ITTC Quality System Manual
Recommended Procedures and Guidelines

Guideline

Scaling Method for ship wake fraction with pre-swirl devices

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1. PURPOSE OF GUIDELINE

The purpose of the guideline is to complement the ITTC 1978 procedure for the prediction of the delivered power and rate of revolutions for single and twin screw ships with either PSS (Pre-Swirl Stator) or PSD (Pre-Swirl Duct) being installed.

2. DESCRIPTION OF GUIDELINE

2.1 Introduction

With a view to reducing EEDI of marine vessels, various kinds of ESD (Energy Saving Device) have been devised to improve propulsive efficiency. Typical ESDs are PSS (Pre-Swirl Stator), PSD (Pre-Swirl Duct), CRP (Contra Rotating Propeller), PBCF (Propeller Boss Cap Fin), etc.

PSS, which is located in front of the propeller, improves the propulsion efficiency through the recovery of rotational energy generated during propeller rotation, making a counter-swirl flow against the tangential velocity caused by the propeller. The device achieves about 5% reduction in energy consumption (Lee *et al.* 1994). PSD, which also is located in front of the propeller, consists of two ESD: PSS and duct. The device makes the oncoming flow more uniform to the propeller. Although the performance varies according to ship type and operating condition, its energy reduction effect is about 3% to 6% (Mewis and Guiard 2011; Dang 2012; Shin *et al.* 2013; Song *et al.* 2015).

The powering performance prediction method for the model test of conventional ship has been established by ITTC successfully in 1978. The ITTC 1978 method has been applied to the single screw conventional ships. However, the ITTC 1978 method has a limitation for extrapolation method for such a pre-swirl device. The newly proposed so called ITTC 1999 method is also not clear in the physics of flow mechanism around propeller section.

2.2 Flow characteristics around pre-swirl device and propeller

Pre-swirl device generates a counter swirl flow to save rotational energy from propeller. For the prediction of powering performance, ITTC 1978 method adopts the thrust identity method to find out the effective mean wake fraction. As shown in Figure 1, the angle of attack α depends on the inflow velocity on propeller plane (U_A) and the rotational velocity ($2\pi nr$) if the induced velocity is neglected. If the rotational velocity (speed of revolution) is kept same as in the POW (Propeller Open Water) condition and in the propeller behind ship condition, the inflow velocity is therefore colinear to the thrust. The counter swirl flow generated will be of potential nature rather than viscous.

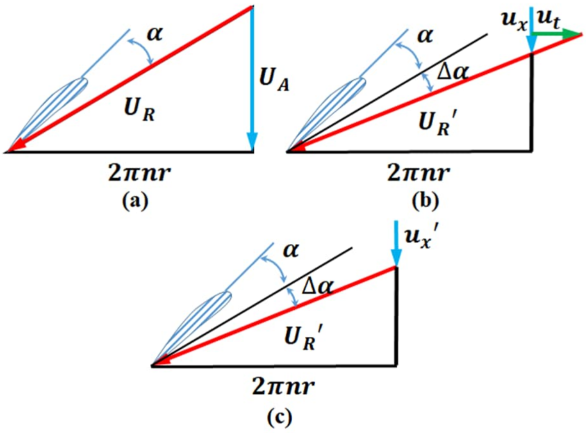

Figure 1: Change of inflow angle at the propeller blade section due to the induced velocity of the ESD

The difficulty in scaling arises from the point that the pre-swirl device makes not only a counter swirl but also axial flow retardation. It is therefore necessary to decompose the axial and tangential components separately. As shown in Figure 1 (b), the presence of pre-swirl device causes the relative velocity to propeller blade to change as U_R' with increased angle of attack $\alpha + \Delta\alpha$, thereby increasing thrust. Therefore, the open water characteristics of the compound propulsor (propeller & pre-swirl device) become different from that of propeller only. If the scaling is applied to the total amount of model wake based on the thrust identity defined in the ITTC 1978, this might result in overestimating axial induced velocity u_x', as depicted in Figure 1 (c). Thus, the increase in thrust due to both axial and tangential induced velocity might be misinterpreted solely by the axial induced velocity by ITTC 1978 method.

2.3 ITTC 1999 method: background and limitation

This so-called “ITTC 1999 method” does not actually belong to the ITTC recommended procedures and guidelines. This was introduced in the 22nd ITTC final report of the Specialist Committee on Unconventional Propulsors (ITTC 1999).

The combined propulsor, such as PSS – propeller system, can be analyzed with two kinds of method shown in Figure 2. In method A, the pre-device is considered as a combined propulsor, which means the pre-device and propeller are treated as a whole propulsor. This assumption implies that in both open water and self-propulsion tests, the thrusts of propeller and stator are measured simultaneously and their sum is used as the thrust of the propulsion system. The report addressed that the ITTC 1978 procedure fails to scale the performance of unconventional propulsion systems correctly, and this is due to two main causes. The first one is the laminar flow generated around the devices in the model test environment (scale); the second is that the model hull has a boundary layer that differs from the full scale one both in thickness and in velocity distribution.

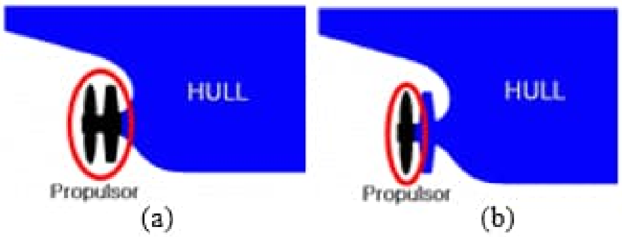

Figure 2: ITTC 1999 Method

In method B, which is commonly referred to as ITTC 1999, the pre-device is considered as a part of hull, therefore the resistance test is carried out with pre-device while the POW test is executed with propeller alone. This procedure does not require the joint test of the stator and the propeller because the stator is tested being considered as the part of the hull. On the other hand, it requires a double set of resistance and self-propulsion tests are done: with and without the stator.

The scaling process is again the two dimensional approach of the ITTC 1957 method with an exception made for the determination of the full-scale wake, which is performed by means of the following formula that closely resembles that suggested by the ITTC 1978 correlation procedure:

$$w_S = (t_{MO} + 0.04) + (w_{MO} - t_{MO} - 0.04)\frac{C_{FS}+C_A}{C_{FM}} + (w_{MS} - w_{MO}) \quad (1)$$

while the standard ITTC 1978 ship wake is:

$$w_S = (t + 0.04) + (w_M - t - 0.04)\frac{(1+k)C_{FS}+\Delta C_F}{(1+k)C_{FM}} \quad (2)$$

The major difference compared with the ITTC 1978 formulation is the term $(w_{MS} - w_{MO})$.

Since in the opinion of Van *et al.* (1993) the main effect of the stator is the increase of the angles of attack of the propeller blade sections, the stator action can be considered as mainly potential phenomenon. Thus, the difference in wakes with and without stator can be directly transferred to full scale.

2.4 Scaling method for pre swirl devices

Lee (2015) carried out a comparative full-scale performance prediction for the pre-swirl devices based on the ITTC 1978 method and the ITTC 1999 method. It was addressed that the ITTC 1978 method has a limitation for extrapolating such a pre-swirl device. The ITTC 1999, a newer procedure which adopts different scaling for the axial and tangential component of wake, has not appear to clarify the flow mechanism around the propeller section. It was then proposed a new extrapolation method which leads to a more reasonable estimate for the angle of attack to the propeller. This approach has been presented by Kim *et al.* (2017) at the 5th International Symposium on Marine Propulsion and the corresponding extrapolation formula is given as follows:

$$w_S = (t_{MS} + 0.04) + (w_{MS,axial} - t_{MS} - 0.04)\frac{C_{FS}+C_A}{C_{FM}} + w_{MS,tangential} \quad (3)$$

$$w_{MS,axial} = w_{MO} + (w_{MS} - w_{MO}) \cdot Factor_{axial} \quad (4)$$

$$w_{MS,tangential} = (w_{MS} - w_{MO}) \cdot Factor_{tangential} \quad (5)$$

This is a compromise between ITTC 1978 and ITTC 1999 in that the axial velocity component and tangential velocity component are scaled separately. The axial wake, being of viscous nature, is scaled following ITTC 1978. On the contrary, the tangential wake, considered as potential flow phenomenon, is not scaled after the assumption of ITTC 1999. In addition, the thrust deduction factor is changed from that without a pre-swirl device in the ITTC 1999 method to that with a pre-swirl device.

It was found that the portions of tangential and axial velocity vary according to the vessel type as well as the device type. As shown in Table 1, Kim *et al.* (2017) proposed the factors of axial and tangential portion to be 0.3 and 0.7 in PSS case and 0.8 and 0.2 in PSD case, respectively. It is worthwhile to mention that the factors in Table 1 have been derived from limited ship types, i.e., KCS for PSS and KVLCC for PSD. Therefore, a generalization toward identifying a reasonable value range for each factor based on case studies with more ship types is necessary.

Table 1: Factors of axial and tangential portion

ESD Type	$Factor_{axial}$	$Factor_{tangential}$
PSS	0.3	0.7
PSD	0.8	0.2

The newly proposed method is then applied to extrapolate model test results for KCS and KVLCC in comparison with ITTC 1978 and ITTC 1999 methods. Whilst the three methods give almost the same values for the thrust deduction factor, the new method (Kim *et al.* 2017) gives the values of the full scale wake, delivered power and speed of revolution between the values given by the ITTC 1978 and ITTC 1999 methods. In case of PSS, the new method gives estimates closer to those by ITTC 1999. On the other hand, the estimated values by the new method for PSD are closer to those by ITTC 1978. As the newly proposed method is based on a limited number of CFD simulation results, and some recent numerical analyses (Nicorelli *et al.* 2023) are not completely in line with the outcomes of Kim *et al.* 2017, it needs to be verified by results obtained using such detailed flow measurement techniques as LDV and PIV. Furthermore, feedback from more comprehensive full-scale data as well as from systematic CFD investigations will be required to establish and refine the extrapolation strategies proposed.

3. PARAMETERS; SYMBOLS

C_A	Model-ship correlation allowance
C_F	Frictional resistance coefficient
$Factor_{axial}$	factor of axial wake portion
$Factor_{tangential}$	factor of tangential wake portion
k	Form factor
n	Propeller rate of revolution
Q	Torque
Re	Reynolds number
t	thrust deduction factor
t_{MO}	model thrust deduction factor without pre-swirl device
t_{MS}	model thrust deduction factor with pre-swirl device
U_A	propeller advance speed (m/s)
U_R	relative inflow velocity (m/s)
u_x	axial induced velocity (m/s)
u_t	tangential induced velocity (m/s)
w_M	model wake fraction defined in ITTC 1978
w_{MO}	model wake fraction without pre-swirl device
w_{MS}	model wake fraction with pre-swirl device
w_S	ship wake fraction
ΔC_F	Roughness allowance
α	angle of attack

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