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1978 ITTC Performance Prediction Method

1. PURPOSE OF PROCEDURE

The procedure gives a general description of an analytical method to predict delivered power and rate of revolutions for single and twin screw ships from model test results.

2. DESCRIPTION OF PROCEDURE

2.1 Introduction

The method requires respective results of a resistance test, a self propulsion test and the characteristics of the model propeller used during the self propulsion test,

The method generally is based on thrust identity which is recommended to be used to predict the performance of a ship. It is supposed that the thrust deduction factor and the relative rotative efficiency calculated for the model remain the same for the full scale ship whereas on all other coefficients corrections for scale effects are applied.

In some special cases torque identity (power identity) may be used, see section 2.4.4.

2.2 Definition of the Variables

C_{A}	Correlation allowance
C_{AA}	Air resistance coefficient
C_{App}	Appendage resistance coefficient
C_D	Drag coefficient
C_{F}	Frictional resistance coefficient
C_{FC}	Frictional resistance coefficient at the temperature of the self propulsion test
C_{NP}	Trial correction for propeller rate of revolution at power identity
C_P	Trial correction for delivered power
C_N	Trial correction for propeller rate of revolution at speed identity
C_{R}	Residual resistance coefficient
C_{T}	Total resistance coefficient
D	Propeller diameter
F_{D}	Skin friction correction in self propulsion test
J	Propeller advance coefficient
J_T	Propeller advance coefficient achieved by thrust identity
J_Q	Propeller advance coefficient achieved by torque identity
K_T	Thrust coefficient
K_Q	Torque coefficient
K_{QT}	Torque coefficient achieved by thrust identity
k	Form factor
k_{P}	Propeller blade roughness
N_{P}	Number of propellers
n	Propeller rate of revolution
n_{T}	Propeller rate of revolution, corrected using correlation factor
P	Propeller pitch
P_{D}, P_{P}	Delivered Power, propeller power
P_{DT}	Delivered Power, corrected using correlation factor

P_E, P_R	Effective power, resistance power
Q	Torque
R_C	Resistance corrected for temperature differences between resistance- and self propulsion test
Re	Reynolds number
R_T	*Total* resistance
S	Wetted surface
S_{BK}	Wetted surface of bilge keels
T	Propeller thrust
t	Thrust deduction factor
V	Ship speed
V_A	Propeller advance speed
w	Taylor wake fraction in general
w_Q	Taylor wake fraction, torque identity
w_R	Effect of the rudder(s) on the wake fraction
w_T	Taylor wake fraction, thrust identity
Z	Number of propeller blades
β	Appendage scale effect factor
ΔC_F	roughness allowance
ΔC_{FC}	Individual correction term for roughness allowance
Δw_C	Individual correction term for wake
η_D	Propulsive efficiency or quasi-propulsive coefficient
η_H	Hull efficiency
η_0	Propeller open water efficiency
η_R	Relative rotative efficiency
ρ	Water density in general

Subscript "M" signifies the model
Subscript "S" signifies the full scale ship

2.3 Analysis of the Model Test Results

The calculation of the residual resistance coefficient C_R from the model resistance test results is found in the procedure for resistance test (7.5-02-02-01).

Thrust T_M, and torque Q_M, measured in the self-propulsion tests are expressed in the non-dimensional forms as in the procedure for propulsion test (7.5-02-03-01.1).

$$K_{TM} = \frac{T_M}{\rho_M D_M^4 n_M^2} \quad \text{and} \quad K_{QM} = \frac{Q_M}{\rho_M D_M^5 n_M^2}$$

Using thrust identity with K_{TM} as input data, J_{TM} and K_{QTM} are read off from the model propeller open water diagram, and the wake fraction

$$w_{TM} = 1 - \frac{J_{TM} D_M}{V_M}$$

and the relative rotative efficiency

$$\eta_R = \frac{K_{QTM}}{K_{QM}}$$

are calculated. V_M is model speed.

Using torque identity with K_{QM} as input data, J_{QM} is read off from the model propeller open water diagram, and the wake fraction

$$w_{QM} = 1 - \frac{J_{QM} D_M}{V_M}$$

V_M is model speed.

In case of using torque identity the relative rotative efficiency

$$\eta_R = 1.0$$

The thrust deduction is obtained from

$$t = \frac{T_M + F_D - R_C}{T_M}$$

where F_D is the towing force actually applied in the propulsion test. R_C is the resistance corrected for differences in temperature between resistance and self-propulsion tests:

$$R_C = \frac{(1+k).C_{FMC} + C_R}{(1+k).C_{FM} + C_R} R_{TM}$$

where C_{FMC} is the frictional resistance coefficient at the temperature of the self-propulsion test.

2.4 Full Scale Predictions

2.4.1 Total Resistance of Ship

The total resistance coefficient of a ship without bilge keels is

$$C_{TS} = (1+k)C_{FS} + \Delta C_F + C_A + C_R + C_{AAS}$$

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 ITTC-1957 model-ship correlation line

- C_R is the residual resistance coefficient calculated from the total and frictional resistance coefficients of the model in the resistance tests:

$$C_R = C_{TM} - (1+k)C_{FM}$$

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. The separation of ΔC_F from C_A was proposed by the Performance Prediction Committee of the 19th ITTC. This is essential to allow for the effects of newly developed hull coating systems.

The 19th ITTC also proposed a modified formula for C_A that excludes roughness allowance, which is now given in this procedure.

- ΔC_F is the roughness allowance

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

where k_s indicates the roughness of hull surface. When there is no measured data, the standard value of $k_s = 150\times10^{-6}$ 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

$$C_A = (5.68 - 0.6\log Re)\times10^{-3}$$

to give values of ΔC_F+C_A that approximates the values of ΔC_F of the original 1978 ITTC method. It is recommended that each institution maintains their own model-full scale correlation. See section 2.4.4 for a further discussion on correlation.

- C_{AAS} is the air resistance coefficient in full scale

$$C_{AAS}=\frac{1}{2}\rho_A V_S^2 C_{DA}\frac{A_{VS}}{S_S}$$

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:

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

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

When the model appendage resistance is separated from the total model resistance, as described as an option in the ITTC Standard Procedure 7.5-02-02-01, the full scale appendage resistance needs to be added, and the formula for total resistance (with bilge keels) becomes:

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

There is not only one recommended method of scaling appendage resistance to full scale. The following alternative methods are well established:

1) Scaling using a fixed fraction:

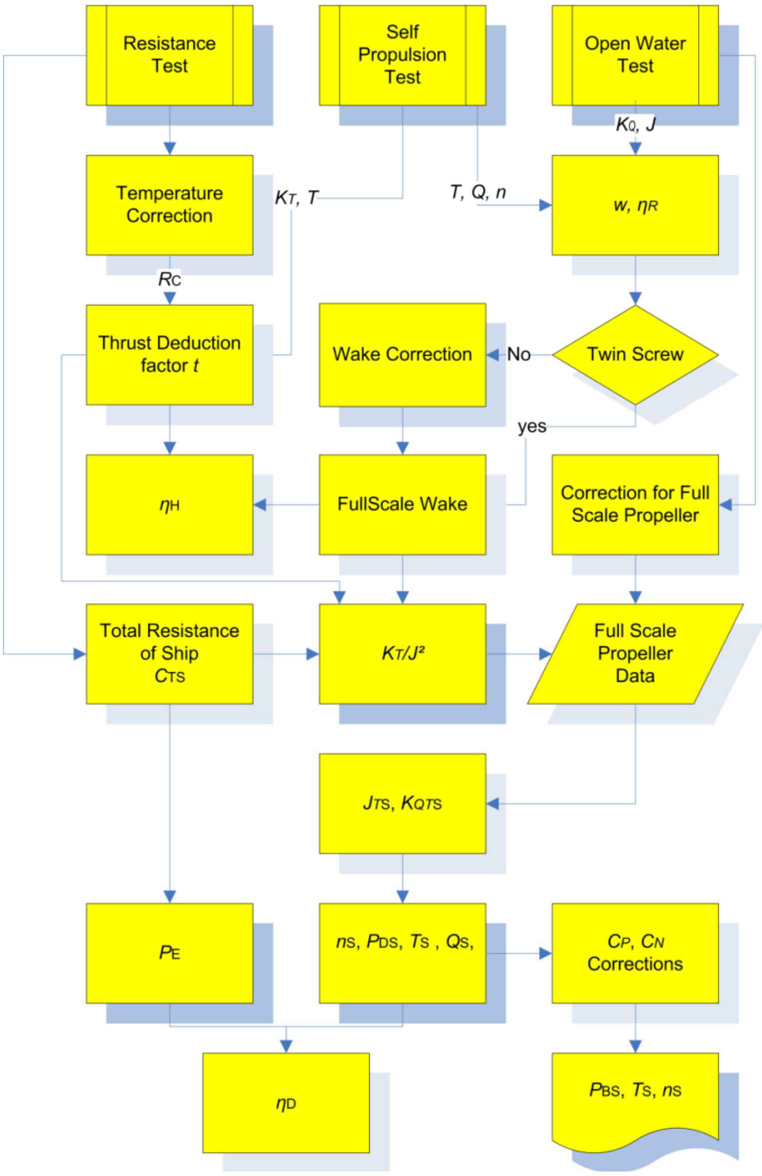
$$C_{AppS}=(1-\beta)\cdot C_{AppM}$$

where $(1-\beta)$ is a constant in the range 0.6-1.0.

2) Calculating the drag of each appendage separately, using local Reynolds number and form factor.

$$C_{AppS}=\sum_{i=1}^{n}(1-w_i)^2\cdot(1+k_i)\cdot C_{FSi}\cdot\frac{S_i}{S_S}$$

where index i refers to the number of the individual appendices. w_i is the wake fraction at the position of appendage i. k_i is the form factor of appendage i. C_{FSi} is the frictional resistance coefficient of appendage i, and S_i is the wetted surface area of appendage i. Note that the method is not scaling the model appendage drag, but calculating the full scale appendage drag. The model appendage drag, if known from model tests, can be used for the determination of e.g. the wake fractions w_i. Values of the form factor k_i can be found from published data for generic shapes, see for instance Hoerner (1965) or Kirkman and Klöetsli (1980).



2.4.2 Scale Effect Corrections for Propeller Characteristics.

The characteristics of the full-scale propeller are calculated from the model characteristics as follows:

$$K_{TS} = K_{TM} - \Delta K_T$$

$$K_{QS} = K_{QM} - \Delta K_Q$$

where

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

$$\Delta K_Q = \Delta C_D \cdot 0.25 \cdot \frac{c \cdot Z}{D}$$

The difference in drag coefficient ΔC_D is

$$\Delta C_D = C_{DM} - C_{DS}$$

where

$$C_{DM} = 2\left(1+2\frac{t}{c}\right)\left[\frac{0.044}{(Re_{c0})^{\frac{1}{6}}} - \frac{5}{(Re_{c0})^{\frac{2}{3}}}\right]$$

and

$$C_{DS} = 2\left(1+2\frac{t}{c}\right)\left(1.89+1.62\cdot\log\frac{c}{k_{\mathrm{P}}}\right)^{-2.5}$$

In the formulae listed above c is the chord length, t is the maximum thickness, P/D is the pitch ratio and Re_{c0} is the local Reynolds number with Kempf's definition at the open-water test. They are defined for the representative blade section, such as at r/R=0.75. k_{P} denotes the blade roughness, the standard value of which is set $k_{\mathrm{P}}=30\times10^{-6}$ m. Re_{c0} must not be lower than 2×10^5.

2.4.3 Full Scale Wake and Operating Condition of Propeller

The full-scale wake is calculated by the following formula using the model wake fraction w_{TM}, and the thrust deduction fraction t obtained as the analysed results of self-propulsion test:

$$w_{TS} = (t + w_{\mathrm{R}}) + (w_{TM} - t - w_{\mathrm{R}})\frac{(1+k)C_{\mathrm{FS}} + \Delta C_{\mathrm{F}}}{(1+k)C_{\mathrm{FM}}}$$

where w_{R} stands for the effect of rudder on the wake fraction. If there is no estimate for w_{R}, the standard value of 0.04 can be used.

If the estimated w_{TS} is greater than w_{TM}, w_{TS} should be set as w_{TM}.

The wake scale effect of twin screw ships with open sterns is usually small, and for such ships it is common to assume $w_{TS} = w_{TM}$.

For twin skeg-like stern shapes a wake correction is recommended. A correction like the one used for single screw ships may be used.

The load of the full-scale propeller is obtained from

$$\frac{K_T}{J^2} = \frac{S_{\mathrm{S}}}{2D_{\mathrm{S}}^2}\cdot\frac{C_{\mathrm{TS}}}{(1-t)\cdot(1-w_{TS})^2\cdot N_{\mathrm{P}}}$$

where N_{P} is the number of propellers.

With this K_T/J^2 as input value the full scale advance coefficient J_{TS} and the torque coefficient K_{QTS} are read off from the full scale propeller characteristics and the following quantities are calculated.

- the rate of revolutions:

$$n_{\mathrm{S}} = \frac{(1-w_{TS})\cdot V_{\mathrm{S}}}{J_{TS}\cdot D_{\mathrm{S}}} \quad \text{(r/s)}$$

- the delivered power of each propeller:

$$P_{\mathrm{DS}} = 2\pi\rho_{\mathrm{S}}D_{\mathrm{S}}^5 n_{\mathrm{S}}^3\frac{K_{QTS}}{\eta_{\mathrm{R}}}\cdot10^{-3} \quad \text{(kW)}$$

- the thrust of each propeller:

$$T_{\mathrm{S}} = \left(\frac{K_T}{J^2}\right)\cdot J_{TS}^2\rho_{\mathrm{S}}D_{\mathrm{S}}^4 n_{\mathrm{S}}^2 \quad \text{(N)}$$

- the torque of each propeller:

$$Q_{\mathrm{S}} = \frac{K_{QTS}}{\eta_{\mathrm{R}}}\cdot\rho_{\mathrm{S}}D_{\mathrm{S}}^5 n_{\mathrm{S}}^2 \quad \text{(Nm)}$$

- the effective power:

$$P_{\mathrm{E}} = C_{\mathrm{TS}}\cdot\frac{1}{2}\rho_{\mathrm{S}}V_{\mathrm{S}}^3 S_{\mathrm{S}}\cdot10^{-3} \quad \text{(kW)}$$

- the total efficiency:

$$\eta_D = \frac{N_P \cdot P_{DS}}{P_E}$$

- the hull efficiency:

$$\eta_H = \frac{1-t}{1-w_{TS}}$$

2.4.4 Model-Ship Correlation Factor

The model-ship correlation factor should be based on systematic comparison between full scale trial results and predictions from model scale tests. Thus, it is a correction for any systematic errors in model test and powering prediction procedures, including any facility bias.

In the following, several different alternative concepts of correlation factors are presented as suggestions. It is left to each member organisations to derive their own values of the correlation factor(s), taking into account also the actual value used for C_A.

(1) Prediction of full scale rates of revolutions and delivered power by use of the C_P - C_N correction factors

Using C_P and C_N the finally predicted trial data will be calculated from

$$n_T = C_N \cdot n_S \qquad \text{(r/s)}$$

for the rates of revolutions and

$$P_{DT} = C_P \cdot P_{DS} \qquad \text{(kW)}$$

for the delivered power.

(2) Prediction of full scale rates of revolutions and delivered power by use of ΔC_{FC} - Δw_C corrections

In such a case the finally trial predicted trial data are calculated as follows:

$$\frac{K_T}{J^2} = \frac{S_S}{2D_S^2} \cdot \frac{C_{TS} + \Delta C_{FC}}{(1-t)\cdot(1-w_{TS}+\Delta w_C)^2 \cdot N_P}$$

With this K_T/J^2 as input value, J_{TS} and K_{QTS} are read off from the full scale propeller characteristics and the following is calculated:

$$n_T = \frac{(1-w_{TS}+\Delta w_C)\cdot V_S}{J_{TS}\cdot D_S} \qquad \text{(r/s)}$$

$$P_{DT} = 2\pi\rho_S D_S^5 n_T^3 \frac{K_{QTS}}{\eta_R} \cdot 10^{-3} \qquad \text{(kW)}$$

(3) Prediction of full scale rates of revolutions and delivered power by use of a C_{NP} correction

For prediction with emphasis on stator fins and rudder effects, it is sometimes recommended to use power identity for the prediction of full scale rates of revolution.

At the point of K_T-(J)-Identity the condition is reached where the ratio between the propeller induced velocity and the entrance velocity is the same for the model and the full scale ship. Ignoring the small scale effect ΔK_T on the thrust coefficient K_T it follows that J-identity correspond to K_T- and C_T-identity. As a consequence it follows that for this condition the axial flow field in the vicinity of the propeller is on average correctly simulated in the model experiment. Also the axial flow of the propeller slip stream is on average correctly simulated. Due to the scale effects on the propeller blade friction, which affect primarily the torque, the point of K_Q-identity (power identity) represents a slightly less heavily loaded propeller than at J-, K_T- and C_T-identity. At the power identity the average rotation in the slipstream corresponds to that of the actual ship and this condition is regarded as important if tests on stator fins and/or rudders are to be done correctly.

In this case, the shaft rate of revolutions is predicted on the basis of power identity as follows:

$$\left(\frac{K_Q}{J^3}\right)_{\mathrm{T}} = \frac{1000 \cdot C_P \cdot P_{\mathrm{DS}}}{2\pi \rho_{\mathrm{S}} D_{\mathrm{S}}^2 V_{\mathrm{S}}^3 (1 - w_{T\mathrm{S}})^3}$$

$$\frac{K_{Q0}}{J^3} = \left(\frac{K_Q}{J^3}\right)_{\mathrm{T}} \cdot \eta_{\mathrm{RM}}$$

$$n_{\mathrm{S}} = \frac{(1 - w_{T\mathrm{S}}) \cdot V_{\mathrm{S}}}{J_{T\mathrm{S}} \cdot D_{\mathrm{S}}}$$

$$n_{\mathrm{T}} = C_{NP} \cdot n_{\mathrm{S}}$$

3. VALIDATION

3.1 Uncertainty Analysis

Not yet available

3.2 Comparison with Full Scale Results

The data that led to 1978 ITTC performance prediction method can be found in the following ITTC proceedings:

(1) Proposed Performance Prediction Factors for Single Screw Ocean Going Ships (13th 1972 pp.155-180) Empirical Power Prediction Factor (1+X)

(2) Propeller Dynamics Comparative Tests (13th 1972 pp.445-446)

(3) Comparative Calculations with the ITTC Trial Prediction Test Programme (14th 1975 Vol.3 pp.548-553)

(4) Factors Affecting Model Ship Correlation (17th 1984 Vol.1 pp274-291)

4. REFERENCES

(1) Hoerner, S.F. (1965) “Fluid-Dynamic Drag”. Published by the author.

(2) Kirkman, K.L., Klöetsli, J.W. (1980) “Scaling Problems of model appendages”, 19th American Towing Tank Conference, Ann Arbor, Michigan