# ITTC Quality System Manual

# Recommended Procedures and Guidelines

## Guideline

# Guideline on the determination of model-ship correlation factors

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|---|---|
| 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.

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 might obtain slightly different results on the model due to individual characteristics.

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

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

Model

- Model roughness
- Propeller roughness
- Turbulence stimulation
- Model level of detail
  This means to which level of detail individual institutes built their models, e.g. bow thruster tunnels fully modelled or just recesses.

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 contract speed-power performance is usually defined on loaded drafts, commonly called “design draft”. For the verification of the Energy Efficiency Design Index (EEDI)[1] also loaded draughts have been defined as reference. 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 under consideration.

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 guideline presents reasons for test facilities using 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

| | |
|---|---|
| $C_\mathrm{A}$ | Correlation allowance on resistance. |
| $C_\mathrm{AA}$ | Wind resistance coefficient |
| $C_\mathrm{B}$ | Block coefficient |
| $C_\mathrm{F}$ | 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 |
| $C_\mathrm{T}$ | Total resistance coefficient |
| $C_\mathrm{W}$ | Wave-making resistance coefficient |
| $J$ | Propeller advance coefficient |
| $P_\mathrm{D}$ | Delivered power |
| $P_\mathrm{E}$ | Effective power |
| $Re$ | Reynolds number |
| $R_\mathrm{T}$ | Total resistance |
| $S$ | Wetted surface |
| $T$ | Draught of the ship |
| $V$ | Ship speed |
| $\Delta C_\mathrm{F}$ | Roughness allowance |
| $\Delta C_\mathrm{FC}$ | Individual correction term for roughness allowance |
| $\Delta w_C$ | Wake fraction allowance |
| $\eta_\mathrm{D}$ | Propulsive efficiency or quasi-propulsive coefficient |
| $\rho$ | Water density |
| $t$ | Water temperature |
| $\rho$ | Viscosity of water |

## 3. DESCRIPTION OF CORRELATION PROCEDURES

This guideline provides a general approach on how a model-ship power correlation can be established. This shall be based on systematic comparison between sea trial results and speed-

[1] MARPOL Annex VI, Chapter 4, see [4]

power performance predictions. The correlation shall be a correction for any systematic error in the model-ship – power correction, including any facility and procedural 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 the results of the predictions. This correlation factor accounts for effects not covered by the applied models, procedures and assumptions made herein (see ITTC Recommended Procedures and Guidelines: Performance Prediction Method [1]). The following four basic schemes for correlation are available in the performance prediction method:

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 and rates of revolution.
3. $\Delta C_{FC}$-$\Delta w_C$ -correlation scheme which also results in a resistance correction.
4. $C_P$-$C_{NP}$ -correlation assuming power identity. Here the procedure for deriving the correlation factors is equivalent to the $C_P$-$C_N$ correlation scheme.

Using a correlation scheme correcting the vessel's resistance ($C_A$) is favorable as the relationship between rates of revolution and delivered power is derived from physical principles.

Only one single correlation scheme should be applied at a time. Before calculating correlation factors from the comparison of sea trial results and predictions, 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 is made for the same conditions as the evaluated and corrected sea trial results (i.e. draught, speed, water temperature, water density, etc.).
3. The prediction for trial condition has been made without applying any correlation factors.

The following consecutive steps need to be carried out for deriving a correlation formula:

1. Find an individual correlation factor for each pair of available $P_{\mathrm{D,Trial}}/P_{\mathrm{D,Model}}$ and $n_{\mathrm{Trial}}/n_{\mathrm{Model}}$, respectively. This should be done for all speeds where corresponding pairs are available.

Find input parameters which are correlated with the resulting factors

From the whole set of individual correlation factors and the identified input parameters, regression formulas can be derived (see 3.3 Parameters of the correlation model)

In case a $C_P$ –correlation model is used, 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:

$$C_P = \frac{P_{\mathrm{D,Trial}}}{P_{\mathrm{D,Model}}}$$

The same applies to $C_N$.

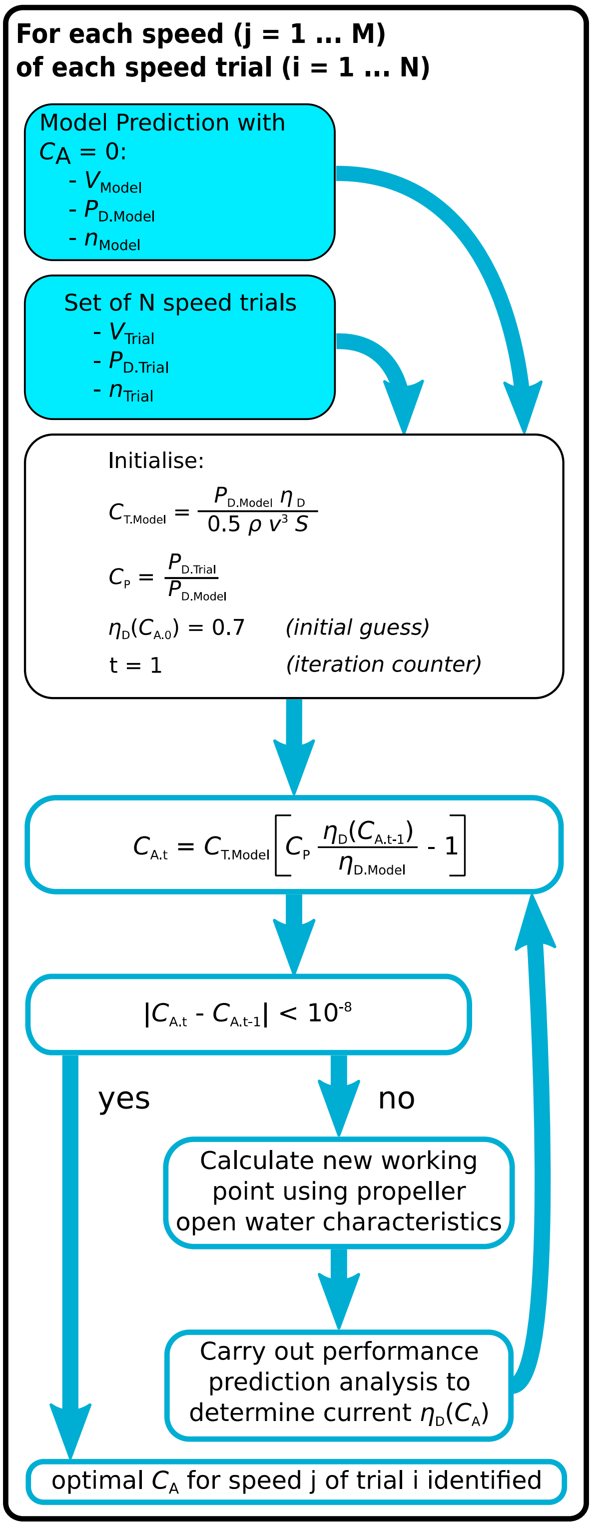


Figure 1. Determining optimal $C_A$ iteratively

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 solution is necessary as the propulsive efficiency $\eta_D$ represents a non-linear relationship between effective power $P_E$ and delivered power $P_D$. For the determination of the correlation factor $C_A$, the values for $\eta_H$ and $\eta_R$ are taken from the model tests while the propeller efficiency $\eta_0$ is obtained from the propeller open water characteristics.

The prediction of full scale power with $C_A = 0$ delivers:

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

and

$$P_{D,Model} = C_{T,Model} \cdot \frac{\rho}{2} \cdot V^3 \cdot S \cdot \frac{1}{\eta_{D,Model}}$$

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

Together with the relationship of delivered power $C_P$ as derived above the following relationship can be found:

$$C_A = C_{T,Model}\left[C_P \frac{\eta_{D,Trial}(C_A)}{\eta_{D,Model}} - 1\right]$$

From this $C_A$ can be found for individual pairs of values by iteration as shown in the flowchart (Figure 1).

For correlation schemes applying $\Delta C_{FC}$ and $\Delta w_C$ a similar approach can be used. This correlation scheme corrects the resistance as well as the propulsive efficiency. Again an iterative procedure is needed. The determination of the correlation factors requires a system of two equations with two unknowns to be solved:

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

$$C_{\mathrm{T,trial}} = C_{\mathrm{W}} + \Delta C_F + C_{\mathrm{F}}(1 + k) + C_{\mathrm{A}} + C_{\mathrm{AA}} + \Delta C_{\mathrm{FC}}$$

The accuracy of the correlation factors received by the above formulae is highly dependent on the quality of $P_{\mathrm{D}}$ and $V$ determined in sea trials. Please note the influence of speed is to the power of three in this context.

### 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 various studies and publications, examples for candidate parameters for use in correlation models have been found as listed below:

- Ship dimensions (Displacement)
- Model scale ($\lambda$)
- Hull form characteristics (L/B, B/T, $C_{\mathrm{B}}$, $L_{\mathrm{CB}}$, etc.)
- Reynolds number ($Re$)
- Tank characteristics (e.g. size of model in relation to tank size)
- Draught of the vessel ($T$)

The regression model may be derived 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. According to Green [5] the following rule of thumb may be used for the determination of required sample sizes:

$$n > 50 + 8 \cdot m$$

$n$ number of samples, $m$ number of independent variables in the regression formula.

### 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 provides 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, 2020.

[2] ITTC 7.5-04-01-01.1, Recommended Procedures and Guidelines: Preparation, Conduct and Analysis of Speed/Power Trials, ITTC 2020.

[3] ITTC 7.5-02-01-01, Recommended Procedures and Guidelines: Guide to the Expression of Uncertainty in Experimental Hydrodynamics, ITTC 2014.

[4] International Maritime Organization (IMO), MARPOL Consolidated Edition 2017

[5] Green, S.B.: How many subjects does it take to do a regression analysis? Multivariate Behavioural Research, 26, 499-510

# 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 $\Delta C_P$ ($C_P$-ballast minus $C_P$-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 $\Delta C_{FC}$ – $\Delta w_C$.
- 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 $\Delta C_{FC}$ .

The result is shown in Figure A1. 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.

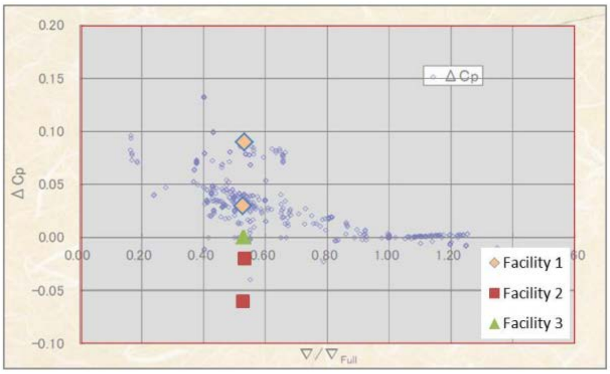


Figure A1: Result of method-dependency survey. (Blue marks come from the SAJ-study referred to in “2015 Industry Guidelines for Calculation and Verification of the EEDI.”)

## 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 ($\Delta C_{FC}$ - $\Delta w_C$) 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 B1 shows difference of correlation factor for the method 1 ($\delta C_P$) versus displacement ratio ($\nabla_{\text{trial}}/\nabla_{\text{full}}$). The tendency indicates increasing $\delta C_P$ 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 B2 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 B2. The scatter is not small, but is distributed around the SRC data.

Where,

$\delta C_P$ $= C_{P\text{trial}} - C_{P\text{full}}$

$\delta\Delta C_{FC}$ $= \Delta C_{FC\text{trial}} - \Delta C_{FC\text{full}}$

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

$C_{P\text{full}}$: model-ship correction factor in method 1 at full load condition

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

$\Delta C_{FC\text{full}}$: model-ship correction factor in method 1 at full load condition

$\nabla_{trial}$: displacement at trial condition in cubic meter ($m^3$)

$\nabla_{full}$: displacement at trial condition in cubic meter ($m^3$)

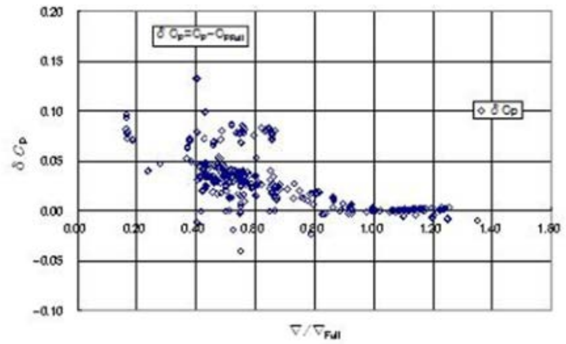


Figure B1 Variation of $\delta C_P$ as a function of the displacement ratio. Data provided to demonstrate general trend, not to be used for correlation purposes.

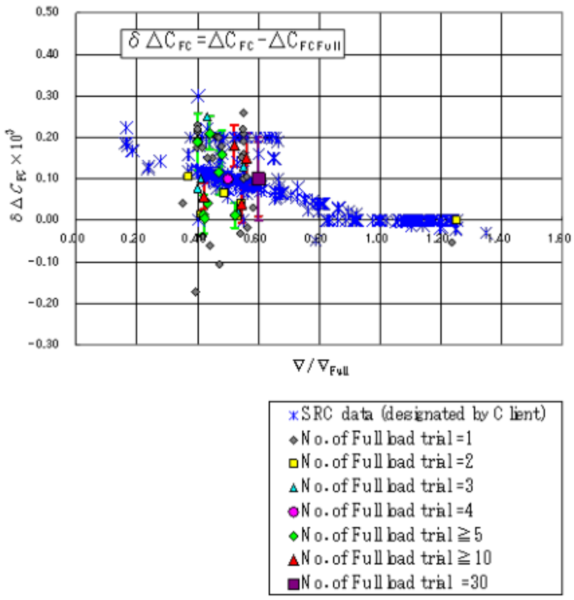


Figure B2 Variation of $\delta \Delta C_{FC}$ as a function of the displacement ratio. Data provided to demonstrate general trend, not to be used for correlation purposes.

## 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;