ITTC Quality System Manual

Recommended Procedures and Guidelines

Guideline

Resistance and Propulsion Test and Performance Prediction with Skin Frictional Drag Reduction Techniques

7.5	Process Control
7.5-02	Testing and Extrapolation Methods
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7.5-02-02-03	Resistance and Propulsion Test and Performance Prediction with Skin Frictional Drag Reduction Techniques

Updated / Edited by	Approved
Specialist Committee on Energy Saving Methods of the 28th ITTC	28th ITTC 2017
Date: 04/2017	Date: 09/2017

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Resistance Test and Performance Prediction Method with Skin Frictional Drag Reduction Techniques

1. PURPOSE OF THE GUIDELINE

The purpose of the procedure is to complement the existing procedures for the resistance and propulsion model tests when the skin frictional drag reduction techniques are employed in the model test to predict the full scale performance. Such techniques include air lubrication, low frictional coating and hull appendages. The existing resistance and propulsion performance prediction method are not applicable in such cases, because the model-ship extrapolation is based on the skin frictional drag coefficient for the "baseline" surface without skin frictional drag reduction.

2. PARAMETERS

2.1 Data Reduction Equations

Total resistance coefficient $$C_\mathrm{T}=\frac{R_\mathrm{T}}{\frac{1}{2}\rho SV^2}$$

Residual Resistance Coefficient

$$C_\mathrm{R}=C_\mathrm{TM}-C_\mathrm{FM}(1+k)$$

Schoenherr Correlation Line (ATTC line)

$$\frac{0.242}{\sqrt{C_F}}=\log_{10}(ReC_\mathrm{F})$$

Froude number $$Fr=\frac{V}{\sqrt{gL}}$$

Depth Froude number $$Fr_h=\frac{V}{\sqrt{gh}}$$

Reynolds number $$Re=\frac{VL}{\nu}$$

2.2 Definition of Variables

C_A	Correlation allowance
C_AA	Air resistance coefficient
C_D	Drag coefficient
C_F	Frictional resistance coefficient
C_FL	Local skin friction coefficient
C_R	Residual resistance coefficient
C_T	Total resistance coefficient
D	Propeller diameter (m)
F_D	Skin friction correction in self-propulsion test
J	Propeller advance coefficient
K_T	Thrust coefficient
g	Acceleration of gravity (m/s^2)
k	Form factor
L	Representative length [normally L_{WL} for Fr and L_{OS} for Re] (m)
R_T	Total resistance (N)
Re	Reynolds number
S	Wetted surface area (m^2)
S_BK	Wetted surface area of bilge keels (m^2)
t	Thrust deduction factor
V	Ship speed (m/s)
w	Taylor wake fraction in general
w_T	Taylor wake fraction, thrust identity
ΔC_F	Roughness allowance
η_D	Propulsive efficiency or quasi-propulsive coefficient
η_H	Hull efficiency
η_O	Propeller open water efficiency
η_R	Relative rotative efficiency
α	Frictional drag reduction factor
ρ	Water density in general (kg/m^3)
λ	Scale factor
ν	Kinematic viscosity (m^2/s)

Subscript "$_\mathrm{M}$" signifies the model scale value.

Subscript "$_\mathrm{S}$" signifies the full scale value.

Subscript "$_\mathrm{BASELINE}$" signifies the case without skin frictional reduction.

Subscript "$_{\text{smooth}}$" signifies the case with smooth surface.

Subscript "$_{\text{SFR}}$" signifies the case with skin frictional reduction.

3. BASIC REMARKS: CATEGORIZATION OF SKIN FRICTIONAL DRAG REDUCTION TECHNIQUES

Skin frictional drag reduction has been noted as an effective way to improve the fuel efficiency of ships. This is because the skin frictional drag is the major resistance component, occupying more than 60% of total resistance for Froude number below 0.15. The most noticeable technique is the air lubrication, where air is injected onto the hull surface to form a bubbly flow or air layer (Jang *et al.* 2014). Application of low frictional anti-fouling coating (Yang *et al.* 2014) could be alternative way to achieve skin frictional drag reduction. Yet another possibility is the surface mounted hull appendage like outer-layer vertical blades array (An *et al.* 2014). Although these techniques vary in the underlying physical mechanism leading to skin friction reduction and the quantitative drag reduction efficiency, they pose a significant common issue performance prediction based on the scaled model test. The extrapolation method in the existing performance prediction procedure is based on the ITTC 57 Model-Ship Correlation Line originated from the ATTC line $\frac{0.242}{\sqrt{C_{\mathrm{F}}}} = \log_{10}(Re \cdot C_{\mathrm{F}})$, which is an empirical skin friction correlation for a smooth surface. Therefore, if a certain skin frictional drag reduction technique is employed in a model test, then the skin frictional characteristics of the model will no longer follow the existing Model-Ship Correlation Line, leading to an incorrect performance prediction of full-scale ship. This draft guideline proposes a new scaling method which can be employed when a skin frictional drag reduction technique is employed in model test.

Depending on the nature of the skin friction techniques, different extrapolation methods need to be employed. In the present guideline, the skin friction techniques are to be divided into two categories; homogeneous and inhomogeneous.

In the homogeneous category, the entire surface characteristics are modified so that the skin frictional drag reduction occurs everywhere. Low frictional coating falls in this category. In this category, the presence of drag reduction mechanism at a particular location is scarcely affected by the local conditions such as pressure gradient, surface curvature, etc. In addition, the skin friction reduction effect can hardly be switchable, so the comparison between model tests with skin friction reduction (hereinafter called as "SFR" test) and without skin friction reduction (hereinafter called as "BASELINE" test) would require two identical models. This is however, impractical in most cases, so the comparison between two states needs to be performed in a canonical flow around simpler geometry, i.e., a total drag measurement of a towed flat plate or a floating-element skin friction measurement in a turbulent boundary layer developing in a circulating water tunnel. The advantage of canonical test is that the "BASELINE" test result as well as the "SFR" test result can be compared with the empirical correlation such as the ATTC line $\frac{0.242}{\sqrt{C_{\mathrm{F}}}} = \log_{10}(Re \cdot C_{\mathrm{F}})$ for a smooth surface.

In the inhomogeneous category, the boundary layer is influenced locally and the skin friction effect takes place at a certain locations. Air lubrication, polymer injection and replaceable hull appendage belong to this category. Taking air lubrication for example, the local skin friction greatly varies whether the injected air layer is present or not in the immediate vicinity of the location at question. Since the drag reduction mechanism (presence of injected air/polymer, interaction between appendage and boundary layer) is strongly affected by the local conditions, the drag reduction effect can't be quantified in terms of canonical flow measurement. Also the skin friction reduction effect to can be turned "ON" and "OFF" in this category. Therefore, a single model would suffice for both SFR test and BASELINE test. In this draft guideline, attention is paid to set up a procedure to carry out model test and then to extrapolate to full scale for the inhomogeneous techniques.

4. DESCRIPTION OF PROCEDURE: RESISTANCE TEST FOR INHOMOGENEOUS TECHNIQUES

Resistance tests are conducted to provide data from which the resistance of the model hull at any desired speed may be determined. For this purpose, the model resistance and its speed through the water are simultaneously measured. The running attitude of the model - i.e. the sinkage fore and aft, or the running trim and sinkage - is usually also measured.

The resistance (or drag) is the horizontal component of the force opposing the steady forward motion of the model hull. The resistance is determined by measuring a towing force.

4.1 Model and Installation

4.1.1 Model

The model should generally follow the ITTC Recommended Procedure 7.5-01-01-01, Ship Models and 7.5-02-02-01, Resistance Test. Model tests with skin frictional drag reduction inherently require comparison between test with skin friction reduction (SFR" test) and without skin friction reduction ("BASELINE" test).

Care must be taken to ensure that the skin frictional reduction apparatus such as air injection hole(s) and hull appendage installation slot(s) have minimal influence on the resistance measured during the BASELINE test. In other words, the hull surface of the model during the BASELINE case should be maintained as smooth as possible, devoid of any noticeable step and discontinuity.

4.1.2 Test Condition

Models should be tested in both of the following conditions:

1. "BASELINE" test. This is intended to determine the resistance coefficients of the baseline case
2. "SFR" test. This test is intended to determine the decrease in resistance coefficients due to the skin friction reduction technique applied.

4.1.3 Installation

The model(s) should be run at the correct calculated displacement. For model installation and trimming see ITTC Recommended Procedures 7.5-01-01-01, Ship Models and 7.5-02-02-01, Resistance Test.

4.2 Measurement Systems

In case of resistance test, this should comply with the ITTC Recommended Procedure 7.5-02-02-01, Resistance Test.

4.3 Instrumentation

This should comply with the ITTC Recommended Procedure 7.5-02-02-01, Resistance Test.

4.4 Calibration

This should comply with the ITTC Recommended Procedure 7.5-02-02-01, Resistance Test.

4.5 Test Procedure and Data Acquisition

This should comply with the ITTC Recommended Procedure 7.5-02-02-01, Resistance Test.

4.6 Data Reduction and Analysis

The speed, resistance, sinkage and trim and any other continuously recorded quantities of the test should be presented as mean values derived from an integration of the instantane-ous measured values over the same measuring interval (chosen according to the guidelines in section 3.5.1 and 3.5.2 of the ITTC Recommended Procedure 7.5-02-02-01, Resistance Test.), with the appropriately averaged zero measurements subtracted from the average values.

Total resistance and residuary resistance coefficients, together with Froude Number, are calculated for each speed using the data reduction equations given in Section 2.1.

Resistance $R_{\mathrm{TM,BASELINE}}$ measured in the "BASELINE" resistance tests is expressed in the non-dimensional form

$$C_{\mathrm{TM,BASELINE}} = \frac{R_{\mathrm{TM,BASELINE}}}{\frac{1}{2}\rho_{\mathrm{M}} S_{\mathrm{M}} V_{\mathrm{M}}^2}$$

Details regarding the evaluation of S_M and ρ_M should be referred to the ITTC Recommended Procedure 7.5-02-02-01, Resistance Test. Similarly, Resistance $R_{TM,SFR}$ measured in the "SFR" resistance tests is expressed in the non-dimensional form

$$C_{\mathrm{TM,SFR}} = \frac{R_{\mathrm{TM,SFR}}}{\frac{1}{2}\rho_{\mathrm{M}} S_{\mathrm{M}} V_{\mathrm{M}}^2}$$

The residuary resistance of the ship is calculated from the 'BASELINE' tests without skin friction reduction assuming the form factor to be independent of scale and speed. The residuary resistance can therefore be calculated as:

$$C_{R,BASELINE} = C_{TM,BASELINE} - (1+k)C_{FM,BASELINE}$$

where $C_{\mathrm{FM,BASELINE}}$ is derived from the ATTC line as follows;

$$\frac{0.242}{\sqrt{C_{\mathrm{FM,BASELINE}}}} = \log_{10}\left(Re\ \ C_{\mathrm{FM,BASELINE}}\right)$$

The reason why the ATTC line is adopted instead of the ITTC 57 Model-Ship Correlation Line is that the physically meaningful skin frictional characteristics is required to give a correct estimate of the amount of skin friction reduction in the consequent comparison with the SFR test results. It should be kept in mind that the ITTC 57 Model-Ship Correlation Line does not represent the actual skin frictional coefficient especially in low Reynolds numbers.

The form factor is determined from low speed tests as described in Section 3.6.2 of the ITTC Recommended Procedure 7.5-02-02-01, Resistance Test.

The difference between the total resistance coefficients from the "SFR" test and the "BASELINE" test gives the frictional drag reduction factor α, assuming that the residuary resistance is not affected by the reduced skin frictional drag.

$$C_{\mathrm{R,SFR}} = C_{\mathrm{TM,SFR}} - (1+k)C_{\mathrm{FM,SFR}}$$

$$C_{\mathrm{R,BASELINE}} = C_{\mathrm{R,SFR}}$$

$$C_{\mathrm{TM,BASELINE}} - (1+k)C_{\mathrm{FM,BASELINE}} = \\ = C_{\mathrm{TM,SFR}} - (1+k)C_{\mathrm{FM,SFR}}$$

$$C_{\mathrm{FM,BASELINE}} - C_{\mathrm{FM,SFR}} \\ = \frac{C_{\mathrm{TM,BASELINE}} - C_{\mathrm{TM,SFR}}}{1+k}$$

$$\alpha \equiv \frac{C_{\mathrm{FM,SFR}}}{C_{\mathrm{FM,BASELINE}}} = 1 - \frac{C_{\mathrm{TM,BASELINE}} - C_{\mathrm{TM,SFR}}}{(1+k)C_{\mathrm{FM,BASELINE}}}$$

4.7 Geosim Tests for the Extrapolation of α for Full Scale

It is reasonable to assume that the frictional drag reduction factor α depends on the Reynolds number, $\alpha(Re)$. In order to predict such dependence, the geosim tests with varying Reynolds number are recommended. Each test should be based on Froude scaling and the respective Reynolds number needs to be spaced at least one order of magnitude. From each test with respective Reynolds number $Re_{\mathrm{M},i}(i = 1,2,\cdots)$, $\alpha(Re_{\mathrm{M},i})$ is calculated by the process described in the previous section. The dependence of $\alpha(Re_{\mathrm{M},i})$ on $Re_{M,i}$ is required to be appropriately analysed to predict the extrapolated value of $\alpha(Re_{\mathrm{S}})$ for the full scale.

It is worthwhile to mention that test using multiple models with varying scale factors are very costly process. Even the highest Reynolds number involved in such test might not be close enough to the full scale Reynolds number to avoid scale effect. Considering the practical size limitation in the tank test, the scale factor $\lambda$of the largest model is recommended to become smaller than 35. This will have the ratio of Reynolds numbers between the full scale and the model, which is equal to $\lambda^{3/2}$, to be less than 200.

4.8 Full Scale Predictions

The full scale frictional reduction factor $\alpha(Re_S)$ obtained from the procedure in the above will satisfy the following relationship;

$$\alpha(\mathrm{Re_S}) = \frac{C_{\mathrm{FS,SFR}}}{C_{\mathrm{FS,BASELINE}}}$$

Thus, the total resistance coefficient of a ship without bilge keels is

$$C_{\mathrm{TS}} = (1+k)C_{\mathrm{FS,SFR}} + \Delta C_{\mathrm{F}} + C_{\mathrm{R}} + C_{\mathrm{A}} + C_{\mathrm{AAS}} = \\ = \alpha(1+k)C_{\mathrm{FS,BASLINE}} + \Delta C_{\mathrm{F}} + C_{\mathrm{R}} + C_{\mathrm{A}} + C_{\mathrm{AAS}}$$

where

- k is the form factor determined from the resistance test, see ITTC standard procedure 7.5-02-02-01.
- C_{FS} is the frictional resistance coefficient of the ship according to the ATTC line
- C_{R} is the residual resistance coefficient calculated from the total and frictional resistance coefficients of the model in the resistance tests: $C_{\mathrm{R}} = C_{\mathrm{TM}} - C_{\mathrm{FM}}(1+k)$

The form factor $k$and the total resistance coefficient for the model C_{TM} are determined as described in the ITTC standard procedure 7.5-02-02-01.

The correlation factor for the calculation of the resistance has been separated from the roughness allowance. The roughness allowance ΔC_{F} per definition describes the effect of the roughness of the hull on the resistance. The correlation factor C_{A} is supposed to allow for all effects not covered by the prediction method, mainly uncertainties of the tests and the prediction method itself and the assumptions made for the prediction method. Both correlation factors are determined as described in the ITTC standard procedure 7.5-02-02-01.

- ΔC_F is the roughness allowance:

$$\Delta C_F = 0.044\left[\left(\frac{k_S}{L_{WL}}\right)^{\frac{1}{3}} - 10\mathrm{Re}^{-\frac{1}{3}}\right] + 0.000125,$$

where k_S indicates the roughness of hull surface. When there is no measured data, the standard value of k_S=150×10^{-6} m can be used.

- C_A is the correlation allowance. C_A is determined from comparison of model and full scale trial results. When using the roughness allowance as above, the 19th ITTC recommended using $C_A = (5.68 - 0.6\log Re) \times 10^{-3}$.
- C_{AAS} is the air resistance coefficient in full scale $C_{AAS} = C_{DA}\frac{\rho_A A_{VS}}{\rho_S S_S}$, where, A_{VS} is the projected area of the ship above the water line to the transverse plane, S_S is the wetted surface area of the ship, ρ_A is the air density, and C_{DA} is the air drag coefficient of the ship above the water line. C_{DA} can be determined by wind tunnel model tests or calculations. Values of C_{DA} are typically in the range 0.5-1.0, where 0.8 can be used as a default value.

If the ship is fitted with bilge keels of modest size, the total resistance is estimated as follows:

$$C_{TS} = \alpha(1+k)C_{FS,BASLINE} + \frac{S_S + S_{BK}}{S_S}[\Delta C_F + C_A] + $$
$$+ C_R + C_{AAS}$$

where S_{BK} is the wetted surface area of the bilge keels.

5. DESCRIPTION OF PROCEDURE: SKIN FRICTIONAL RESISTANCE MEASUREMENT FOR HOMOGENEOUS TECHNIQUES

Whilst the comparative resistance ship model test are conducted for the inhomogeneous techniques as in Section 4, those model tests are replaced with a canonical flow tests to directly quantify the skin frictional drag for both “SFR” and “BASELINE” conditions. As far as the coating is concerned, the “BASELINE” test refer to the measurement of skin frictional drag with the baseline coating. There could be two subcategory of canonical flow test; the first one is a global one to measure the skin frictional drag of a towed flat plate, leading to the skin frictional drag coefficient $C_F = \frac{R_F}{\frac{1}{2}\rho S V^2}$. Schultz (2004) is a notable example of towed flat plate measurement. The second one is local measurement of wall shear stress using floating-element skin friction balance in a turbulent boundary layer in a circulating water tunnel, which then leads to local skin friction coefficient $C_f = \frac{\tau_w}{\frac{1}{2}\rho V^2}$.

5.1 Test Procedure

Unlike the ship model tests described in section 4, there is no currently available ITTC recommended procedures and guidelines for the canonical flow tests. Care should be undertaken to identify all the possible errors in the particular test conducted. Usually comparison of the tests result for smooth surface with the following correlation is helpful in quantifying such measurement errors;

For global measurement,

$$\frac{0.242}{\sqrt{C_F}} = \log_{10}(Re_L C_F)$$

where Re_L is based on the length of flat plate, L. For local measurement,

$$\frac{1}{\sqrt{C_{\mathrm{FL}}}} = 4.15\ln(Re_{\mathrm{x}}C_{\mathrm{FL}}) + 1.7$$

where Re_x is defined by the local streamwise coordinate x of the measurement location in the boundary layer.

5.2 Data Reduction

Once either C_F or C_f is measured for both “SFR” condition and “BASELINE” condition, the frictional drag reduction factor α is then given as follows;

For global measurement,

$$\alpha \equiv \frac{C_{\mathrm{F,SFR}}}{C_{\mathrm{F,BASELINE}}}$$

For local measurement,

$$\alpha \equiv \frac{C_{\mathrm{FL,SFR}}}{C_{\mathrm{FL,BASELINE}}}$$

5.3 Extrapolation of α for Full Scale

Here, the Granville’s similarity law scaling procedure described in Schultz (2007) is adopted. Originally, this method is devised to extrapolate the effect of coating roughness to full scale resistance performance. Granville (1987) describes how to quantify the roughness function ΔU^+ for either global measurement or local measurement. For rough surface, ΔU^+ represent a downward shift of log-law velocity profile, which is associated with the momentum deficit due to roughness.

Following the Granville’s frictional drag characterization methods, the roughness function for “SFR” condition can be calculated as follows;

For global measurement,

$$(\Delta U^+)_{\mathrm{SFR}} = \left(\sqrt{\frac{2}{C_{\mathrm{F}}}}\right)_{\mathrm{smooth}} - \left(\sqrt{\frac{2}{C_{\mathrm{F}}}}\right)_{\mathrm{SFR}} - 19.7\left[\left(\sqrt{\frac{2}{C_{\mathrm{F}}}}\right)_{\mathrm{smooth}} - \left(\sqrt{\frac{2}{C_{\mathrm{F}}}}\right)_{\mathrm{SFR}}\right] - \frac{1}{\kappa}\Delta U^{+\prime}\left(\left(\sqrt{\frac{C_{\mathrm{F}}}{2}}\right)_{\mathrm{SFR}}\right)$$

For local measurement,

$$(\Delta U^+)_{\mathrm{SFR}} = \left(\sqrt{\frac{2}{C_{\mathrm{FL}}}}\right)_{\mathrm{smooth}} - \left(\sqrt{\frac{2}{C_{\mathrm{FL}}}}\right)_{\mathrm{SFR}} - 19.7\left[\left(\sqrt{\frac{2}{C_{\mathrm{FL}}}}\right)_{\mathrm{smooth}} - \left(\sqrt{\frac{2}{C_{\mathrm{FL}}}}\right)_{\mathrm{SFR}}\right]$$

$(\Delta U^+)_{BASELINE}$ can be calculated similarly.

Granville’s similarity law scaling procedure is illustrated graphically in Figure 1 The procedure consists of first plotting the frictional resistance coefficient of a smooth plate $\frac{0.242}{\sqrt{C_{\mathrm{F}}}} = \log_{10}(Re_{\mathrm{L}}C_{\mathrm{F}})$ as a function of $\log_{10}(Re_{\mathrm{L}})$. The frictional resistance coefficient for the rough plate laboratory measurement is then plotted on the graph of C_{F} versus $\log_{10}(Re_{\mathrm{L}})$. This point coincides with the intersection of two curves. The first curve is the smooth friction line displaced horizontally by $\kappa\Delta U^+/\ln 10$. The second curve is the line of constant $L^+_{\mathrm{plate}} = L_{\mathrm{plate}}U_\tau/\nu$ which satisfies the following equation;

$$Re_{\mathrm{L}} = \frac{L^+_{\mathrm{plate}}}{\sqrt{\frac{C_{\mathrm{F}}}{2}}\left(1 - \frac{1}{\kappa}\sqrt{\frac{C_{\mathrm{F}}}{2}}\right)}$$

For full scale C_{FS} determination, the line of constant L^+_{plate} is shifted by $\log\left(L_{\mathrm{s}}/L_{\mathrm{plate}}\right)$. The intersection of this line and the first shifted curve then identifies C_{FS}. This process can be performed for both "SFR" condition and "BASELINE" condition to give $C_{\mathrm{FS,SFR}}$ and $C_{\mathrm{FS,BASELINE}}$. Finally, The full scale frictional drag reduction factor $\alpha(Re_{\mathrm{S}})$ is given by the following relationship;

$$\alpha(\mathrm{Re_S}) = \frac{C_{\mathrm{FS,SFR}}}{C_{\mathrm{FS,BASELINE}}}$$

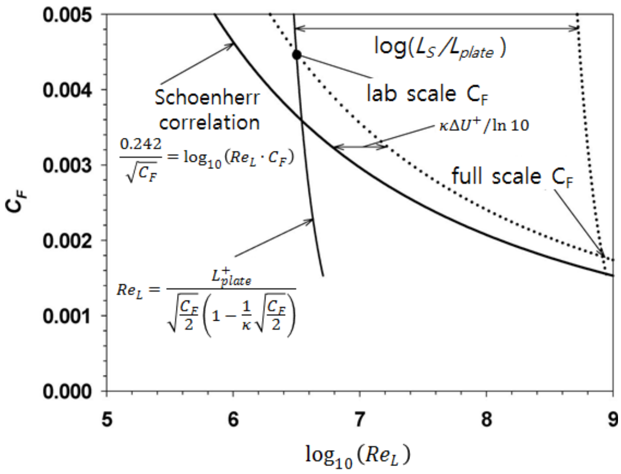

Fig. 1 Graphical representation of Granville's similarity law scaling

5.4 Full Scale Predictions

The total resistance coefficient of a ship without bilge keels is

$$C_{\mathrm{TS}} = (1+k)C_{\mathrm{FS,SFR}} + C_{\mathrm{R}} + C_{\mathrm{A}} + C_{\mathrm{AAS}} = \\ = \alpha(1+k)C_{\mathrm{FS,BASLINE}} + C_{\mathrm{R}} + C_{\mathrm{A}} + C_{\mathrm{AAS}}$$

If the ship is fitted with bilge keels of modest size, the total resistance is estimated as follows:

$$C_{\mathrm{TS}} = \frac{S_{\mathrm{S}} + S_{\mathrm{BK}}}{S_{\mathrm{S}}}\left[\alpha(1+k)C_{\mathrm{FS,BASLINE}} + C_{\mathrm{A}}\right] + \\ + C_{\mathrm{R}} + C_{\mathrm{AAS}}$$

where S_{BK} is the wetted surface area of the bilge keels.

These equations are similar to those in Section 4.8 except that the roughness allowance. ΔC_{F} is omitted. This is because the model-ship roughness allowance has been already accounted in predicting $C_{\mathrm{FS,SFR}}$ and $C_{\mathrm{FS,BASELINE}}$ in Section 5.3.

6. DESCRIPTION OF PROCEDURE: SELF-PROPULSION TEST FOR INHOMOGENEOUS TECHNIQUES

Similarly, as the comparative resistance tests described in Section 4, comparative self-propulsion tests can be conducted to investigate the effect of skin frictional drag reduction technique on the propulsion performance. Since some parts of the existing propulsion test procedure and performance prediction such as the skin friction correction force can be affected by the reduced skin friction, appropriate amendment to the existing guidelines seems to be necessary. This is the background of the present section.

6.1 Model and Installation

6.1.1 Models

6.1.1.1 Hull Model

The model hull should be manufactured according to the Standard Procedure 7.5-01-01-01, Ship Models. The condition of the hull model prepared for self-propulsion tests should be the same as its condition for the resistance test.

6.1.1.2 Propeller/Propulsion Unit Model

This should comply with the Section 3.1.1.2 of the ITTC Recommended Procedure 7.5-02-03-01.1, Propulsion/Bollard Pull Test.

6.1.2 Installation

This should comply with the Section 3.1.2 of the ITTC Recommended Procedure 7.5-02-03-01.1, Propulsion/Bollard Pull Test.

6.2 Instrumentation

This should comply with the Section 3.2 of the ITTC Recommended Procedure 7.5-02-03-01.1, Propulsion/Bollard Pull Test.

6.3 Calibration

This should comply with the Section 3.3 of the ITTC Recommended Procedure 7.5-02-03-01.1, Propulsion/Bollard Pull Test.

6.4 Test Procedure and Data Acquisition

6.4.1 Methods

This should comply with the Section 3.4.1 and the Section 3.4.2 of the ITTC Recommended Procedure 7.5-02-03-01.1, Propulsion/Bollard Pull Test.

6.4.2 Skin Friction Correction Force

The skin friction correction force (F_D), applied as an external tow force, is to achieve the theoretically correct propeller loads during the self-propulsion test. It takes into account the difference in skin friction coefficients between the model and the full scale ship. General terms should be consistent with those described in the Section 3.4.3 of the ITTC Recommended Procedure 7.5-02-03-01.1, Propulsion/Bollard Pull Test.

For the “BASELINE” self-propulsion test, the skin friction correction force is given as:

$$F_{\mathrm{D,BASELINE}} = \frac{1}{2}\rho_{\mathrm{M}} S_{\mathrm{M}} V_{\mathrm{M}}^2 \left\{(1+k)\left(C_{\mathrm{FM,BASELINE}} - C_{\mathrm{FS,BASELINE}}\right) - \Delta \mathrm{C_F}\right\}$$

For the “SFR” self-propulsion test, the skin friction correction force is given as:

$$F_{\mathrm{D,SFR}} = \frac{1}{2}\rho_{\mathrm{M}} S_{\mathrm{M}} V_{\mathrm{M}}^2 \left\{(1+k)\left(C_{\mathrm{FM,SFR}} - C_{\mathrm{FS,SFR}}\right) - \Delta C_F\right\}$$

6.5 Data Reduction and Analysis

This should comply with the Section 3.5 of the ITTC Recommended Procedure 7.5-02-03-01.1, Propulsion/Bollard Pull Test.

The required values of t, w_T, η_R and η_H are calculated according to the data reduction equations defined in the Section 2.1 of the ITTC Recommended Procedure 7.5-02-03-01.1, Propulsion/Bollard Pull Test. For “BASELINE” and “SFR” self-propulsion test, those values should be calculated using data measured in the respective test.

6.6 Full Scale Predictions

6.6.1 Scale Effect Corrections for Propeller Characteristics

This should comply with the Section 2.4.2 of the ITTC Recommended Procedure 7.5-02-03-01.4, 1978 ITTC Performance Prediction Method.

6.6.2 Full Scale Wake and Operating Condition of Propeller

General terms should be consistent with those described in the Section 2.4.3 of the ITTC Recommended Procedure 7.5-02-03-01.4, 1978 ITTC Performance Prediction Method.

Full scale wake in the case of "BASELINE" case is calculated by the following formula:

$$w_{\mathrm{TS,BASELINE}} = (t_{\mathrm{BASELINE}} + 0.04) + \\ +(w_{\mathrm{TM,BASELINE}} - \mathrm{t}_{\mathrm{BASELINE}} - 0.04) \frac{(1+k)\mathrm{C}_{\mathrm{FS,BAELINE}} + \Delta C_{\mathrm{F}}}{(1+k)C_{\mathrm{FM,BASELINE}}}$$

For "SFR" case, full scale wake is given as:

$$w_{\mathrm{TS,SFR}} = (t_{\mathrm{BASELINE}} + 0.04) + \\ +(w_{\mathrm{TM,SFR}} - t_{\mathrm{BASELINE}} - 0.04) \frac{(1+k)C_{\mathrm{FS,SFR}} + \Delta C_{\mathrm{F}}}{(1+\mathrm{k})\mathrm{C}_{\mathrm{FM,SFR}}}$$

The load of the full-scale propeller is obtained using the formula described in the Section 2.4.3 of the ITTC Recommended Procedure 7.5-02-03-01.4, 1978 ITTC Performance Prediction Method.

For "BASELINE" case,

$$\left(\frac{K_{\mathrm{T}}}{J^2}\right)_{\mathrm{BASELINE}} = \\ = \frac{S}{2D^2} \frac{C_{\mathrm{TS,BASELINE}}}{(1-t_{\mathrm{BASELINE}})(1-w_{\mathrm{TS,BASELINE}})^2}$$

For "SFR" case,

$$\left(\frac{K_{\mathrm{T}}}{J^2}\right)_{\mathrm{SFR}} = \frac{S}{2D^2} \frac{C_{\mathrm{TS,SFR}}}{(1-t_{\mathrm{SFR}})(1-w_{\mathrm{TS,SFR}})^2}$$

The full scale quantities for respective case, "BASELINE" and "SFR", are calculated using the formulae described in the Section 2.4.3 of the ITTC Recommended Procedure 7.5-02-03-01.4, 1978 ITTC Performance Prediction Method.

7. REFERENCES

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