a-b): Raw surface model, (a) Suction side and (b) Pressure side

PHYSICAL TO VIRTUAL MODEL TRANSFORMATION

The process of acquiring or converting the physical model into a digital virtual 3-D model can be achieved with high accuracy with today's technology. This conversion process is carried out through the 3-D scanning machine. The scanning raw or non-uniform rational B-Spline surface model, as shown in Fig. 2, is obtained with acceptable geometric and presentation tolerance.

PROPELLER BLADE GEOMETRY CHARACTERIZATION

The characterization process is carried out by referring to the Munar *et al.* (2007) methodology in propeller geometry modeling process. In this case, the propeller 3-D model is available for extracting the 2-D geometry details.

Propeller model preparation: The propeller geometry is formed by a series of wrapped hydrofoil sections, where the wrapped hydrofoil sections are defined by 3-D coordinates on the dedicated blade radius. The model is orientated and translated to the assigned coordinate system and plane. The rotating axis of the propeller is the *Z*-axis and the blade radius section '0' (0R) center coincides with the Y-axis, as shown in the Fig. 3.

The propeller blade is sectioned into several radius sections (nR) up to the tip for extracting the hydrofoil profile details, shown in the Fig. 4a and b. Each of the blade radius sections, a close boundary line is laid on the sectional edge to form the blade section curved hydrofoil profile, as shown in the Fig. 4c. The curvature hydrofoil radius is equal to the blade section radius and its geometric data is specified in 3-D coordinate system.

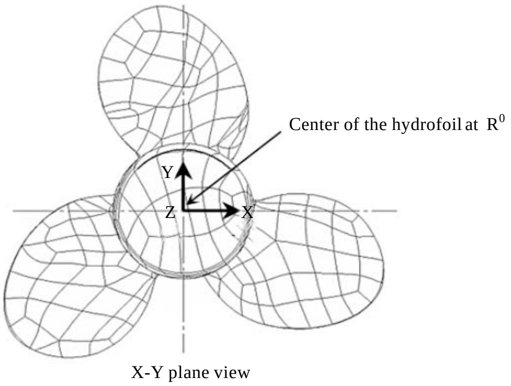

Fig. 3: Propeller model orientation

A new parallel plane Z^n-X^n to the original Z-X axis plane is elevated to or introduced at the blade radius section of nR. Referring to Fig. 4d, the projected 2-D hydrofoil profile is then constructed by projecting the wrapped hydrofoil profile to the Z^n-X^n plane. Series of the wrapped and projected hydrofoils are shown in the Fig. 5.

From the view of the Z-X plane in the Fig. 6, each of the radius sectional hydrofoil profiles is then layout. The sizes of each of the hydrofoil profiles are decreasing and the skew and rake distances are moving in the negative direction from the propeller reference point along with the increasing of the blade sectional radius.

Characterizing process conditions and preparation: The characterizing process is also carried out under conditions or setup to ensure standardization. Firstly, all the propeller model geometry terminology and nomenclatures is based on the International Towing Tank Conference-ITTC definition as in Fig. 7.

Secondly, the 3-D propeller model is oriented to a specific orientation, where the blade 0R centre point is coincident with the Y-axis or the propeller reference axis. Third, Kuiper (1992) reported the existing industrial practices, the nominal or significant propeller radius is common used to represent the propeller diameter and it

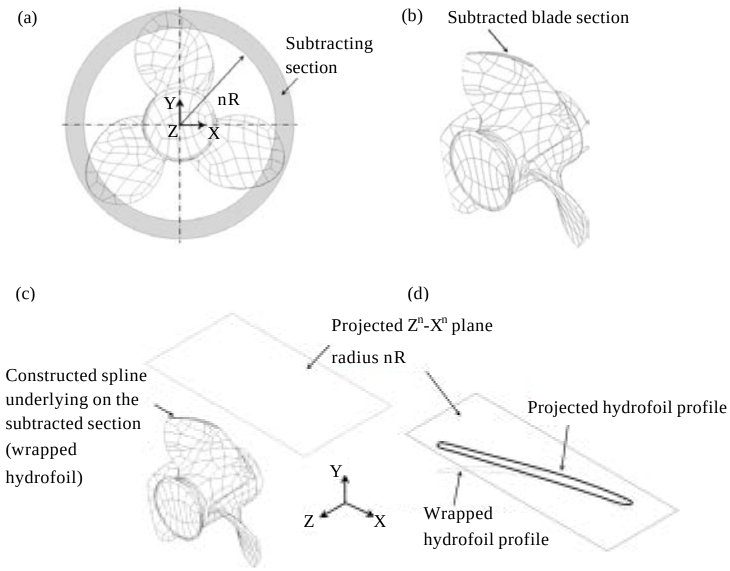

Fig. 4(a-d): Construction of wrapped and projected hydrofoil profile by (a) Subtracting the blade radius section, (b) Subtracted blade nR section, (c) Constructing the blade radius section close loop boundary line and (d) Projecting the hydrofoil profile to Z-X plane

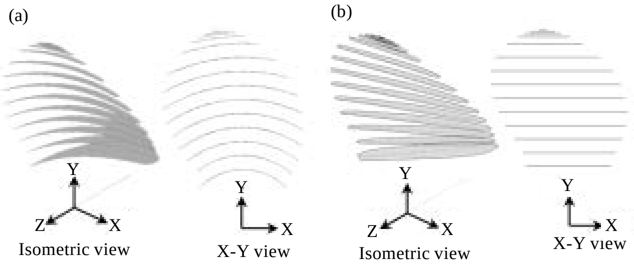

Fig. 5(a-b): Series of (a) Wrapped and (b) Projected hydrofoil profiles

located at the radius ratio of r/R = 0.7 or written as 7R. Therefore, the propeller nominal parameters are measured at 7R.

Propeller blade geometry characteristics: The propeller blade geometry characterization is carried out by comparing each of the sectional blades layout as in the Fig. 6 with the ITTC propeller geometric terminology and definition addressed in Fig. 7. The 7R sectional blade properties are as clearly defined in the Fig. 8.

For a defined nR hydrofoil pitch angle, the pitch distance value is determined as:

$$P^R = \tan(2\pi.\phi^R.nR) \qquad (1)$$

Table 1: '9.25×8J1' propeller blade radius section characteristics

r/R	Pitch distance, P (mm)	Pitch angle (ϕ)	Chordline, c (mm)	Skew distance, S (mm)	Rake, iG (mm)
0R	260.40	50.02	79.06	1.15	1.43
1R	251.09	42.92	78.34	1.23	3.18
2R	246.14	37.42	83.06	-0.21	5.25
3R	237.59	32.47	86.91	-1.55	7.55
4R	233.68	28.80	86.63	-3.53	9.17
5R	221.29	24.90	87.89	-5.87	10.53
6R	210.18	21.69	84.33	-8.23	12.05
7R	203.26	19.31	77.51	-10.46	13.86
8R	196.65	17.29	65.51	-12.85	15.35
9R	180.70	14.81	46.41	-14.64	16.53
9.5R	187.40	14.80	31.73	-15.16	17.15
9.75R	177.53	13.81	22.19	-15.46	17.61

Hence, the '9.25×8J1' propeller nominal and blade sectional parameters are defined and tabulated in the Table 1.

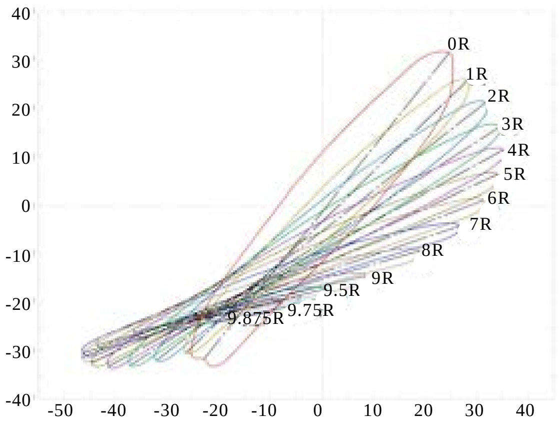

Fig. 6: 9.25×8J1 propeller blade sectional hydrofoil profiles

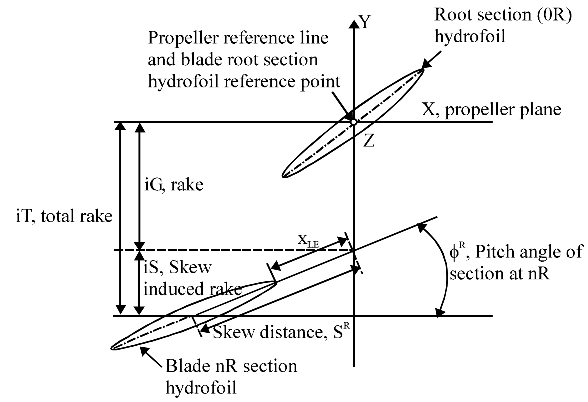

Fig. 7: Propeller blade sectional terminology and nomenclature

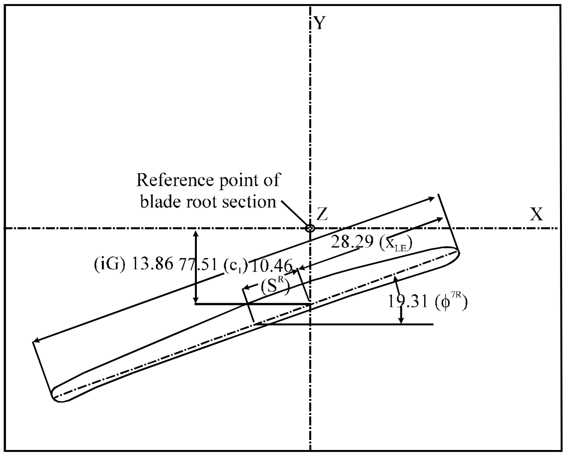

Fig. 8: 7R hydrofoil profile cross-section of 9.25×8J1 propeller

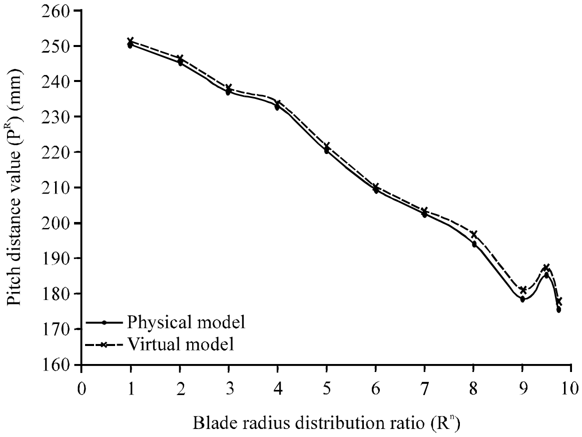

Fig. 9: Pitch distance value against propeller blade radius distribution ratio

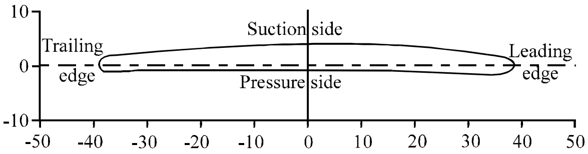

Fig. 10: 9.25×8J1 propeller nominal hydrofoil profiles characteristic

The comparison of the pitch distance measurement value between the virtual and physical model can be shown as in the Fig. 9. The physical model pitch distance measurement value is obtained accordingly to the pitch meter method. Significantly, the virtual model values are larger than the physical model values. By referring the values from 9.75R and the physical model value as reference, the virtual model value averages an error of 0.83%. The average error of 0.83% or less than 1.95 mm in this case is acceptable. However, if to compare the evaluation of machining end product and its tool path accuracy, an error of more than 1.0 mm over 250.0 mm shall not be acceptable. In case of high precision machining, error percentage is acceptable at level of units of micrometer. Further calibration on 3-D scanning system is required to enhance the measurement accuracy.

SECTIONAL HYDROFOIL PROFILE PROPERTIES

Besides defining the blade geometry characteristics, the process will also provide data for each of the radius sectional hydrofoil profile, either in the graphical form or 2-D coordinate data. In Fig. 10, the 9.25×8J1 propeller blade radius sectional hydrofoil of the 7R blade sectional

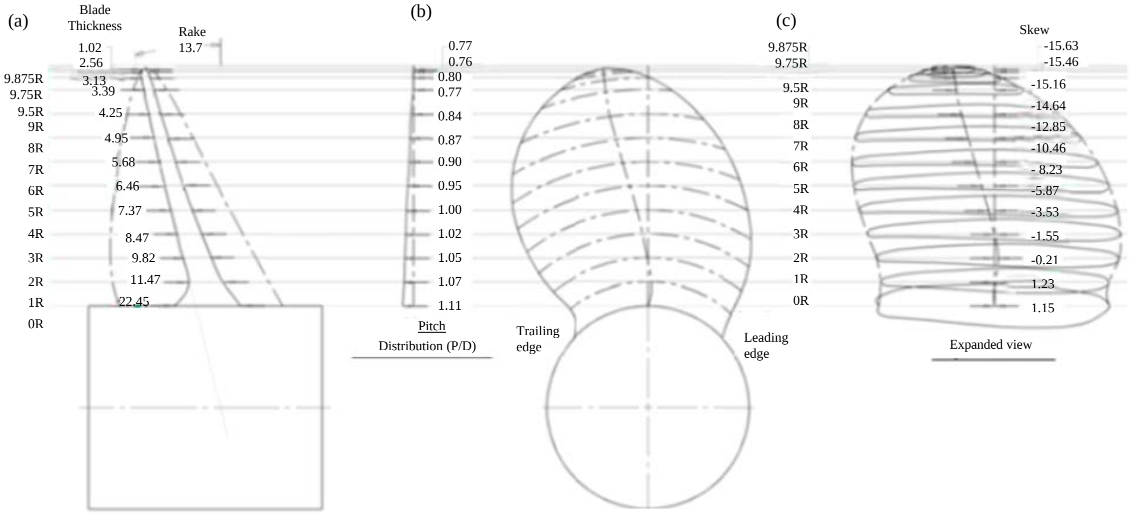

Fig. 11(a-c): 9.25×8J1 propeller design drawing, (a) Profile, (b) Transverse and (c) Expanded view

is defined. For this propeller blade hydrofoil profile, the entire pressure side is a concave shape, while a part of the suction side towards the trailing edge is a convex shape and another part towards the leading edge being concave in shape.

PROPELLER BLADE DRAWING

Generally, the marine propeller geometry properties or parameters are presented in a standard drawing presentation to translate it as a common language to the community. The standard drawing include the pitch distribution, profile, transverse and expanded view to completely define the propeller geometry properties. The standard drawings of 9.25×8J1 propeller are shown in the Fig. 11.

CONCLUSION

An introduction of systematic and sustainable methodology of marine propeller geometry characterization had been presented. The characterization methodology is a non-contact method involving the conversion of physical model to 3-D virtual model through 3-D scanning system and computer aided drawing application tool. The effectiveness of this methodology is demonstrated by characterizing the '9.25×8J1' outboard marine propeller geometry properties has resulted an acceptable error. It is a feasible and cost saving method as a solution for non-existing specialize facility. Thus, the characterizing process has concluded successfully by presenting the obtained geometry parameters into the standard propeller design drawing.

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