Sixth International Symposium on Marine Propulsors
smp'19, Rome, Italy, May 2019

Critical values of Rn defining transitional flow to be applied in the extrapolation of Open Water Tests (OWT) of unconventional tip shaped propellers.

Ramón Quereda[1], Luis Bernal[1], Mariano Pérez-Sobrino[2], Juan González-Adalid[2]

[1]INTA-CEHIPAR, El Pardo Model Basin, Madrid, Spain (queredalr@inta.es). [2]SISTEMAR, Madrid, Spain (mps@sistemar.com)

ABSTRACT

This paper presents an improvement of the procedure based in the strip method to compute OWT corrections already presented. In this method it is necessary to establish the type of flow developed on each blade section and to apply corresponding formulations for viscous resistance coefficient. The values of critical Reynolds number (R_n) that define the flow as laminar, transitional or turbulent have been reviewed and a new validation process has been performed. Two criteria have been established for the validation:

Criterion for conventional propellers: corrections obtained with this method for conventional propellers have to match reasonably the values obtained with ITTC'78-PPM within a small tolerance;

Criterion for unconventional propellers: corrections obtained for unconventional propellers must produce full scale predictions in accordance with sea trials results. As in the former version of the method just CLT propellers cases are available to the authors.

Results of model paint tests and CFD calculations have been taken into account for this validation.

Several conclusions and recommendations on the advantages of the proposed extrapolation method are presented at the end of the paper.

Keywords

Propellers performance prediction, Open Water Tests, propellers scale effects, unconventional tip blade shape.

1 INTRODUCTION

OWT (Open Water Tests) corrections used in ITTC'78-PPM are based in the approach of the equivalent profile that identifies the behaviour of the blade with the blade cylindrical section at 0,75R. With this approach it is impossible to distinguish advanced forms of blade propellers like end plate, tip raked, etc. Last ITTC Reports on propellers have recognized that this method cannot be applied to others than conventional propellers.

Basic principle to apply corrections to OWT model results is the different Reynolds number (Rn) of the model tests compared to full scale operation. That means that viscous effects in propeller blades are also different (Pérez-Sobrino et al 2016a). As consequence propeller open water parameters K_T and K_Q measured at model scale must be corrected to obtain appropriated values to be used for predictions at full scale.

Three main approaches have been published in recent years trying to contribute to solve this problem:

A) Semi-empirical methods: Are based on the addition of new correlation coefficients for propeller blade and for end plate to the formulation used in ITTC'78-PPM. These coefficients have been adjusted to obtain a good correlation with sea trials results.

B) Strip methods: The scaling is achieved by dividing the propeller in a series of chord-wise "strips", by calculating the "local" scale effects on each strip, and finally by integrating the "local" scale effects in order to obtain the "global" propeller scale effects.

C) CFD based methods: General approach is to compute independently for model scale and full scale cases and correlate the results. There exist several possible computer codes that usually imply to prepare different mesh types and sizes, different turbulent models, etc., being at the moment large resources and time consuming. In addition to that, different benchmarking exercises performed have shown that the final results depend to high degree not only on the code itself but also on the user of the code.

Present method belongs to approach "B" and has been validated mainly with data available to the authors. It would be encouraging if other institutions having more data of different ships and propeller types could use this method checking and communicating their results.

2 DESCRIPTION OF THE OPEN WATER SCALING PROCEDURE

Firstly, a brief summary of the way to compute OWT corrections in ITTC'78-PPM is presented with the only purpose of making clear comparisons.

2.1 Open Water Tests corrections according to ITTC'78-PPM

The propeller characteristics $K_T(J)$ and $K_Q(J)$ obtained in Open Water model test have to be scaled to full scale using the following expressions:

$$K_{TS} = K_{TM} - \Delta K_T \quad (1)$$

$$K_{QS} = K_{QM} - \Delta K_Q \quad (2)$$

Where ΔK_T and ΔK_Q are computed from ΔC_D:

$$\Delta K_T = -\Delta C_D \cdot 0.3 \cdot \frac{P}{D} \cdot \frac{c \cdot Z}{D} \quad (3)$$

$$\Delta K_Q = \Delta C_D \cdot 0.25 \cdot \frac{c \cdot Z}{D} \quad (4)$$

And the increment of drag coefficient ΔC_D is:

$$\Delta C_D = C_{DM} - C_{DS} \quad (5)$$

where

$$C_{DM} = 2\left(1 + 2\frac{t}{c}\right)\left[\frac{0.044}{(R_{nco})^{\frac{1}{6}}} - \frac{5}{(R_{nco})^{\frac{2}{3}}}\right] \quad (6)$$

and

$$C_{DS} = 2\left(1 + 2\frac{t}{c}\right)\left(1.89 + 1.62 \cdot log\,\frac{c}{k_p}\right)^{-2.5} \quad (7)$$

All these formulae have been derived by using the equivalent profile theory that is a simplification of the blade element theory applied to the station x= 0.75.

The condition that R_{nco} must not be lower than $2x10^5$ at the OWT is the criterion generally accepted in order to avoid that laminar flow which will be developed over the blade. But as this condition is usually applied to section 0.75R this not assures that there is not a significant part of the blade with laminar flow at lower radius.

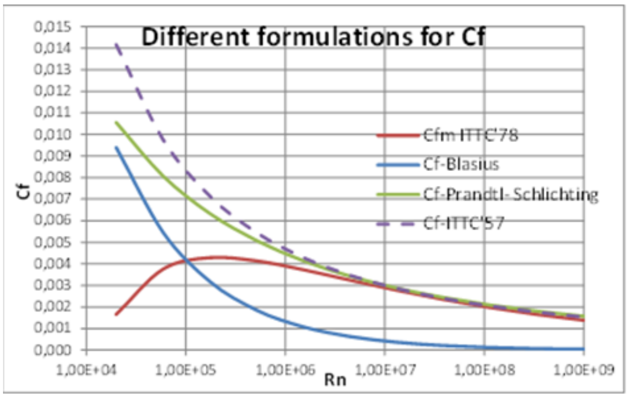

Figure 1: Comparison of different formulae for CF.

2.2 Summary of the strip method for OWT scaling

Pérez-Sobrino et al (2016a) presented the so called SISTEMAR strip method in detail. The summary of the method is to obtain the OWT corrections by integration of the corrections obtained at each blade and eventually end plate sections, by using the following expressions:

$$\delta K_T = -\frac{z}{2}\int_{x_{hub}}^{x_{tip}} \delta(C_D) \cdot [J^2 + (\pi x)^2] \cdot \frac{c}{D} \cdot sen\varphi \cdot dx \quad (8)$$

$$\delta K_Q = \frac{z}{4}\int_{x_{hub}}^{x_{tip}} \delta(C_D) \cdot [J^2 + (\pi x)^2] \cdot \frac{c}{D} \cdot cos\varphi \cdot x \cdot dx \quad (9)$$

The differences in the viscous drag coefficient will be calculated from the respective frictional coefficients of the blade sections at model and ship scales:

$$\delta(C_D) = C_{Dm} - C_{Ds} \quad (10)$$

$$C_{Dm} = 2 \cdot \left(1 + 2\frac{t}{c}\right) \cdot C_{Fm} \quad (11)$$

$$C_{Ds} = 2 \cdot \left(1 + 2\frac{t}{c}\right) \cdot C_{Fs} \quad (12)$$

As the R_n is very different during model tests compared to full scale, the main question of these methods is how to compute the frictional coefficient, C_F, as a function of the type of flow developed over each blade section. In figure 1 there is a comparison of different formulations for C_F. Figure 2 presents the scheme of how different types of flow can be developed over a blade section as R_n increases.

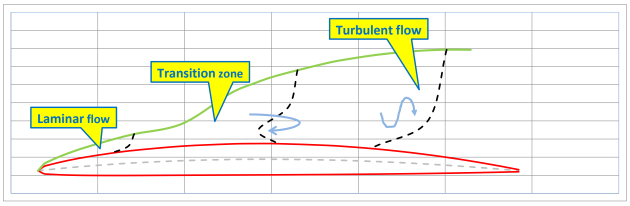

Figure 2: Scheme of flow developed over the blade sections.

Figure 3 shows the division of the blade in strips to compute the scale effects of each element.

Figure 3. Division of propeller blade in strips.

When flow can be considered as laminar, the formula to be used is the well-known expression due to Blasius for laminar boundary layers on smooth surfaces:

$$C_{Fm} = \frac{1{,}3282}{\sqrt{R_n}} \quad (13)$$

For fully turbulent flow the well-known formula due to Prandtl and Schlichting for smooth plates can be used both for model and for full scale.

$$C_{Fs} = \frac{0{,}455}{(\log R_n)^{2{,}58}} \quad (14)$$

In the already mentioned reference (Pérez-Sobrino et al 2016a) it is explained that flow can be considered turbulent if the section R_n is larger than this critical number:

$$R_{n\,critical\,turbulent} = 415 \cdot \frac{c}{k_p} \quad (15)$$

The value of the constant (415), used in equation 15, has been obtained comparing the nominal size of the roughness grain of a section profile with the boundary-layer thickness, and it has been established that this criterion agrees very well with existing experimental data. This criterion is valid both at model and full scales.

In this paper and after the analysis and validation carried out from the first version of this method, it has been considered that flow will be laminar at ship scale until the value of R_n = 2x10^5 which is a limit value generally accepted for the laminar flow in profiles.

$$R_{n\ crit\ lam-trans\ (ship)} = 2.0 \cdot 10^5 \qquad (16)$$

But at model scale both paint tests and CFD calculations have shown that flow developed over the blades is quite different mainly in the upper part of the blade, figure 4, for conventional and unconventional propellers.

CONVENTIONAL UNCONVENTIONAL(CLT)

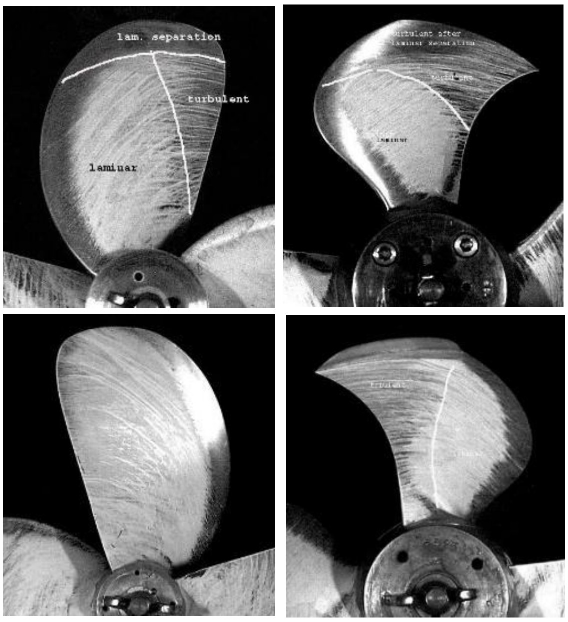

Figure 4. Paint tests results.Taken from R&D Project "LEADING EDGE"

In order to take also into account the differences in diameter, rps of the OWT and the roughness of the blades, similar expressions to equation 15 have been derived for conventional and unconventional blades.

For conventional blades:

$$R_{n\ crit\ lam-trans\ (model-CONV)} = 42 \cdot \frac{c}{k_p} \qquad (17)$$

It has been deduced from model paint tests and CFD calculations that the extension of laminar zone in unconventional (CLT) propellers is smaller than in the case of conventional propellers, so critical $R_{n,}$ to define laminar zone, must be smaller for unconventional (CLT) propellers.

For unconventional blades:

$$R_{n\ crit\ lam-trans\ (model-UNCONV)} = 30 \cdot \frac{c}{k_p} \qquad (18)$$

In the middle of these two sectional critical R_n numbers (so for R_n larger than $R_{n\ crit\ lam-trans}$ but smaller than $R_{n\ crit\ turbulent}$) the flow over the blade profiles is in a so called transition zone, where there exists some uncertainty about the value of C_F.

In fact, flow would be partially laminar and partially turbulent along the chord of the section, see figure 2, and probably somehow different in pressure side or suction side. This method proposes to interpolate with actual R_n of the section between the C_F values corresponding to laminar and turbulent limits. In this way the proposal does not include any specific friction line for transition zone but values of C_F in transition zone depend on each specific case and section data.

3 ITTC BENCHMARKING OF CFD CALCULATIONS OF OPEN WATER SCALE EFFECTS.

The propulsion committee of the 27th ITTC conference carried out a benchmark test for CFD calculations, then continued by the propulsion committee of 28th ITTC, (Grabert et al SVA-2016), with the intention to investigate the capabilities of CFD to predict scale effects on the propeller performance. Two different types of propellers had to be investigated, a conventional and an unconventional propeller. This exercise belongs to the approach C mentioned in the introduction of this paper.

The unconventional propeller P1727 was a design of SVA Postdam for other research project, being a Tip Raked propeller type. 16 institutions participated in the exercise, 14 of them provided calculations for the conventional propeller VP1304 and 13 participants for the Tip Raked propeller P1727.

The exercises consisted in the comparison of CFD calculations at model scale with CFD calculations at full scale; model tests results have been also performed and supplied in the final report as well as the extrapolation by ITTC'78 scaling method. Each participant used its own solver and procedure, including different modelizations of transient approximation and turbulent treatment. A complete statistical analysis is presented in the mentioned report.

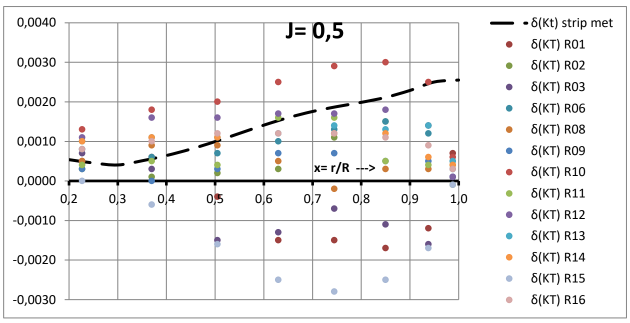

Figure 5. Comparison of scale effects in δK_T

In this section a comparison of the Open Water scale effects computed by CFD codes and the results of the SISTEMAR strip method for P1727 are presented. In figure 5 the scale effects in K_T are plotted.

In figure 6 the scale effects in $10K_Q$ are plotted. δK_T and $\delta(10K_Q)$ of these figures correspond to the definitions of equation 1 and equation 2 computed for J=0.5.

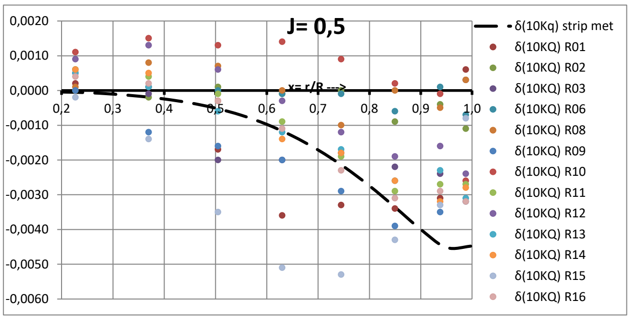

Figure 6. Comparison of scale effects in δ(10KQ)

It is evident that the dispersion of these results is quite large so confirming what has been said of the "C" type approaches in the introduction of this paper, about the use of CFD codes to compute the scale effects of OWT.

But in addition it can be seen that the trend of the distribution of the additive scale effects components of the blade sections are quite similar for most of the cases of CFD and SISTEMAR strip method. Due to the physics of the problem it may be expected that in these cases δK_T will be positive while $\delta(10K_Q)$ will be negative; some CFD calculations give different results but they have not been well explained.

4 VALIDATION OF SISTEMAR STRIP METHOD.

The procedure has been validated by analysing a comprehensive set of OWT results, both for conventional and end plate tip loaded (CLT) propellers available to the authors. Two criteria have been established for the validation:

Criterion for conventional propellers: corrections obtained with present method for conventional propellers have to match reasonably the values obtained with ITTC'78-PPM within a small tolerance. ITTC'78-PPM has been used for conventional propellers during many years by many institutions producing accurate predictions; so it seems a good criterion that a new procedure should give similar results.

Criterion for unconventional propellers: corrections obtained with present method for unconventional propellers must produce full scale predictions in accordance with sea trials results.

4.1 Conventional Propellers

A comprehensive set of calculations with conventional propellers, covering a wide range of number of blades, area and pitch ratios, have been carried out in order to show that this method generates practically same values of corrections as ITTC'78-PPM for conventional propeller cases.

4.1.1 Propellers data

A reduced set of the original data base, used in (Pérez-Sobrino et al 2016a), are presented here for validation purposes of the method with conventional propellers.

This set of propellers covers the normal values of number of blades (Z), Disc area ratio, Pitch ratio and design RPM of conventional propellers.

Table 1. Conventional propellers used for validation.

CONV	Full scale data					Model test data		
prop ID	z=	D, m	Ae/Ao	P/D 0,75R	RPM design	Scale	RPS OW test	Dmod, mm
2197	4	5,900	0,620	0,723	97,4	28,800	18,00	204,86
2204	4	6,100	0,600	0,698	97,4	26,700	16,00	228,46
2480-CPP	4	4,200	0,580	0,989	147,3	23,770	17,68	176,69
2429	5	8,470	0,583	0,96	220,0	36,385	11,00	232,79
2495	5	8,250	0,780	1,013	90,0	38,913	15,00	212,01
2514	5	8,700	0,780	0,9	84,4	39,430	18,00	220,64
1697	6	4,800	0,800	0,83	122,0	21,500	14,00	223,26
2174	6	6,000	0,802	1,099	85,0	27,000	11,50	222,22
1822	6	6,520	0,767	0,767	97,0	31,000	14,00	210,32

4.1.2 Comparison of SISTEMAR strip method with ITTC'78-PPM calculations.

To compare calculations of OWT scale effects using this strip method with results of ITTC'78-PPM next ratios have been calculated:

$$Ratio\ K_T = \frac{K_{TS\,(str\ meth)} - K_{TS\,(ITTC'78-PPM)}}{K_{TS\,(ITTC'78-PPM)}}\ (\%)$$

$$Ratio\ 10K_Q = \frac{10K_{QS\,(str\ meth)} - 10K_{QS\,(ITTC'78-PPM)}}{10K_{QS\,(ITTC'78-PPM)}}\ (\%)$$

$$Ratio\ \eta_0 = \frac{\eta_{0S\,(str\ meth)} - \eta_{0S\,(ITTC'78-PPM)}}{\eta_{0S\,(ITTC'78-PPM)}}\ (\%)$$

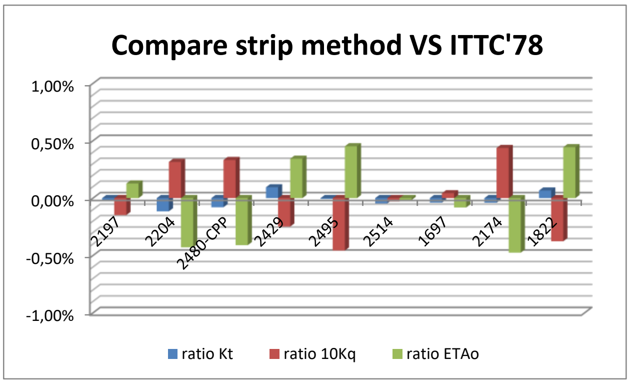

Figure 7. Distribution of comparison ratios used for validation of CONVENTIONAL propellers.

The dispersion of these ratios is presented in figure 7. All these ratios are in the interval [-0.5%, +0.5%] confirming that the strip method is practically equivalent to the application of ITTC'78-PPM for calculation of OWT scale effects of conventional propellers.

4.2 Unconventional CLT Propellers

Validation of this strip method for unconventional propellers must be done correlating predictions obtained by applying it to OWT with sea trials results.

To carry out this exercise of prediction from model tests to full scale it is necessary that a full set of model tests data and sea trials results be available. Unfortunately, the authors only have data of their own projects with CLT propellers to perform this correlation.

Pérez-Sobrino et al (2016a and 2016b) presented several cases including all necessary data at model and full scale. One of the most representative modern cases is a series of four sister ships LEG carriers of 12000 m^3 delivered in a reduced space of time. Detail data have been presented by González-Adalid et al (2016). Extrapolations have been carried out by both procedures, present strip method and ITTC'78-PPM, and these correlation calculations show that SISTEMAR strip method gives more accurate predictions.

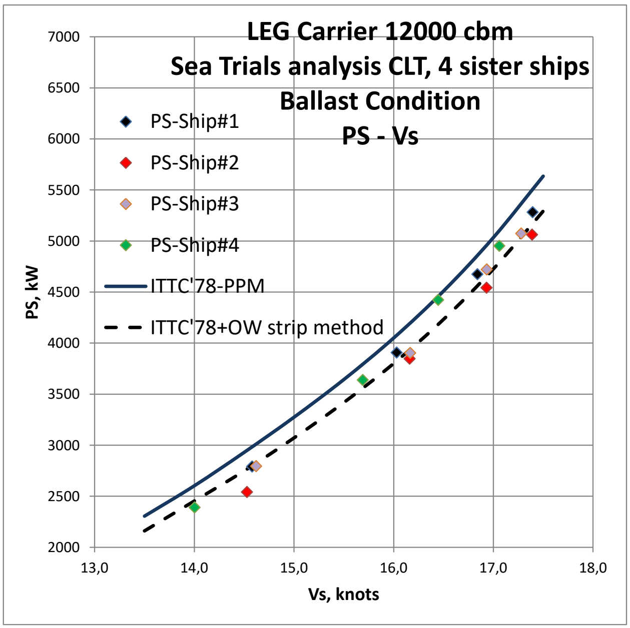

Figure 8. Comparison of full scale predictions using ITTC'78-PPM versus SISTEMAR Strip Method.

5 CONCLUSIONS

In the reports of Propellers Committees of last ITTC's have been clearly stated that ITTC'78-PPM is not applicable to unconventional tip shape propellers. But in section 3 of this paper and in others similar exercises it is also clear that, at this time, there is not a procedure that could be recommended for general use, to compute the scale effects in OWT based in CFD calculations

However, methods based in strip blades calculations like this, going a step deeper than ITTC'78-PPM in the basic principles of viscous effects, and take the complete blade geometry into consideration have several advantages:

1.- Are easy to implement in any prediction method based in model tests results like ITTC'78-PPM or similar methods used by towing tanks and other institutions.

2.- Compute with reasonable accuracy scale effects to be applied to OWT to predict propulsion characteristics of conventional and unconventional propellers, mono-block or CPP type.

3.- Have a repetitive character, so same values for propellers scale effects will be obtained for different users with the same input data. This is not the case when using CFD codes because of complication of the codes and differences among users and the implemented features of each code.

The fact is that at present and from several years ago there not exists a recommended method to compute scale effects of model tests of unconventional propellers. Every institution (towing tanks, design offices, designers…) apply each own procedure which yield very different results. This is a clear source of uncertainty that can be seen from the point of view of the ship operators as a lack of reliability.

It is important to get a general agreement on the use of practical methods allowing that the results obtained with unconventional propellers can be analysed and compared with other conventional designs.

Authors consider that the non-existence of a method generally accepted is a barrier to development of unconventional propellers that in many cases have proven to be more efficient than the conventional ones. In spite of that the level of implementation of advanced unconventional propellers does not correspond with the propulsive advantages that can produce in efficiency and gases emissions.

Authors do not know detailed published data of model tests and sea trials of other unconventional propellers. It is expected that interested institutions will apply this method to their own projects and publish the corresponding results in order to confirm the validity of this procedure.

REFERENCES

González-Adalid, J. et al. (2016).“Propulsion Optimization of a Series of Liquified Ethane Gas Carriers Including CLT Propellers”. 38th Motorship Propulsion & Emissions Conference, Hamburg, Germany, 11-12 May 2016.

Grabert, R., Lübke, L., Klose, R., and Barkmann, U.(2016). SVA Report 4487. ITTC Propeller Benchmark – Tip Rake Propeller –P1727.

ITTC'78-PPM. ITTC [International Towing Tank Conference], (1978) Performance Prediction Method. ITTC-Recommended Procedures and Guidelines 7.5-02-03-01.4. Revised 2011.

Morán-Guerrero, A. et al. (2018). “On the influence of transition modelling and crossflow effects on open water propeller simulations”

Pérez-Sobrino, M., et al. (2016a). “Scale effects in open water test results for performance prediction of conventional and unconventional propellers”. Ingeniería Naval Académica. 2016. (Nº 5). Download available in web: “http://sectormaritimo.es/numero-5-abril2016”. ISSN: 2340-4779.

Pérez-Sobrino, M., et al. (2016b). “A new performance prediction procedure for propellers with unconventional tip shape”. 12th International Conference on Hydrodynamics, 18 – 23 September 2016, Delft, The Netherlands. Paper ID: 73.