ITTC Quality System Manual

Recommended Procedures and Guidelines

Guideline

Guideline on the determination of model-ship correlation factors

7.5   Process Control

7.5-04   Full Scale Measurements

7.5-04-05   Model-ship correlation

7.5-04-05-01   Guideline on the determination of model-ship correlation factors

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Guideline on the determination of model-ship correlation factors

1. INTRODUCTION

ITTC recommended procedure 7.5-02-03-01.4 [1] references four schemes to correlate the predicted full scale power of a ship from model test with the power demand obtained from corresponding sea trials:

a) Correlation allowance C_A
b) Correlation scheme applying C_P - C_N coefficients
c) Correlation scheme applying $\Delta C_{FC} - \Delta w_C$ coefficients
d) Correlation applying power identity with correlation factor C_{NP} for correction of the ship's full scale rate of revolutions [not considered here].

The basis for the determination of these correlation factors is always the comparison between predicted full scale values based on the towing tank experiments and the speed-power performance obtained from sea trials. Aiming to ensure a consistent quality of the obtained correlation factors, this guideline provides a general procedural approach on how to derive them.

Generally, institutes conducting model tests use their individual correlation formulas following one of the 4 basic concepts mentioned above. This is necessary as each towing tank delivers slightly different measurement results due to individual characteristics.

A partial but by no means exhaustive list of correlation-related variables specific to each towing tank is given below:

1. Test Facility

- Size of tank (length, breadth, depth)
- Associated water turbulence and flow characteristics (largely influenced by the time between subsequent test runs)
- Cross sectional area of the tank building
- Blockage effect of towing carriage
- Blockage effect of model
- Vibrations due to carriage movement
- Measurement equipment as well as test setup (load variation versus constant load approach)
- Speed measurement of model relative to the water

2. Model

- Model roughness
- Propeller roughness
- Turbulence stimulation

3. Post Processing

- Treatment of additional resistance components - appendages/openings not existent on the model e.g. tunnel thruster openings, screen grids, bilge keels, etc.
- Treatment of wind resistance
- Form factor: (none, from empirical relations, from Prohaska plot or CFD based)
- Propeller open water test correction (none, ITTC, 2-POT-method, proprietary scaling method)
- Wake scaling method

Full scale speed trials are most commonly performed at one draught only, typically ballast draught for dry cargo ships. The EEDI speed is derived at a loaded draught. Hence, the speed trial results have to be converted from ballast to

loaded condition. This is done based on predictions from model test results for the two draughts.

The correlation factors for trial (ballast) draught are normally well validated using the feedback from a large number of sea trials, whereas there is very limited data available to validate the correlation factors for other draughts. This introduces an uncertainty when determining the EEDI speed.

This guideline presents reasons why test facilities use different correlation factors to predict ship power and identifies key variables that influence the correlation factors. The guideline presents a general approach for establishing a model-ship power correlation and addresses the uncertainty in validating the correlation factors for other draughts.

2.   PARAMETERS AND SYMBOLS

C_A Correlation allowance on resistance.

C_{AA} Wind resistance coefficient

C_F Frictional resistance coefficient according to ITTC 1957

C_N Trial correction for propeller rate of revolution at speed identity

C_{NP} Trial correction for propeller rate of revolution at power identity

C_P Correlation allowance on delivered power

C_W Wave-making resistance coefficient

C_T Total resistance coefficient

P_D Delivered power

P_E Effective power

R_T Total resistance

η_D Propulsive efficiency or quasi-propulsive coefficient

ΔC_F Roughness allowance

ΔC_{FC} Individual correction term for roughness allowance

J Propeller advance coefficient

S Wetted surface

V Ship speed

ρ Water density

Δw_C Wake fraction allowance

Re Reynolds number

T Draught of the ship

C_B Block coefficient

3.   DESCRIPTION OF CORRELATION PROCEDURES

This guideline provides a general approach on how a model-ship power correlation can be established. It shall be based on systematic comparison between sea trial results and predictions from model scale tests. The correlation is a correction for any systematic error in model test and powering prediction procedures, including any facility bias. It is therefore recommended that each institution maintains its own model-ship power correlation [1].

3.1   General Procedure and minimum requirements for determination of towing tank specific correlation factors

A correlation factor is derived from the comparison of sea trial data and model test results. This correlation factor accounts for effects not covered by the prediction method, mainly uncertainties of the tests and the prediction method itself; and assumptions made herein (see ITTC

Recommended Procedures and Guidelines: Performance Prediction Method [1]). The following three basic schemes are presented exemplarily:

1. C_A correlation scheme is based on the difference in total resistance, deduced from the sea trials.
2. C_P-C_N correlation scheme is based on the relation of delivered powers (see also ITTC 1978 Performance Prediction Method [1])
3. ΔC_{FC}-Δw_C correlation scheme also results in a resistance correction.

There is strong tendency to use a correlation scheme correcting the vessels' resistance rather than power only, but in any case only one single correlation scheme shall be applied. Before comparing sea trial results and prediction from model test, the following preconditions must be satisfied:

1. Full scale sea trial results are evaluated and corrected according to ITTC recommended procedure (see [2])
2. The prediction for trial condition based on model tests is calculated for the same conditions as the evaluated and corrected sea trial results (i.e. draught, speed, water temperature, water density, etc.).

With the preconditions fulfilled, the determination of C_P(tank, ship type......etc.) is straight forward as it is simply the ratio of the delivered power in sea trials to the predicted power from the model test results:

$$C_P = \frac{P_{D,Trial}}{P_{D,Tank}}$$

It is the same with C_N

The determination of C_A requires additional effort. In an iterative process, the performance prediction is evaluated by altering the C_A value until the corrected delivered power at sea trials is met.

The iterative process begins with the delivered power obtained from the sea trials. The total resistance $R_{T,trial}$ then can be derived from:

$$R_{T,trial} = \frac{P_{D,trial} \cdot \eta_D(C_A)}{V}$$

With $C_T = \frac{R_T}{\frac{\rho}{2} \cdot V^2 \cdot S}$ it follows that

$$C_{T,trial} = \frac{P_{D,trial} \cdot \eta_D(C_A)}{\frac{\rho}{2} \cdot V^3 \cdot S}$$

Finally, following ITTC standard performance prediction method [1], C_A can be expressed by:

$$C_A = C_{T,trial} - C_W - \Delta C_F - C_F(1 + k) - C_{AA}$$

Here all coefficients except $C_{T,trial}$ are to be taken equal to those used for the model test prediction, whereas:

$$C_W = C_T - \Delta C_F - C_F(1 + k) - C_A - C_{AA}$$

The wind coefficient and the frictional resistance coefficient including the roughness allowance are determined according to the ITTC performance prediction method [1].

As parts of η_D depend on the self-propulsion point given by the advance coefficient J, which in turn depends on C_A, an iterative approach is necessary to determine C_A.

The accuracy of C_A determined using the above formulae is highly dependent on the quality of P_D and V determined in sea trials. Please note the influence of speed is to the power of three in this context.

For correlation schemes applying ΔC_{FC} and Δw_C a similar approach can be used. As this correlation scheme also corrects the resistance, again an iterative procedure is needed. Input parameters are $P_{D, \text{trial}}$, n_{trial}. This results in a system of two equations with two unknowns:

$$n_{\text{trial}} = \frac{(1 - w + \Delta w_C) \cdot V}{J \cdot D}$$

$$C_{T,trial} = C_W + \Delta C_F + C_F(1 + k) + C_A + C_{AA} + \Delta C_{FC}$$

3.2 Minimum Requirements

The following minimum requirements have to be met in order to maintain consistency in the data and to obtain a valid dataset suitable for deriving a correlation formula:

- Geometric conformity of ship hull, appendages and propeller
- Model tests and full scale trials shall be performed in accordance with the ITTC recommended procedures
- When performing the analysis, all sea trial results shall be evaluated according to the same procedure (ITTC Recommended Procedures and Guidelines: Analysis of Speed/Power Trial Data [2])
- When deriving a correlation factor, consistent methods shall be applied for predictions from the model test.

3.3 Parameters of the correlation model

Each towing tank is using its own, specific regression model for the correlation scheme. Consequently, the correlation formulae depend on different variables and do not have the same number of degrees-of-freedom. Usually the correlation formulae are not made public as they are proprietary know-how of the towing tanks. From the various studies and publications, a few candidate parameters used in the correlation models are listed below:

- Ship dimensions (Displacement)
- Model scale (λ)
- Hull form characteristics (L/B, B/T, CB, etc.)
- Reynolds number (Re)
- Tank characteristics (e.g. size of model in relation to tank size)
- Draught of the vessel (T)

The regression model has to be addressed by multivariate regression analysis. The significance of the individual parameters has to be tested by statistical instruments. In order to obtain statistical significant results, the sample has to be of a certain minimum size. This depends on the number of parameters used for the correlation scheme.

3.4 Uncertainties in the Source Data and the Influence on the Correlation Factors

The uncertainty in the model-ship correlation factor incorporates uncertainties from the model tests, uncertainties associated with the full scale prediction procedure and uncertainties related to sea trials and sea trial evaluation. Further uncertainties may arise from geometry deviations of the actual hull, propeller and hull deflections during sea trials.

ITTC Guideline 7.5-02-01-01 [3] provided general guidance on how to assess uncertainty in experimental hydrodynamics.

ITTC provided additional guidelines listed below on how to assess uncertainty in resistance and propulsion tests:

- 7.5-02-02-02
General Guideline for Uncertainty Analysis in Resistance Tests
- 7.5-02-02-02.1
Example for Uncertainty Analysis of Resistance Tests in Towing Tanks
- 7.5-02-02-02.2
Practical Guide for Uncertainty Analysis of Resistance Measurement in Routine Tests

- 7.5-02-03-01.2
Propulsion, Performance Uncertainty Analysis, Example for Propulsion Tests

4. REFERENCES AND BIBLIOGRAPHY

[1] ITTC 7.5-02-03-01.4, Recommended Procedures and Guidelines: 1978 ITTC Performance Prediction Method, 2014.

[2] ITTC 7.5-04-01-01.2, Recommended Procedures and Guidelines: Analysis of Speed/Power Trial Data, ITTC 2014.

[3] ITTC 7.5-02-02-02, Recommended Procedures and Guidelines: Guide to the Expression of Uncertainty in Experimental Hydrodynamics, ITTC 2008.

Appendix A : **STUDY ON THE DRAUGHT DEPENDENCY OF C_A CORRELATION FACTOR (INFORMATIVE)**

This study was carried out by selected towing tanks in order to identify in how far draught dependencies of the correlation factors (e.g. C_A) can be handled in a uniform way.

A.1. Background

Full scale speed trials are most commonly performed at one draught only, typically ballast draught for dry cargo ships. The EEDI-speed is derived at a loaded draught. Hence, the speed trial results have to be converted from ballast to full load. This is done by using model test predictions for the two draughts. The correlation factors for ballast draught are normally well validated using feedback from a large number of sea trials, whereas there is very limited statistics available in the world to validate the correlation factors for other draughts. This introduces an uncertainty when determining the EEDI speed.

Test facilities world-wide have addressed this problem in different ways. Some facilities assume that the correlation factors derived at ballast draught are also valid for full load. Other facilities are assuming that the correlation factors vary with the draught. This has led to a large discrepancy in the full load speed power predictions between the different test facilities in the world.

The question on how the correlation factors vary with draught has been discussed widely in the community in the recent past.

A.2. General guidelines

One solution would be that those yards or institutes that do have statistics of multi-draught sea trials or performance data are willing to share this. Some data of this kind have been published in the "2015 Industry Guidelines from the MEPC Joint Industry Working Group". A large number of data based on the experiences are presented as ΔCp (Cp-ballast minus Cp-full load) against the ratio of the displacements for the two draughts, i.e. it indicates a correlation-factor-to-draught-relation.

A problem with this approach is that correlation factors are by nature specific for a given towing tank and for a given extrapolation method. Each towing tank institute uses its own variant of the ITTC extrapolation method. The following items are some, but not all, choices that can affect the draught dependency:

- Type of correlation factors, C_P - C_N or ΔC_{FC} – Δw_C.
- Use of C_A: none at all, a function of Reynolds number, or a function of main dimensions?
- Form factor: none, from empirical relations, from Prohaska plot, or other?
- Wind resistance: from wind tunnel test, empirical formula, or other?
- Hull roughness, dependent on draught?

A.3. Method-dependency study

In order to study how the differences in extrapolation method affect the correlation-factor-to-draught-relations, we performed a small survey among a few selected ITTC members. Two fictive model test cases were provided together with fictive sea trial results, for two draughts. The participants were firstly asked to evaluate the model test data with their own extrapolation method. Secondly, to pretend that they would use the provided fictive sea trial data to adjust their own correlation factors, in the same way as they would normally do at their institute. As the last step, the participants were asked to compute the difference of the adjusted correlation factors for the two draughts, i.e. C_P or ΔC_{FC} .

The result is shown in Figure 1. Clearly, there is a large dependency between C_P and the extrapolation method (i.e. the facility). The conclusion is that correlation-factor-to-draught-relations cannot be valid in common. They have to be derived individually for each facility.
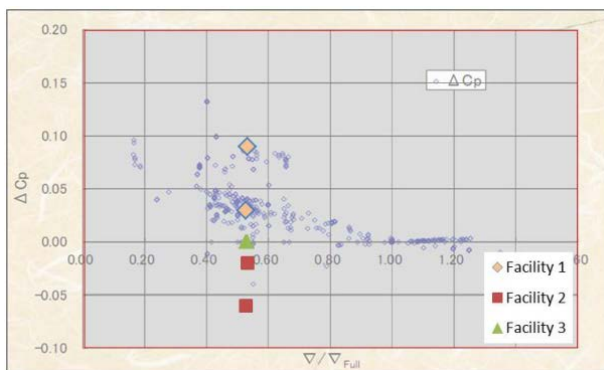

Figure 1: Result of method-dependency survey. (Blue marks come from the SAJ-study referred to in "2015 Industry Guidelines for Calculation and Verification of the EEDI.")

A.4. Individual guidelines

Even though it is highly appreciated that yards and other organizations publish full scale data, as the mentioned SAJ-study, it is concluded above that these cannot be used in common. However, for many test facilities getting hold of a sufficient amount of multi-draught full scale data is unmanageable task. One solution would be that full scale data is published together with the corresponding model scale data. With published model and full scale data, each facility could check their own correlation-factor-to-draught-relation using their own variant of extrapolation method.

ITTC could assist their members in this question by persuading yards and ship-owners to publish full scale data together with model scale data. The type of full scale data that can be used is:

- Speed trials at different draughts carried out in a sequence.
- Full load speed trials carried out once the ship is taken in operation, to be compared with the yard speed trials at ballast.
- Several in-service speed trials carried out at different draughts during operation.
- Comparison of performance index at various draughts from operational data over longer periods.

In any of these cases, care should be taken that the full scale data is of sufficient quality and contain sufficient number of individual samples (individual hull forms). Moreover, the effect of fouling will be significant when comparing speed trials separated in time, which can lead to misleading conclusions. The latter should be subject of future work in order to develop suitable correction strategies.

A.5. Summary and Conclusions

- It is very important to clarify how the draught should influence on the correlation factors used for model test extrapolation.

- Since each model basin uses their own variant of extrapolation method, it is not possible to generate general guidelines. Each model test facility has to derive their own correlation-factor-to-draught-relations.

- ITTC can assist by persuading yards and ship owners to provide multi-draught model and full scale data.

Appendix B :**RESULTS OF THE SAJ-ITTC STUDY (INFORMATIVE)**

B.1. Basic Principles

For dry cargo vessels it is difficult or unfeasible to conduct speed trials at full load condition or a stipulated condition. For such cases speed trials are performed at "trial condition" and the result of the speed trials is converted to that of full load/stipulated condition using tank test results.

The power curve for full load/stipulated condition is obtained from the results of the speed trials at 'trial condition' by using the power curves predicted by the tank tests. The tank tests shall be carried out at both conditions; 'trial condition', corresponding to the actual condition during the speed trials, and full load/stipulated condition.

Power curve prediction based on the ITTC Recommended Procedure 7.5-02-03-01.4 "1978 ITTC Performance Prediction Method (PPM)" requires not only tank test results but also model-ship correlation factors. Therefore the difference of the model-ship correlation between the full load/stipulated condition and "trial condition" is very important.

SAJ-ITTC study was conducted so as to offer the relationship of model-ship correlation between the full load/stipulated condition and "trial condition".

SAJ-ITTC Study for the Model-Ship Correlation between Full Load and Ballast Condition

Since each tank test institution or shipyard is generally using its own model-ship correlation method based on the ITTC PPM", this study was carried out by evaluating difference of model-ship correlation between full load/stipulated condition and trial condition against ratio of displacement of trial condition to full load/stipulated condition. The correlation method used in this study was according to method 1 (C_P - C_N) or method 2 (ΔC_{FC} - Δw_C) of the 1978 ITTC PPM.

The study was originally carried out based on the data from SRC, Shipbuilding Research Centre of Japan. Number of data is 773 of all kind of ships.

- Design Full load condition 312
- The other condition 461

Figure 1 shows difference of correlation factor for the method 1 (δC_P) versus displacement ratio ($\nabla_{trial}/\nabla_{full}$). The tendency indicates increasing δC_P values with decreasing displacement. These values, however, are provided by clients and not derived from standardized correlation procedures. Most of them are not confirmed at sea trial or other.

Figure 2 shows difference of model-ship correlation for method 2 ($\delta \Delta C_{FC}$) using the same data as those for method 1. The sea trial data of 59 series of tanker data are also plotted in Figure 2. The scatter is not small, but is distributed around the SRC data.
Where,

$\delta C_P = C_{Ptrial} - C_{Pfull}$
$\delta \Delta C_{FC} = \Delta C_{FCtrial} - \Delta C_{FCfull}$
C_{Ptrial} : model-ship correction factor in method 1 at trial condition

C_{Pfull} : model-ship correction factor in method 1 at full load condition

$\Delta C_{FCtrial}$: model-ship correction factor in method 1 at trial condition

ΔC_{FCfull} : model-ship correction factor in method 1 at full load condition

∇_{trial} : displacement at trial condition in cubic meter (m^3)

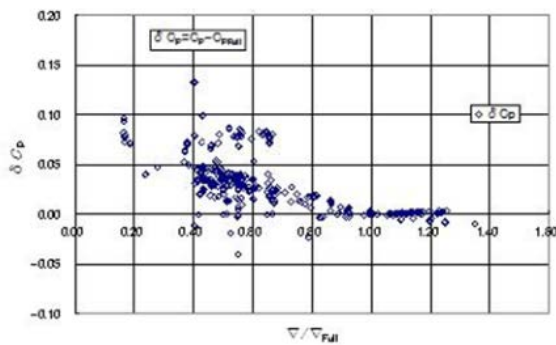∇_{full} : displacement at trial condition in cubic meter (m^3)

Figure 1 Variation of δC_P as a function of the displacement ratio. Data provided to demonstrate general trend, not to be used for correlation purposes.
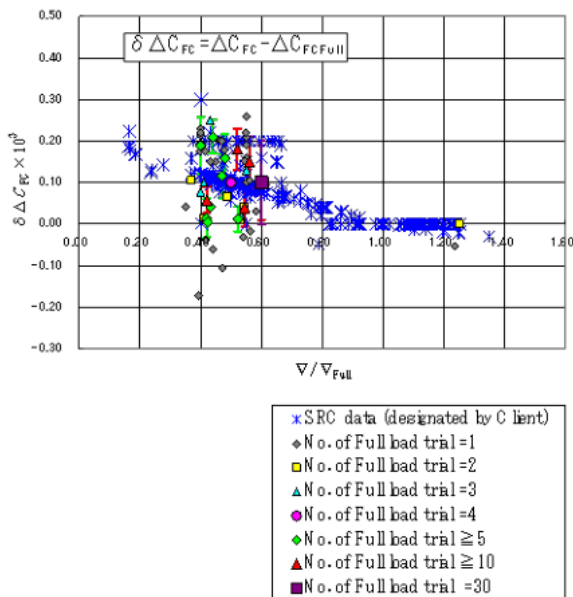

Figure 2 Variation of $\delta \Delta C_{FC}$ as a function of the displacement ratio. Data provided to demonstrate general trend, not to be used for correlation purposes.

B.2. Conclusions

- It is very important to evaluate the difference of the model-ship correlation between the full load/stipulated condition and trial condition.

- SAJ-ITTC study was conducted to offer the relationship of model-ship correlation between the full load/stipulated condition and trial condition.

- From the results of plotting the model-ship correlation obtained from SAJ-ITTC study, it is observed that the scatter of actual sea trial data is distributed around the SRC data.

- Data not suitable for general use/not applicable to other model basins for correlation purposes;