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BSI Standards Publication

# Ships and marine technology — Guidelines for the assessment of speed and power performance by analysis of speed trial data

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**National foreword**

This British Standard is the UK implementation of ISO 15016:2015. It supersedes BS ISO 15016:2002 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee EPL/80, Maritime navigation and radiocommunication equipment and systems.

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This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.



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INTERNATIONAL STANDARD

**ISO 15016**

Second edition
2015-04-01

# Ships and marine technology — Guidelines for the assessment of speed and power performance by analysis of speed trial data

*Navires et technologie maritime — Lignes directrices pour l'évaluation des performances de vitesse et de puissance par analyse des données d'essais de vitesse*

Reference number
ISO 15016:2015(E)

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# Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 8, *Ships and marine technology*, Subcommittee SC 6, *Navigation and ship operations*.

This second edition cancels and replaces the first edition (ISO 15016:2002), which has been technically revised.

Annexes A, B, C, D, E, F, G, H, I and J form a normative part of this International Standard, whereas Annex K is informative.

# Introduction

This International Standard concerns the method of analysing the results obtained from speed trials.

The primary purpose of speed and power trials is to determine a ship's performance in terms of ship's speed, power and propeller shaft speed under prescribed ship's conditions and thereby verify the satisfactory attainment of a ship's speed stipulated by Energy Efficiency Design Index (EEDI) regulations and/or contract. Ship's speed is that realized under conditions stipulated by contract and/or EEDI regulations, which are usually; smooth hull and propeller surfaces, no wind, no waves, no current and deep water of 15°C.

In general it cannot be expected that all such stipulated conditions will be met during the actual trials. In practice, certain corrections for the environmental conditions have to be considered, such as for water depth, wind, waves and current [1][2].

The purpose of this International Standard is to define the basic requirements for the performance of speed trials, and provide procedures for evaluation and correction of speed trial data, covering all influences which may be relevant to the individual trial runs based on sound scientific grounds, thereby enabling owners and others to have confidence in the validity of the final results.

This International Standard is intended to help the interested parties achieve the desired target accuracy of, within 2 % in shaft power and 0,1 kn in speed.

The procedure specified in this International Standard has been developed largely on the basis of published data on speed trials and on ship's performance, the more important among them being listed in Clause 2.

ISO has invited the International Towing Tank Conference (ITTC) to co-operate on the development of a new standard for speed/power trials taking into account the new guidelines issued by ITTC and approved by MEPC65 for EEDI. The contribution of the STA-group and the ITTC is highly appreciated.

**Substitution of terms clause**

This International Standard is generally applied to those ships for which survey and certification of EEDI is required under International Maritime Organization (IMO) Resolution MEPC.214(63) [as amended by MEPC.234(65)]. In the case of other ships, to which the above IMO resolutions are not applicable, the terms or phrases of this International Standard are deemed to be replaced as necessary (e.g. "agreement between the Shipbuilder, the Owner and the Verifier" shall be read as "agreement between the Shipbuilder and the Owner" etc.)

# Ships and marine technology — Guidelines for the assessment of speed and power performance by analysis of speed trial data

## 1 Scope

The primary purpose of speed and power trials is to determine a ship's performance in terms of ship's speed, power and propeller shaft speed under prescribed ship's conditions and thereby verify the satisfactory attainment of a ship's speed stipulated by EEDI regulations and/or contract.

This International Standard defines and specifies the following procedures to be applied in the preparation, execution, analysis and reporting of speed trials for ships, with reference to the effects which may have an influence upon the speed, power and propeller shaft speed relationship:

— the responsibility of each party involved,

— the trial preparations,

— the ship's condition,

— the limiting weather and sea conditions,

— the trial procedure,

— the execution of the trial,

— the measurements required,

— the data acquisition and recording,

— the procedures for the evaluation and correction,

— the processing of the results.

The contracted ship's speed and the ship's speed for EEDI are determined for stipulated conditions and at specific draughts (contract draught and/or EEDI draught). For EEDI, the environmental conditions are: no wind, no waves, no current and deep water of 15°C.

Normally, such stipulated conditions are unlikely to be experienced in part or in full during the actual trials. In practice, certain corrections for the environmental conditions such as water depth, surface wind, waves, current and deviating ship draught, have to be considered. For this purpose, during the speed and power trials, not only are shaft power and ship's speed measured, but also relevant ship data and environmental conditions.

The applicability of this International Standard is limited to ships of the displacement type.

In this International Standard, it was decided that the unit to express the amount of an angle should be "rad" (radian) and that the unit of speed should be "m/s" (metres per second). Nevertheless, "°" (degree) as a unit for an angle and "knots" as a unit for speed may be used. However, the units for the angles and speeds which appear in calculation formulas are to be "rad" and "m/s" without exception. Moreover, for the convenience of the users of this International Standard, numerical values using the units of degree and knots are stated jointly at appropriate places.

If it is physically impossible to meet the conditions in this International Standard, a practical treatment is allowed based on the documented mutual agreement among the Owner, the Verifier and the Shipbuilder.

 

## 2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ITTC 7.5-04-01-01.4:2002, *ITTC Recommended Procedures and Guidelines, Speed and Power Trials, Part 4: Instrumentation Installation and Calibration*

ITTC 7.5-02-07-02.2, *ITTC Recommended Procedures and Guidelines, Prediction of Power Increase in Irregular Waves from Model Test*

## 3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

**3.1**
**brake power**
power delivered by the output coupling of the propulsion machinery before passing through any speed-reducing and transmission devices

**3.2**
**contract power**
brake power or shaft power that is stipulated in the new build or conversion contract between the Shipbuilder and the Owner

**3.3**
**contract speed**
ship's speed to be achieved as agreed within the terms of the new build/conversion contract

**3.4**
**Double Run**
two consecutive speed runs at the same power setting on reciprocal headings

Note 1 to entry: See 3.16 for speed runs.

**3.5**
**EEDI**
Energy Efficiency Design Index as formulated by IMO

**3.6**
**EEDI power**
brake power that is stipulated by the Energy Efficiency Design Index (EEDI) regulations

**3.7**
**EEDI Speed**
ship's speed achieved under the conditions specified by the IMO Resolution MEPC.245(66) (as amended)

**3.8**
**ideal conditions**
ideal weather and sea conditions: no wind, no waves, no current and deep water of 15°C

**3.9**
**measured ship's speed**
ship's speed during a speed run derived from the headway distance between start and end position and the elapsed time of the speed run

**3.10**
**Owner**
party that signed the new building or conversion contract with the Shipbuilder

 

**3.11**
**power setting**
setting of engine throttle and propeller shaft speed for fixed pitch propellers and setting of the pitch angle for controllable pitch propellers

**3.12**
**propeller pitch**
design pitch for a fixed pitch propeller

**3.13**
**pitch angle**
operating pitch angle of a Controllable Pitch Propeller (CPP)

**3.14**
**shaft power**
net power supplied by the propulsion machinery to the propulsion shafting after passing through all speed-reducing and other devices and after power for all attached auxiliaries has been taken off and accounting for losses in shaft between propeller and the location of power measurement at the shaft

**3.15**
**Shipbuilder**
shipyard that signed the new building or conversion contract with the Owner

**3.16**
**ship's speed**
speed of the ship that is realised under the stipulated conditions

Note 1 to entry: See also measured ship's speed, contract speed and EEDI speed.

**3.17**
**sister ships**
ships with identical main dimensions, body lines, appendages and propulsion system built in a series by the same Shipyard

**3.18**
**S/P trials**
speed and power trials to establish the relationship between power and speed for a particular ship

**3.19**
**S/P trial agenda**
document outlining the scope of a particular S/P trial

**3.20**
**speed run**
ship's track with specified heading, distance and duration for which the measured ship's speed and shaft power are calculated

Note 1 to entry: This International Standard contains the procedures on how to conduct the trial and table(s) portraying the runs to be conducted.

**3.21**
**tank tests**
model tank tests for the prediction of the speed power relation for the stipulated conditions

**3.22**
**trial baseline**
the track of the first S/P run

**3.23**
**Trial Leader**
duly authorised (Shipbuilder's representative) person responsible for the execution of all phases of the S/P trials including the pre-trial preparation

**3.24**
**trial log**
all the data recorded before, during and after the S/P trial

**3.25**
**Trial Team**
team that consists of the Trial Leader, the Owner's representative, the appointed persons responsible for the S/P trial measurements and, if the ship requires EEDI, the Verifier

**3.26**
**Verifier**
third party responsible for verification of the EEDI

**3.27**
**zero pitch**
Controllable Pitch Propeller (CPP) blade angle at which the pitch angle at the representative radius is equivalent to zero

## 4 Symbols and abbreviated terms

### 4.1 Symbols

| | |
|---|---|
| $A_{\mathrm{LV}}$ | is the lateral projected area above the waterline including superstructures |
| $A_{\mathrm{M}}$ | is the midship section area under water |
| $A_{\mathrm{OD}}$ | is the lateral projected area of superstructures above upper deck |
| $a_Q$, $b_Q$, $c_Q$ | are the factors for the torque coefficient curve |
| $a_T$, $b_T$, $c_T$ | are the factors for the thrust coefficient curve |
| $A_{\mathrm{XV}}$ | is the transverse projected area above the waterline including superstructures in square metres |
| $B$ | is the ship's breadth |
| $B(x)$ | is the sectional breadth |
| $B_{\mathrm{f}}$ | is the bluntness coefficient |
| $C_{\mathrm{AA}}$ | is the wind resistance coefficient; $C_{\mathrm{AA}}(0)$ means the wind resistance coefficient in head wind |
| $C_{\mathrm{B}}$ | is the block coefficient |
| $C_{\mathrm{F}}$ | is the frictional resistance coefficient for the actual water temperature and water density |
| $C_{\mathrm{F0}}$ | is the frictional resistance coefficient for the reference water temperature and water density |
| $C_{\mathrm{MC}}$ | is the horizontal distance from midship section to centre of lateral projected area $A_{\mathrm{LV}}$, where + means forward from midship |
| $C_{\mathrm{Pv}}$ | is the vertical prismatic coefficient |
| $C_{\mathrm{T0}}$ | is the total resistance coefficient for the reference water temperature and water density |
| $C_U$ | is the coefficient of advance speed |
| $D$ | is the propeller diameter |
| $E$ | is the directional spectrum |
| $e_{\mathrm{i}}$ | is the scale correlation factor of the wake fraction |
| $F_{\mathrm{D}}$ | is the skin friction correction force same as in the normal self-propulsion tests |
| $Fr$ | is the Froude number |

 

| | |
|---|---|
| $F_X$ | is the external tow force measured during load variation test |
| $g$ | is the acceleration of gravity |
| $G$ | is the angular distribution function |
| $h$ | is the water depth |
| $H_1(m)$ | is the function to be determined by the distribution of singularities $\sigma(x)$ which represents a periodical disturbance by the ship |
| $H_{1/3}$ | is the significant wave height |
| $H_{BR}$ | is the height of top of superstructure (bridge etc.) |
| $H_C$ | is the height from waterline to centre of lateral projected area $A_{LV}$ |
| $H_{S1/3}$ | is the significant height of local swell |
| $H_{W1/3}$ | is the significant height of local wind driven waves |
| $(i)$ | is the run number |
| $I_1$ | is the modified Bessel function of the first kind of order 1 |
| $J$ | is the propeller advance coefficient |
| $J_{id}$ | is the propeller advance coefficient in the ideal condition |
| $J_{ms}$ | is the propeller advance coefficient in the trial condition |
| $k$ | is the wave number |
| $K_1$ | is the modified Bessel function of the second kind of order 1 |
| $K_Q$ | is the torque coefficient |
| $K_{Qid}$ | is the torque coefficient in the ideal condition |
| $K_{Qms}$ | is the torque coefficient in the trial condition |
| $K_T$ | is the thrust coefficient |
| $K_{Tid}$ | is the thrust coefficient in the ideal condition |
| $K_{Tms}$ | is the thrust coefficient in the trial condition |
| $k_{yy}$ | is the non-dimensional radius of gyration in the lateral direction |
| $L_{BWL}$ | is the distance of the bow to 95 % of maximum breadth on the waterline |
| $L_{OA}$ | is the ship's length overall |
| $L_{PP}$ | is the ship's length between perpendiculars |
| MCR | is the Maximum Continuous Rating |
| $m_n$ | is the $n^{th}$ moment of frequency spectrum |
| $n_{id}$ | is the corrected propeller shaft speed |
| $n_{ms}$ | is the measured propeller shaft speed |
| $P_1$ | is the power corresponding to displacement volume $\nabla_1$ during the S/P trial |
| $P_2$ | is the power corresponding to displacement volume $\nabla_2$ used in the tank test |
| $P_{Bms}$ | is the measured brake power |
| $P_{Did}$ | is the delivered power in the ideal condition |
| $P_{Dms}$ | is the delivered power in the trial condition |
| $P_{Full,P}$ | is the power at full load/stipulated condition predicted by the tank tests |
| $P_{Full,S}$ | is the power at full load/stipulated condition obtained by the S/P trials |
| $P_{Sms}$ | is the measured shaft power |
| $P_{Trial,P}$ | is the power at the trial condition predicted by the tank tests |
| $P_{Trial,S}$ | is the power at the trial condition obtained by the S/P trials |

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|---|---|
| $R_{AA}$ | is the resistance increase due to relative wind |
| $R_{AS}$ | is the resistance increase due to deviation of water temperature and water density |
| $R_{AW}$ | is the resistance increase due to waves |
| $R_{AWL}$ | is the mean resistance increase in long crested irregular waves, as substitute for $R_{AW}$ |
| $R_{AWM}$ | is the mean resistance increase in regular waves based on Maruo's theory, which is calculated from the radiation and diffraction components |
| $R_{AWR}$ | is the correction term of $R_{AWM}$ |
| $R_F$ | is the frictional resistance for the actual water temperature and water density |
| $R_{F0}$ | is the frictional resistance for the reference water temperature and water density |
| $R_{id}$ | is the resistance in the ideal condition |
| $R_{ms}$ | is the resistance in the trial condition |
| $R_{T0}$ | is the total resistance for the reference water temperature and water density |
| $R_{wave}$ | is the mean resistance increase in regular waves |
| $R_{wave}^{EXP}$ | is the mean resistance increase in regular waves measured in the tank tests |
| $s$ | is the directional spreading parameter |
| $S$ | is the wetted surface area |
| $S_S$ | is the full scale wetted surface, the same value as used in the normal self-propulsion test |
| $S_\eta$ | is the frequency spectrum |
| $t$ | is the thrust deduction factor |
| $T_C$ | is the period of variation of current speed |
| $T_{deep}$ | is the draught; for a trim condition $T_{deep}$ is the deepest draught |
| $t_{id}$ | is the thrust deduction factor in the ideal condition |
| $T_M$ | is the draught at midships |
| $t_{ms}$ | is the thrust deduction factor in the trial condition |
| $V'_{WR}$ | is the corrected relative wind velocity at the vertical position of the anemometer |
| $V'_{WT}$ | is the averaged true wind velocity at the vertical position of the anemometer |
| $V_A$ | is the speed of flow into propeller |
| $V_C$ | is the current speed |
| $V_G$ | is the measured ship's speed over ground |
| $V_{G1}$ | is the measured ship's speed over the ground on the first of four runs |
| $V_{G2}$ | is the measured ship's speed over the ground on the second of four runs |
| $V_{G3}$ | is the measured ship's speed over the ground on the third of four runs |
| $V_{G4}$ | is the measured ship's speed over the ground on the fourth of four runs |
| $V_S$ | is the ship's speed through the water |
| $V_{WR}$ | is the relative wind velocity |
| $V_{WRref}$ | is the relative wind velocity at the reference height |
| $V_{WT}$ | is the true wind velocity |
| $V_{WTref}$ | is the true wind velocity at the reference height |
| $w_M$ | is the model wake fraction |
| $w_{Mid}$ | is the model wake fraction in the ideal condition |
| $w_{Mms}$ | is the model wake fraction in the trial condition |
| $w_S$ | is the full-scale wake fraction |

| | |
|---|---|
| $w_{Sid}$ | is the full-scale wake fraction in the ideal condition |
| $w_{Sms}$ | is the full-scale wake fraction in the trial condition |
| $x$ | is the longitudinal coordinate |
| $Z_a$ | is the vertical position of the anemometer |
| $Z_{ref}$ | is the reference height for the wind resistance coefficients |
| $Z_{\Gamma}$ | is the vertical displacement relative to waves in steady motion |
| $\alpha_P$ | is the power ratio |
| $\alpha_T$ | is the effect of draught and encounter frequency |
| $\alpha$ | is the angle between ship's heading and component waves; 0 means head waves |
| $\beta_W$ | is the slope of the line element *dl* along the water line |
| $\Gamma$ | is the Gamma function |
| $\Delta P$ | is the required correction for power |
| $\Delta R$ | is the total resistance increase |
| $\Delta t$ | is the deviation of the thrust deduction factor |
| $\Delta V$ | is the decrease of ship's speed due to shallow water |
| $\Delta w_M$ | is the deviation of the wake fraction |
| $\Delta \eta_R$ | is the deviation of the relative rotative efficiency |
| $\zeta_A$ | is the wave amplitude |
| $\eta_D$ | is the propulsive efficiency coefficient |
| $\eta_{Did}$ | is the propulsive efficiency coefficient in ideal condition |
| $\eta_{Dms}$ | is the propulsive efficiency coefficient in trial condition |
| $\eta_M$ | is the transmission efficiency |
| $\eta_O$ | is the propeller open water efficiency |
| $\eta_{Oms}$ | is the propeller efficiency in the ideal condition |
| $\eta_R$ | is the relative rotative efficiency |
| $\eta_{Rid}$ | is the relative rotative efficiency in the ideal condition |
| $\eta_{Rms}$ | is the relative rotative efficiency in the trial condition |
| $\eta_S$ | is the shaft efficiency |
| $\theta_m$ | is the angle between ship's heading and wave direction relative to the bow; 0 means head waves |
| $\lambda$ | is the scale factor |
| $\mu$ | is the smoothing range |
| $\xi_n$, $\xi_V$ | are derived considering the load variation effect as described in Annex J |
| $\xi_P$ | is derived considering the load variation effect as described in Annex J |
| $\rho_A$ | is the mass density of air |
| $\rho_M$ | is the water density in the model test |
| $\rho_S$ | is the water density for the actual water temperature and salt content |
| $\rho_{S0}$ | is the water density for the reference water temperature and salt content |
| $\tau_P$ | is the load factor equal to $K_T / J^2$ |
| $\tau_{Pid}$ | is the load factor in the ideal condition |
| $\tau_{Pms}$ | is the load factor in the trial condition |
| $\psi$ | is the ship's heading |
| $\psi'_{WR}$ | is the corrected relative wind direction at the vertical position of the anemometer |
| $\psi'_{WT}$ | is the averaged true wind direction at the vertical position of the anemometer |

| | |
|---|---|
| $\psi_{WR}$ | is the relative wind direction; 0 means head winds |
| $\psi_{WRref}$ | is the relative wind direction at the reference height |
| $\psi_{WT}$ | is the true wind direction in Earth system |
| $\omega$ | is the circular frequency of regular waves |
| $\omega_E$ | is the circular wave frequency of encounter |
| $\nabla_1$ | is the displacement volume during the S/P trial |
| $\nabla_2$ | is the displacement volume used in the tank test |

### 4.2 Abbreviated terms

| | |
|---|---|
| CPP | Controllable Pitch Propeller |
| IMO | International Maritime Organization |
| ITTC | International Towing Tank Conference |
| JASNAOE | The Japan Society of Naval Architects and Ocean Engineers |
| JONSWAP | Joint North Sea Wave Project |
| MEPC | Marine Environmental Protection Committee in IMO |
| SNAJ | The Society of Naval Architects of Japan |
| SNAME | The Society of Naval Architects and Marine Engineers, USA |
| STA-Group | An international group of owners, shipyards, research institutes, classification societies and universities studying and improving sea trial procedures and Sea Trial Analyses (STA) |

## 5 Responsibilities

### 5.1 Ship builders' responsibilities

The Shipbuilder is responsible for the planning, conduct and evaluation of the S/P trials. The Shipbuilder shall ensure that:

— an appropriately authorized Trial Leader is appointed to oversee all aspects of the S/P trial,

— all permits and certificates required for the ship to go to sea are provided,

— all qualified personnel necessary for operating the ship and all engines, systems and equipment required during the sea trials, are on board,

— all regulatory bodies: the Classification Society; the Owner; ship agents; suppliers; subcontractors; harbour facilities; departments organizing the supply of provisions, fuel, water, towage, etc., necessary for conducting these trials; have been informed, are available and on board when required,

— all safety measures have been checked,

— all fixed, portable and individual material (for crew, trial personnel and guests) is on board and operative,

— any safety systems for conducting safe S/P trials have been checked in accordance with the administrative requirements,

— an inclining test has been performed and/or at least a preliminary stability booklet including the S/P trials condition has been approved, in accordance with the SOLAS Convention,

— all ship data relevant for the S/P trials Preparation, Conduct, Analysis and Reporting are made available to the Trial Team prior to the S/P trials. This data shall include the information requested in Annex A as well as the results of the tank tests for this ship at trial draught and trim, EEDI draught and trim and Contract draught and trim.

Speed and power measurements and analysis shall be conducted by persons acknowledged as competent to perform those tasks, as agreed between the Shipbuilder, the Owner and the (where applicable) Verifier.

The Shipbuilder shall arrange for divers to inspect the ship's hull and propulsor(s) if necessary.

The Shipbuilder is responsible for the overall trial co-ordination. A pre-trial meeting between the Trial Team and the ship's crew shall be held to discuss the various trial events and to resolve any outstanding issues.

The Trial Leader shall maintain contact with the Trial Team on the preparation, execution and results of the S/P trials.

### 5.2 The Trial Team

The Trial Team is responsible for correct measurements and reporting of the S/P trials according to this International Standard and for the analysis of the measured data to derive the ship's speed and power at the stipulated conditions.

The Trial Team is responsible for the following:

— conducting an inspection of the ship, including the condition of the hull and propeller(s)/propulsor(s), prior to the commencement of the S/P trial,

— the provision, installation, operation and removal of all necessary trial instrumentation and temporary cabling,

— providing the ship's Master and the Owner's representative with a preliminary data package and initial analysis before disembarking,

— delivering a final report on completion of full analysis of the measurements taken during the trial.

## 6 Trial preparations

The success of the S/P trials largely depends on the preparations. In this Clause the most important steps are summarized.

### 6.1 Step 1: Installation and Calibration

Assemble all the trials instrumentation in the configuration that is to be used on the ship. Test the instrumentation system for any malfunctioning or other complications.

Apart from the obvious inputs such as; shaft torque, propeller shaft speed and DGPS, it is important to check:

a) gyrocompasses,

b) anemometer system,

c) propeller pitch (of each propeller),

d) ship's draught measurement system (if available),

e) water depth measuring system.

After the trial instrumentation is installed, all shipboard input signals to be recorded during the S/P trials shall be calibrated prior to the trials. For this purpose the sensors shall be cycled throughout the full operating range of the system.

This is accomplished by:

— slewing the gyrocompasses,

— changing the propeller pitch.

Prior to departure for S/P trials and with the ship in a steady loading condition, all draught marks, water temperature and specific density, and ship's draught measuring system (if available) shall be measured and recorded. If no ship's draught measuring system is available, all tank sounding data shall be recorded.

The shaft power shall be derived from torque and propeller shaft speed.

Shaft torque shall be measured by means of a calibrated permanent torque sensor or strain gauges on the shaft. The measurement system shall be certified for power measurements with a bias error smaller than 1 % so that an overall bias error smaller than 2 % (on board the ship undergoing trials) can be achieved.

Alternative shaft torque measurement devices with a certified accuracy equal to or better than the above figures are acceptable.

As part of the S/P trial preparation, the torsion meter's zero torque readings shall be determined since there is a residual torque in the shaft, which is resting on the line shaft bearings. The torsion meter zero setting is to be carried out in accordance with its maker's instructions. If not specified otherwise, the zero torque value is determined with the ship at rest by turning the shaft ahead and astern and taking the mean of these two readings as the zero value (refer to ITTC 7.5-04-01-01.4 2002).

The shaft material properties, e.g. the G-Modulus shall be fully described and documented by the Shipbuilder. If no certificate based on an actual shaft torsional test is available, the G-Modulus of 82 400 $N/mm^2$ shall be used. The shaft diameter used in the power calculation shall be derived from the shaft circumference measured at the location of the torsion meter. In the case of controllable pitch propeller(s) there might be a drilling diameter to be taken into account (to be supplied by Shipbuilder).

When shaft torque measurement is not possible, an alternative power measurement method recommended by the engine manufacturer and approved by the Owner and the Verifier is acceptable.

As part of the pre-trial calibration for a ship equipped with controllable pitch propellers, the procedure shall be as follows:

a) Prior to dock-out the oil distribution mechanism showing the propeller pitch shall be checked for zero pitch;

b) Check zero pitch reading in the measurement system against the mechanical reading in the oil distribution box;

c) Determine the design pitch, maximum ahead pitch and maximum astern pitch, then adjust the ship indicators to reflect the measurements. Establish the corrections necessary to account for changes in pitch due to shaft compression as thrust increases and temperature effects on the propeller pitch control rod.

An important deliverable of this stage will be a document describing the test set-up, including evidence of the calibrations that have been carried out.

It is important to note that there are two stages to consider in performing instrumentation checks; the pre-trial check procedures and the post-trial check to verify the calibration results.

## 6.2 Step 2: S/P trial agenda and pre-trial meeting

Before departure, a pre-trial meeting shall be held to fix the S/P trial agenda. During this meeting two items shall be addressed:

— Approval of the S/P trial agenda,

— Approval of the procedures and the consequential correction methods to be used to calculate the trial speed and to deliver the speed trial report, i.e. Clauses 11 to 13.

# 7 Ship's condition

The condition of a ship undergoing an S/P trial shall be as follows:

## 7.1 Displacement

The difference between the ship's actual displacement and the required displacement shall be less than 2 % of the required displacement. If tank test results are used for the analysis of the S/P trials, the deviation of the actual displacement during the S/P trials shall be within 2 % of the displacement used during the tank test.

The ship's draught, trim and displacement shall be obtained immediately prior to the S/P trials by averaging the ship draught mark readings at the perpendiculars and midships port and starboard.

In the event that reading the draught marks will be unsafe or provide an inaccurate result, displacement determination shall be conducted either by reading the internal draught measurement system or by evaluating all tank soundings.

Displacement shall be derived from the Bonjean data or using quadratic equations with hydrostatic data, taking into consideration the hog/sag using the draught data (forward, aft and at half length) and the density of the water.

The ship shall be brought into a loading condition that is as close as possible to contract condition and/or the condition at which tank tests have been carried out. The loading condition shall be confirmed at zero ship's speed.

## 7.2 Trim

The trim shall be maintained within very narrow limits. For the even keel condition the trim shall be less than 0,1 % of the length between perpendiculars. For the trimmed trial condition, the fore draught shall be within ± 0,1 m of the ship's condition for which tank test results are available.

## 7.3 Hull and propeller

The ship shall have a clean hull and propeller(s) for the sea trial. Hull roughness and marine growth can increase the resistance of the ship significantly [3] but are not corrected for in S/P trials. Therefore, it is recommended that the hull and propeller(s) be carefully inspected before the sea trial, and cleaned as needed and as per coating manufacturer's recommendation. The dates of last docking and hull and propeller cleaning shall be recorded in the S/P trials report.

# 8 Trial boundary conditions

During the S/P trial, there may be many conditions that deviate from the contract condition. The objective during the S/P trial is to minimize the number of influencing factors.

Although there are correction methods for certain deviations from the contract condition, these methods are only valid up to certain limits.

In order to arrive at reliable S/P trial results the boundary conditions shall not exceed the values given in this Clause.

## 8.1 Location

High wind and sea state in combination with a heading deviating from head waves and following waves can require the use of excessive rudder deflections to maintain heading which cause excessive fluctuations in shaft torque, propeller shaft speed and measured ship's speed.

The S/P trials shall be conducted in a location where the environmental conditions are expected to be constant and have only the smallest possible impact on the ship in order to avoid unexpected environmental effects in the S/P trial results.

This means that the S/P trial range shall be located in a sheltered area (i.e. limited wind, waves and current). Ideally, the area shall be free from hindrance by small boats and commercial traffic.

## 8.2 Wind

The wind velocity during the S/P trial shall not be higher than:

Beaufort number[1]) 6, for ships with

$$L_{PP} > 100 \text{ m}$$

or

Beaufort number 5, for ships with

$$L_{PP} \leq 100 \text{ m}$$

where $L_{PP}$ is the ship's length between perpendiculars in metres.

## 8.3 Sea state

The total significant wave height $H_{1/3}$ is derived from the significant wave heights of local wind driven seas $H_{W1/3}$ and swells $H_{S1/3}$ by the formula:

$$H_{1/3} = \sqrt{H_{W1/3}^2 + H_{S1/3}^2} \quad (1)$$

For all correction methods related to waves, the following empirical criteria shall be applied in relation to ship's length in order to determine the maximum allowable correction for resistance increases due to waves:

when the wave spectrum encountered during the S/P trials is measured:

$$H_{1/3} \leq 2{,}25\sqrt{L_{PP} / 100} \quad (2)$$

when the wave height is derived from visual observations:

$$H_{1/3} \leq 1{,}50\sqrt{L_{PP} / 100} \quad (3)$$

The above limits are illustrated in Figure 1.

1) The Beaufort Scale is given in Annex B.

When use is made of transfer functions of added resistance from dedicated model tests the wave spectrum encountered during the S/P trials shall be measured unless the wave height is less than:

$$H_{1/3} \leq 0,50\sqrt{L_{PP} / 100} \tag{4}$$

where, in each case:

$L_{PP}$ is the ship's length between perpendiculars in metres;

$H_{1/3}$ is the total significant wave height in metres;

$H_{W1/3}$ is the significant height of local wind driven waves in metres;

$H_{S1/3}$ is the significant height of local swell in metres.

The directions of the waves and swells may be derived from visual observations in all cases.

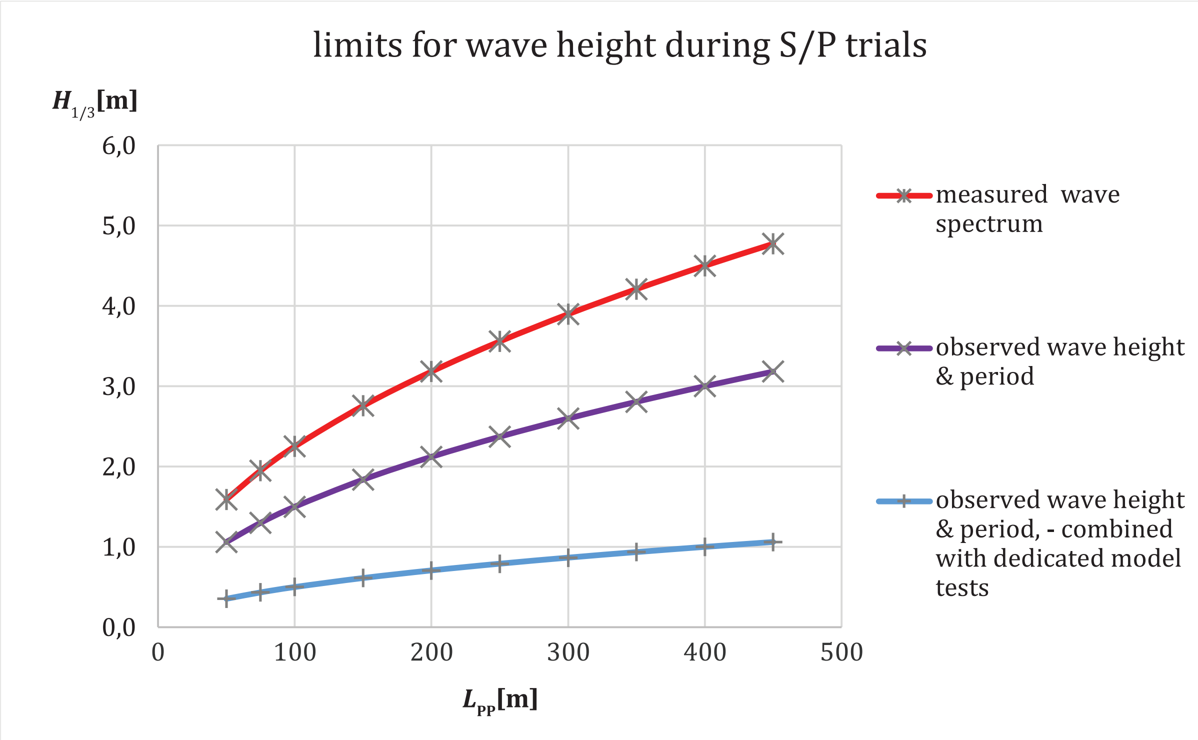



**Figure 1 — Limits for allowable wave height**

## 8.4 Water depth

There are correction methods that compensate for shallow water effects (see Annex G). However, it is preferable to avoid the corrections by selecting a suitable S/P trial location. If the water depth in the S/P trial area is less than the larger of the values obtained from the following two formulae, shallow water correction may be applied [6],[16] :

$$h = 3\sqrt{B \cdot T_M} \text{ and } h = 2{,}75\frac{V_S^2}{g} \tag{5}$$

The value of water depth to be used for correction shall not be less than the larger value obtained from the following two formulae [6] :

$$h = 2\sqrt{B \cdot T_M} \text{ and } h = 2\frac{V_S^2}{g} \tag{6}$$

where:

$h$ is the water depth in metres;

$B$ is the ship's breadth in metres;

$T_M$ is the ship's draught at midships in metres;

$V_S$ is the measured ship's speed in metres per second;

$g$ is the acceleration of gravity in metres per second squared.

Furthermore, significant variations in the bottom contours shall be avoided. The actual water depth during each speed run shall be read from the ship's instruments or the sea chart and recorded in the trial log.

### 8.5 Current

Ideally S/P trials shall be conducted in a location where the current speed and direction are essentially uniform throughout the trial area.

In cases of current time history deviating from the assumed parabolic / sinusoidal trend and the change of the current speed within the timespan of one Double Run is more than 0,5 knots, neither of the correction methods in Annex F are applicable. Areas where this may occur shall be avoided for S/P trials.

## 9 Trial procedures

### 9.1 Parameters that shall be recorded

In this Clause an overview is given of the parameters that influence the trial speed. All these parameters shall be measured and recorded as accurately as possible.

For this purpose a division has been made between parameters measured during each run and parameters measured at the speed trial site. Tables 1 and 2 below list the preferred measurement methods and units for each parameter.

### 9.2 Parameters measured during each run

The accepted measurement devices are given in Table 1.

**Table 1 — Parameters measured during each run**

| | Acceptable measurement devices | Unit |
|---|---|---|
| Ship's position | DGPS | Lat., Lon., ° |
| Speed over ground | DGPS (for information purpose only) | knots |
| Shaft torque<br>or Shaft power | Torsion meter with calibrated torque sensor or strain gauges<br>Power calculated from torque and propeller shaft speed | kNm<br>kW |
| Propeller shaft speed | Pick-up, optical sensor, ship's revolutions counter | $min^{-1}$ |
| Propeller pitch | Bridge replicator, indicator on shaft | ° or mm |
| Time | GPS Time | hh:mm:ss or UTC |
| Water depth | Ship echo sounder and nautical charts | m |
| Ship's heading | Gyro compass, or compass- DGPS | ° |
| Relative wind velocity<br>and direction | Ship's anemometer, however if not available, a dedicated trial anemometer | m/s, ° |
| Wave height, period and direction<br>Swell height, period, and direction | Wave measuring device such as wave buoy, wave radar, or lidar. Observation by multiple mariners. The average observed wave height derived from observations by multiple mariners is assumed to be equal to the significant wave height over the run length. | m, s, ° |
| Bow acceleration (STAWAVE-1) | Acceleration meter | $m/s^2$ |
| Date | Calendar | yyyy-mm-dd |

## 9.3 Parameters measured at the speed trial site

The accepted measurement devices are given in Table 2.

**Table 2 — Parameters measured at the speed trial site**

| | | |
|---|---|---|
| Water density | Salinity sensor, Conductivity Density Temperature (CDT) sensor | $kg/m^3$ |
| Water temperature | Thermometer, CDT sensor | °C |
| Air temperature | Thermometer | °C |
| Air pressure | Barometer | hPa, mb |
| Torsion meter zero setting | Torsion meter with calibrated torque sensor or strain gauges | kNm |
| Trial area | Geographical position (Lat-Long) by DGPS | dddd-mm |
| Vertical position of anemometer | General arrangement plan of the ship | m |
| Draughts | Physical observation and / or calibrated draught gauges | m |

## 9.4 General information

Prior to the trial, the relevant data in Annex A shall be recorded, and shared among the Shipyard, the Owner and (where applicable) the Verifier.

The S/P Run Data as specified in Annex A will be recorded during the trials.

## 9.5 Tank test information

The quality and accuracy of tank tests play a large role in the outcome of full scale S/P trials. For some ship types sea trials are normally carried out in ballast condition, whereas the contractual condition is normally defined as the design loaded condition. For the conversion from ballast trial results to loaded condition the difference between the ballast and loaded tank test curves is used. Therefore, an accurate tank test and a validated consistent method for extrapolation to full scale are required.

The tank tests shall be conducted according to the following criteria:

a) Tank tests shall be conducted at the contract draught and trim and the EEDI draught and trim, as well as the trial draught and trim.

b) Tank tests following the scheme of ITTC Recommended Procedures for Resistance and Propulsion Tank tests [5], including load variation tests shall be conducted.

c) The same methods, procedures and empirical coefficients shall be used to extrapolate the model scale values to full scale for all draughts and trims. Where different empirical coefficients for the different draughts are used, full details shall be recorded in the tank test report, including justification by means of full scale S/P trial data for the specific ship type, size, loading condition, tank test facility and evaluation method.

d) The tank test report shall be transparent and give sufficient information to enable the Verifier to check the tank test results related to the sea trial analysis.

## 9.6 Scope and conduct of the measurements

### 9.6.1 Ship track and speed over ground

The ship's position and speed shall be measured by a global positioning system such as DGPS. The positioning system shall be operated in the differential mode to ensure sufficient accuracy. Position and speed shall be monitored and stored continuously.

### 9.6.2 Torque

The calibration of the torque measurement shall not be altered during the S/P trials.

### 9.6.3 Wind

The ship's own anemometer shall be used. However, if not available, a dedicated trial anemometer is to be used. The anemometer shall be as clear as possible from the superstructure.

### 9.6.4 Water depth

Water depth can be determined by examining a sea chart of the trial area or measured by the ship's echo sounder during the runs. It is important that the echo sounder is calibrated before the speed runs and that the ship's draught (the transducer depth) is taken into account. Calibration shall be combined with a comparison of indicated depth against the water depth given on the chart in the trial area.

### 9.6.5 Waves

Preferably, the wave height, wave period and direction of waves induced by local wind and swell originating from remote wind, shall be measured during the S/P trials. For this purpose, wave buoys in the S/P trial area or instruments on-board the ship such as wave radar, lidar or wave scanner may be used. The wave measurement equipment shall be calibrated and the accuracy shall be validated and documented.

If, for the wave correction, use is made of transfer functions of added resistance in waves derived from model tests for the subject ship, the wave spectrum encountered during the S/P trials shall be measured unless the wave height satisfies: $H_{1/3} \leq 0,50\sqrt{L_{PP} / 100}$ (see 8.3).

If use is made of the empirical wave correction methods described in Annex D (without specific model tests), and if the wave heights satisfy: $H_{1/3} \leq 1,50\sqrt{L_{PP} / 100}$ (see 8.3), the encountered wave heights, periods and directions of both wind waves and swells may be determined from observations by multiple experienced mariners, including the Owner's representative and the Verifier. In addition to the wave observations wave data provided by an experienced and independent meteorological office may be used as well.

#### 9.6.6 Temperature and density

The local water temperature and density shall be recorded to enable the calculation of the ship's displacement and corrections with regard to viscosity. The temperature shall be taken at water inlet level. Air temperature and pressure shall be measured using a calibrated thermometer and barometer, respectively.

#### 9.6.7 Current

Current speed shall be determined as part of the evaluation of each run.

When using the 'Mean of means' method, after the two (2) Double Runs with the same power setting, the current speed is calculated from the measured speed at each run and the 'Mean of means' value of those two (2) Double Runs (see F.2).

Alternatively the 'Iterative' method may be utilized to establish the current speed (see F.1).

## 10 Conduct of the trial

On the day of and during the S/P trial, a number of pre-requisites shall be met in order to arrive at reliable trial results. In this Clause an overview is given of the minimum requirements.

### 10.1 Initiation

Prior to the S/P trials the weather forecast shall be studied.

Where wave height, period or wave directions are derived from visual observation, the schedule for the S/P Trials shall be arranged such that all speed runs around EEDI power are conducted by daylight.

The engine plant configuration during the S/P trial shall be consistent with the normal ship operation at sea.

Prior to the S/P trials, the following actions shall be taken at zero speed through the water:

a) draught reading as described in 7.1 and calculation of displacement,

b) zero setting of shaft torque meter,

c) measuring water temperature and density.

### 10.2 Ship's track during trial

The S/P trial runs shall be conducted over the same ground area. For each base course, each speed run shall be commenced (COMEX) and completed (FINEX) at the same place.

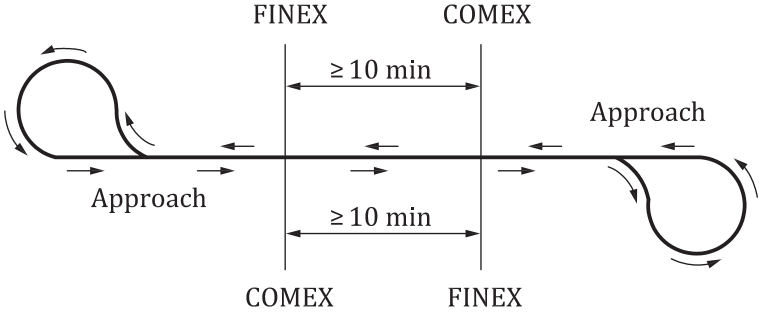



**Figure 2 — Path of ship during Double Run**

Modified Williamson turns or similar types of manoeuvre shall be executed between each run to return the ship to the reciprocal heading on, or parallel to, the trial baseline. Parallel means within one ship's length of the trial baseline (see also 10.6). This procedure shall be used to avoid different sea states, wind or current conditions. Engine throttles, rpm setting(s) or pitch setting(s) shall not be altered during this period. The rudder angle used in this manoeuvre shall be such that the ship's speed loss in the turn is minimised.

## 10.3 Run duration and timing

The S/P Trial duration shall be long enough to accommodate a speed/power measurement within the required accuracy. The run duration shall be the same for all speed runs with a minimum of 10 minutes. The speed runs for the same power setting shall be evenly distributed in time.

## 10.4 Trial direction

The speed runs shall be carried out by heading into and following the dominant wave direction.

Consequently, once the heading for the speed run and the reciprocal heading for the return run are fixed, the selected tracks shall be maintained very precisely throughout the S/P trial. It is imperative that extremely tight control is exercised during the execution of the S/P trials to minimize as many variables as possible that could unduly influence the speed/power relationship.

## 10.5 Steering

An experienced helmsman or adaptive autopilot will be required to maintain heading during each speed run. Minimum rudder angles are to be used while maintaining a steady heading.

During the speed run, the maximum amplitude of rudder used shall be not more than 5 degrees.

## 10.6 Approach

The S/P trial approach shall be long enough to ensure a steady-state ship's condition prior to commencement (COMEX) of each speed run. During the approach run the ship shall be kept on course with minimum rudder angles.

No fixed approach distance can be given. In order to verify that the ship reached the steady ship's condition the measured values of propeller shaft speed, shaft torque and ship's speed at the control position shall be monitored. When all three values are stable the ship's condition shall be deemed 'steady'.

## 10.7 Number of speed runs

All S/P trials shall be carried out using Double Runs, i.e. each run shall be followed by a return run in exactly the opposite direction (see also 10.2) and at the same engine settings.

The number of speed runs required depends on the current correction method to be applied (see Annex F).

a) 'Iterative' method;

b) 'Mean of means' method.

Whenever possible, the runs at EEDI power shall be conducted in daylight to enable a clear visual observation of the wave conditions. For trials in which the encountered wave spectrum and the wave direction (both wind waves and swells) are derived by measurements, these runs may also be conducted without daylight.

### 10.7.1 'Iterative' method

To determine the speed/power curve for the first ship of a ship series, a minimum of four (4) Double Runs at three (3) different power settings are required.

These power settings shall be adequately distributed within the power range of 65 % MCR and 100 % MCR and comprise at least:

— Two (2) Double Runs for the first ship and one (1) Double Run (at the same power setting) for sister ships around EEDI / Contract power,

— One (1) Double Run below EEDI / Contract power,

— One (1) Double Run above EEDI / Contract power.

If the wave height is around the limiting conditions and significant ship motions are observed, one (1) additional Double Run at that power setting shall be conducted.

#### 10.7.2 'Mean of means' method

To determine the speed/power curve for the first ship of a ship series, a minimum of six (6) Double Runs at three (3) different power settings are required.

These power settings shall be adequately distributed within the power range of 65 % MCR and 100 % MCR and comprise at least:

— Two(2) Double Runs around EEDI / Contract power,

— Two(2) Double Runs below EEDI / Contract power,

— Two(2) Double Runs above EEDI / Contract power.

Two (2) Double Runs compensate for the effect of current and second order current variations [4],[6] . In order to obtain sufficient accuracy, the time intervals between each run at the same power setting shall be more or less the same (time interval deviation of 25 % is allowed).

If the results of the S/P trials of the first ship of a series are acceptable, the second and following sister ships may be subjected to a reduced speed trial program. For such sister ships it is sufficient to conduct three (3) Double Runs at three (3) different power settings.

These power settings shall be adequately distributed within the power range of 65 % MCR and 100 % MCR and comprise at least:

— One(1) Double Run around EEDI / Contract power,

— One(1) Double Run below EEDI / Contract power,

— One(1) Double Run above EEDI / Contract power.

If the wave height is around the limiting conditions and significant ship motions are observed, and/or current variations of above 0.2 knots are encountered, one (1) additional Double Run at that power setting shall be conducted.

## 11 Data acquisition

During the S/P trial accurate recording of the speed and power relationship is of great importance.

Apart from this an accurate quantification of the boundary conditions is necessary since the ship's speed and power characteristics are extremely sensitive to factors such as hull and propeller condition, ship displacement, shallow water effects, sea state and wind velocity. Consequently, these factors shall be monitored and documented to the greatest possible extent.

During the S/P trials, two types of data acquisition shall be used. Automated, by means of a data acquisition system (measurement computer), and the manual recording of information by means of a log sheet. The objective shall always be to record as many parameters as possible by means of the measurement computer in order to increase the level of accuracy of the S/P trials.

In general, data to be acquired maybe divided into general data which are applicable to all speed runs and specific data that are varying throughout every run.

## 11.1 General data

Prior to the trial, the data specified below shall be recorded, based on measurements where relevant:

- Area of trial (in Latitude/Longitude coordinates);
- Weather condition;
- Water temperature and density;
- Air temperature;
- Vertical position of the anemometer above waterline;
- Fore, midships and aft draughts;
- Displacement calculated from the draughts;
- Trim calculated from the draughts;
- Transverse projected area above the waterline including superstructures;
- Lateral projected area of superstructures above upper deck (Fujiwara) + height of superstructure;
- Lateral projected area above the waterline including superstructures (Fujiwara) + position of centre of gravity;
- Bow acceleration (STAWAVE-1).

In order to verify the wind data measured during the S/P trials, it is recommended to record the absolute wind velocity and direction at shore based station(s) or as measured directly prior to and after finalising the speed trials while the ship is stopped.

## 11.2 Data on each run

- Date;
- Clock time at commencement;
- Time elapsed over the speed run;
- Ship's heading;
- Measured ship's speed over ground calculated from start and end position of the run and the elapsed time of the speed run;
- Propeller shaft speed;
- Propeller shaft torque and/or power;
- Propeller pitch in case of CPP;
- Relative wind velocity and direction by anemometer;
- Mean wave period, significant wave height and direction of wind driven seas;
- Mean swell period, significant swell height and direction of local swell waves;
- Mean water depth.

### 11.3 Acquisition system

The acquisition system shall record time histories of the measurements described in 11.3.1 in order to ensure quality control and to provide information that will allow for the development of uncertainty analysis.

#### 11.3.1 Minimum data

The following parameters, as a minimum, shall be continuously recorded during each speed run:

— Time;

— Propeller shaft torque or power;

— Propeller shaft speed;

— Pitch of CPP;

— Ship's position;

— Ship's heading;

— Measured ship's speed over ground;

— Relative wind direction;

— Relative wind velocity.

#### 11.3.2 System requirements

The data acquisition system shall:

a) Record all available parameters simultaneously.

b) Perform a time trace recording with a sampling rate of at least 1 Hz.

c) Display time traces of the trial parameters specified in 11.3.1.

d) Calculate statistics (mean min, max, standard deviation).

At the end of each run the data acquisition system shall display all recorded time histories to facilitate evaluation of the quality and consistency of the acquired trial data and store the readings for subsequent graphical presentation.

Furthermore, the acquisition system shall present the following statistical values for each of the measured data:

e) Trial start time.

f) Number of samples taken.

g) Maximum value.

h) Minimum value.

i) Average value.

j) Standard deviation.

Filtering of the run data is recommended to avoid "spikes" in the recorded time histories. Chauvent's criterion, which provides a ratio of maximum acceptable deviation to precision index as a function of the number of readings (N), is to be used. Readings are automatically rejected from use in the data analysis when they fall outside the selected mean value bandwidth.

#### 11.3.3 Location

The data acquisition system shall be located on the bridge.

### 11.4 Manual data collection

For those parameters that are not measured and recorded automatically by means of the data acquisition system, manual data collection using a log sheet is required (see Annex A).

The log sheet is important from two aspects:

a) First, to complete the data set, and

b) Second, to provide a backup for the automated measurements and give a written overview of the measurements.

It is important that the parameters that vary with time shall be recorded every few minutes so that the average can be determined over the run period.

An example of a log sheet to be used is shown in Annex A. The sign conventions to be used for wind and wave direction are illustrated in Figures 3 and 4.

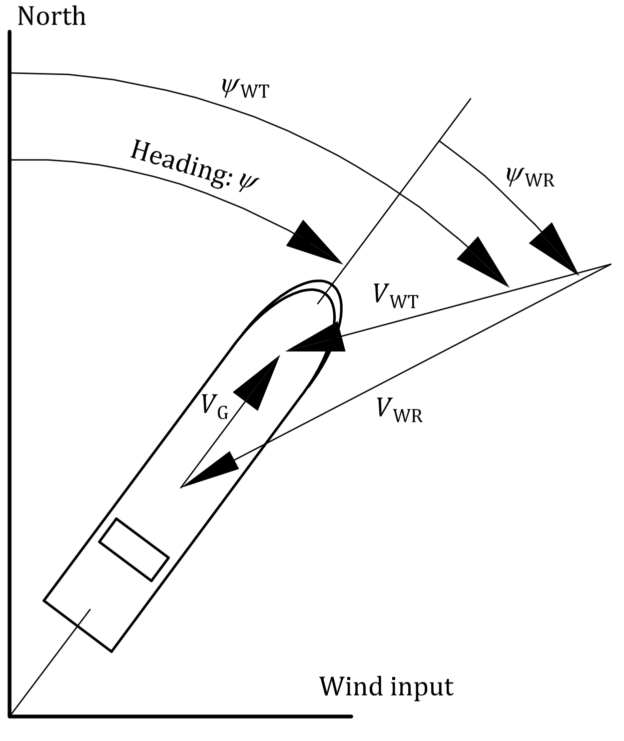



**Figure 3 — Sign convention for wind direction**

The wind direction is defined as the direction from which the wind is blowing.

Zero (0) degrees on the bow and positive to starboard (clockwise).

Input parameters:

$\psi$ is the ship's heading in degrees;

$\psi_{WR}$ is the relative wind direction in degrees; 0 means head winds;

$V_{WR}$ is the relative wind velocity in metres per second;

$V_G$ is the measured ship's speed over ground in metres per second.

Computed parameters:

$\psi_{WT}$ is the true wind direction in Earth system in degrees;

$V_{WT}$ is the true wind velocity in metres per second.

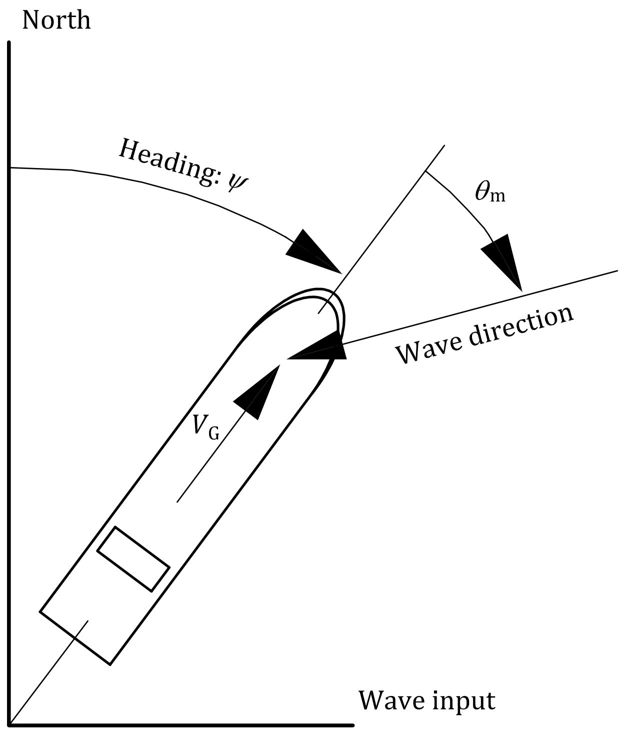



**Figure 4 — Sign convention for wave direction**

The wave direction is defined as the direction relative to the ship's heading from which the wave fronts are approaching.

Zero (0) degrees on the bow and positive to starboard (clockwise).

Input parameters:

$\psi$ is the ship's heading in degrees;

$H_{W1/3}$ is the significant height of local wind driven waves in metres;

$H_{S1/3}$ is the significant height of local swell in metres;

$\theta_m$ is the angle between ship's heading and wave direction relative to the bow in degrees; 0 means head waves;

$V_G$ is the measured ship's speed over ground in metres per second.

# 12 Analysis procedure

## 12.1 General remarks

This Clause describes the essential procedures to analyse the results of S/P trials as conducted according to Clauses 5 to 11.

The analysis includes corrections to power and speed for environmental influences during S/P trials.

This International Standard offers different methods of correction, details of which are described in the Annexes.

## 12.2 Description of the analysis procedure

The analysis of S/P trials consists of:

— evaluation of the acquired data;

— correction to power for resistance increase due to wind and waves. (see Annex C and Annex D);

— correction to power for water temperature and water density(see Annex E);

— correction to speed for current effect (see Annex F);

— correction to speed for the effect of shallow water (see Annex G);

— correction to power for displacement (see Annex H);

— presentation of the trial results.

In the following Clauses, details of the essential procedures are given.

For the power evaluation, the 'direct power' method shall be used.

Details of correction methods, including the choice of a suitable correction method, are given in the Annexes.

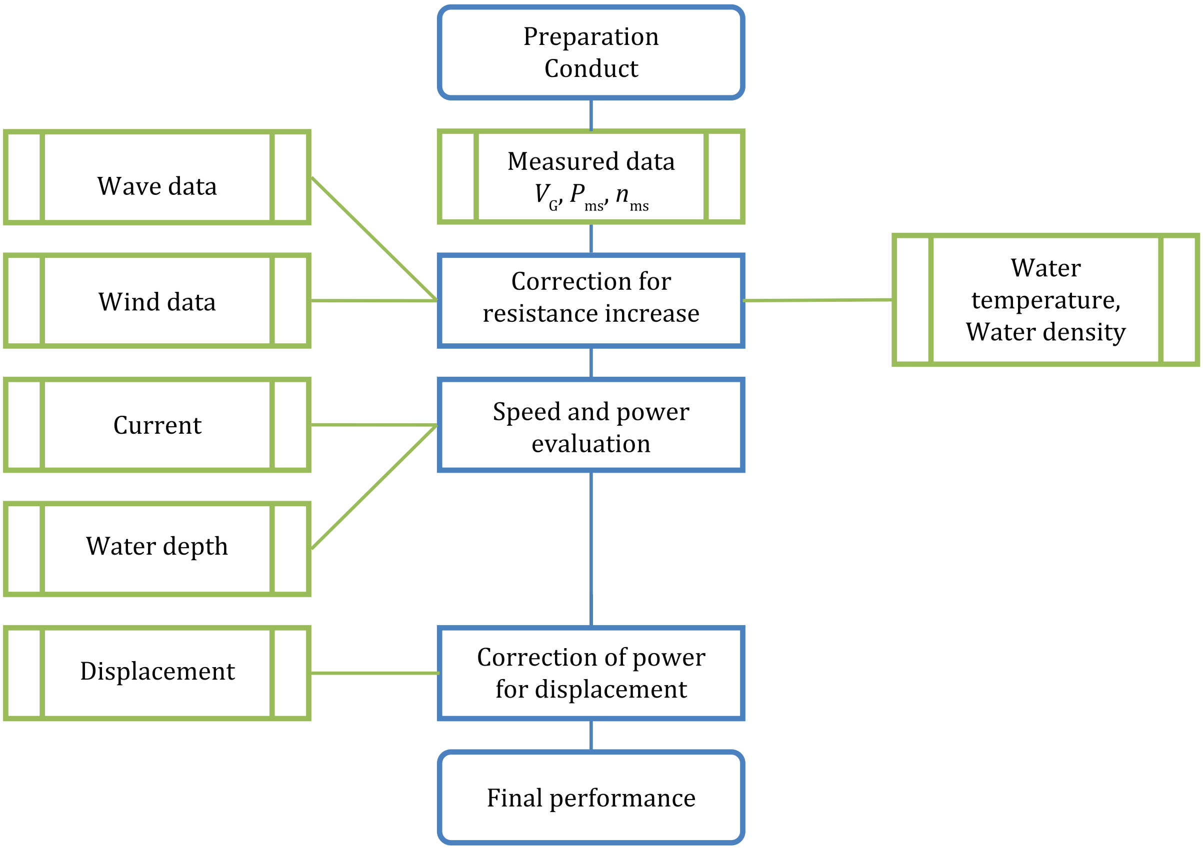



**Figure 5 — Flow chart of analysis**

### 12.2.1 Resistance data derived from the acquired data

The resistance values of each run shall be corrected for environmental influences by estimating the resistance increase $\Delta R$ as

$$\Delta R = R_{AA} + R_{AW} + R_{AS} \quad (7)$$

where:

| | |
|---|---|
| $\Delta R$ | is the total resistance increase in newtons; |
| $R_{AA}$ | is the resistance increase due to relative wind in newtons (see Annex C); |
| $R_{AW}$ | is the resistance increase due to waves in newtons (see Annex D); |
| $R_{AS}$ | is the resistance increase due to deviation of water temperature and water density in newtons (see Annex E). |

### 12.2.2 Evaluation of the acquired data

The evaluation of the acquired data consists of the calculation of the resistance value associated with the measured power value separately for every single run of the speed trials.

The reason that the associated resistance/power shall be calculated for each run is that a careful evaluation shall consider the effects of varying hydrodynamic coefficients with varying propeller loads. The recommended correction methods (except for the ones used for current effect, for shallow water effect and for displacement) are applicable to resistance values.

### 12.2.3 Evaluation based on Direct Power Method

To derive the speed/power performance of the ship from the measured speed over the ground $V_G$, power $P_{ms}$ and propeller shaft speed $n_{ms}$, the 'direct power' method shall be used.

The analysis is based on the delivered power. The relationship between delivered power in the trial condition $P_{Dms}$ and measured power is described in the following formula:

$$P_{Dms} = P_{Sms} \cdot \eta_S \quad (8)$$

where:

$P_{Dms}$ is the delivered power in the trial condition in watts;

$P_{Sms}$ is the measured shaft power in watts;

$\eta_S$ is the shaft efficiency.

or:

$$P_{Dms} = P_{Bms} \cdot \eta_M \quad (9)$$

where:

$P_{Dms}$ is the delivered power in the trial condition in watts;

$P_{Bms}$ is the measured brake power in watts;

$\eta_M$ is the transmission efficiency.

In this method, the delivered power $P_{Dms}$ is directly corrected with the power increase $\Delta P$ due to resistance increase $\Delta R$ in the trial condition.

$$P_{Did} = P_{Dms} - \Delta P \quad (10)$$

where:

$P_{Did}$ is the delivered power in the ideal condition in watts;

$P_{Dms}$ is the delivered power in the trial condition in watts;

$\Delta P$ is the required correction for power in watts.

The required correction for power $\Delta P$ is calculated by the following formula:

$$\Delta P = \frac{\Delta R V_S}{\eta_{Did}} + P_{Dms}\left(1 - \frac{\eta_{Dms}}{\eta_{Did}}\right) \tag{11}$$

where:

$\Delta P$ is the required correction for power in watts;

$\Delta R$ is the total resistance increase in newtons;

$V_S$ is the ship's speed through the water in metres per second;

$P_{Dms}$ is the delivered power in the trial condition in watts;

$\eta_{Dms}$ is the propulsive efficiency coefficient in the trial condition;

$\eta_{Did}$ is the propulsive efficiency coefficient in the ideal condition.

The propulsive efficiency coefficient in the ideal condition $\eta_{Did}$ is obtained from standard towing tank test and interpolated to the speed $V_S$.

The effect of resistance increase on the propeller loading and thus on the propulsive efficiency coefficient $\eta_{Dms}$ is derived considering the load variation effect.

The propulsive efficiency is assumed to vary linearly with the added resistance according to:

$$\frac{\eta_{Dms}}{\eta_{Did}} = \xi_P \frac{\Delta R}{R_{id}} + 1 \tag{12}$$

where:

$\eta_{Dms}$ is the propulsive efficiency coefficient in the trial condition;

$\eta_{Did}$ is the propulsive efficiency coefficient in the ideal condition;

$\xi_P$ is derived considering the load variation effect as described in Annex J;

$\Delta R$ is the total resistance increase in newtons;

$R_{id}$ is the resistance in the ideal condition in newtons.

This leads to the expression for the corrected delivered power:

$$P_{\mathrm{Did}} = P_{\mathrm{Dms}} - \frac{\Delta R V_{\mathrm{S}}}{\eta_{\mathrm{Did}}}\left(1 - \frac{P_{\mathrm{Dms}}}{P_{\mathrm{Did}}}\xi_P\right) \tag{13}$$

Then, the following quadratic equation about $P_{\mathrm{Did}}$ is obtained by transforming Formula (13):

$$P_{\mathrm{Did}}^2 - \left(P_{\mathrm{Dms}} - \frac{\Delta R V_{\mathrm{S}}}{\eta_{\mathrm{Did}}}\right)P_{\mathrm{Did}} - P_{\mathrm{Dms}}\frac{\Delta R V_{\mathrm{S}}}{\eta_{\mathrm{Did}}}\xi_P = 0 \tag{14}$$

Finally, $P_{\mathrm{Did}}$ is obtained as follows under the condition ( $P_{\mathrm{Dms}} - \frac{\Delta R V_{\mathrm{S}}}{\eta_{\mathrm{Did}}} > 0$ ).

$$P_{\mathrm{Did}} = \frac{1}{2}\left(P_{\mathrm{Dms}} - \frac{\Delta R V_{\mathrm{S}}}{\eta_{\mathrm{Did}}} + \sqrt{\left(P_{\mathrm{Dms}} - \frac{\Delta R V_{\mathrm{S}}}{\eta_{\mathrm{Did}}}\right)^2 + 4P_{\mathrm{Dms}}\frac{\Delta R V_{\mathrm{S}}}{\eta_{\mathrm{Did}}}\xi_P}\right) \tag{15}$$

where:

$P_{\mathrm{Did}}$ is the delivered power in the ideal condition in watts;

$P_{\mathrm{Dms}}$ is the delivered power in the trial condition in watts;

$\Delta R$ is the total resistance increase in newtons;

$V_{\mathrm{S}}$ is the ship's speed through the water in metres per second;

$\eta_{\mathrm{Did}}$ is the propulsive efficiency coefficient in the ideal condition;

$\xi_P$ is derived considering the load variation effect as described in Annex J.

The correction of the propeller shaft speed is also carried out considering the load variation effect.

With the $P_{Did}$ found as described above, the correction on propeller shaft speed is:

$$\frac{\Delta n}{n_{id}} = \xi_n \frac{P_{Dms} - P_{Did}}{P_{Did}} + \xi_V \frac{\Delta V}{V_S} \tag{16}$$

and:

$$\Delta n = n_{ms} - n_{id} \tag{17}$$

From this follows that the corrected propeller shaft speed $n_{id}$ is

$$n_{id} = \frac{n_{ms}}{\xi_n \frac{P_{Dms} - P_{Did}}{P_{Did}} + \xi_V \frac{\Delta V}{V_S} + 1} \tag{18}$$

where:

$n_{ms}$ is the measured propeller shaft speed in revolutions per second;

$n_{id}$ is the corrected propeller shaft speed in revolutions per second;

$P_{Did}$ is the delivered power in the ideal condition in watts;

$P_{Dms}$ is the delivered power in the trial condition in watts;

$\xi_n$, $\xi_V$ are derived considering the load variation effect as described in Annex J;

$V_S$ is the ship's speed through the water in metres per second;

$\Delta V$ is the decrease of ship's speed due to shallow water in metres per second, determined in Annex G.

The analysis in Annex K, which is included in this International Standard, is useful to deepen the technological knowledge, since this calculation is based on the full-scale wake fraction.

### 12.2.4 Correction of the measured ship's speed due to the effect of current

The current effect is corrected by subtracting the current speed $V_C$ from the measured ship's speed over the ground $V_C$ at each run as follows:

$$V_S = V_G - V_C \tag{19}$$

where:

$V_S$ is the ship's speed through the water in knots;

$V_G$ is the measured ship's speed over ground in knots;

$V_C$ is the current speed in knots.

The current correction can be applied by two (2) different methods:

a) 'Iterative' method

Based on the assumption that the current speed varies with a semi-diurnal period, a current curve as a function of time will be created. In the same process a regression curve representing the relationship between the ship's speed through the water [Formula (19)] and corrected power (12.2.3) is determined. So both current curve and regression curve are created in one process. The regression curve has no relation with the speed/power curve from the tank tests.

The analysis of the direct power method as described in 12.2.3 shall be repeated after the value of $V_S$ has been derived by the current correction analysis.

b) 'Mean of means' method

Based on the assumption that for a given power setting, the current speed varies parabolically, the influence of current is accounted for by applying the 'Mean of means' method for each set of runs with the same power setting.

The details of the 'Iterative' method and the 'Mean of means' method are given at Annex F.

#### 12.2.5 Correction of the ship's speed due to the effects of shallow water

The speed correction for shallow water is applied in accordance with Annex G.

#### 12.2.6 Correction of the ship's performance due to the effects of displacement

Displacement and trim are, in general, factors that can be adjusted to stipulated values at the time of the trials. However, there may be significant reasons for discrepancies and small deviations in displacement, i.e. within 2 % of the required value, shall be corrected in accordance with Annex H.

#### 12.2.7 Conversion of power curve from trial condition to full load/stipulated condition

For dry cargo ships it is difficult to conduct S/P trials at full load condition. For such cases S/P trials at ballast condition are performed and the speed/power curve is converted to that of the full load/stipulated condition using the power curves based on the tank tests for these conditions.

The conversion method from the trial condition to full load/stipulated condition is shown at Annex I.

## 13 Processing of the results

After completion of the S/P trials the measured data shall be processed in the following sequence:

a) Derive the mean value of every measured parameter for each speed run.

b) The average speed component in the heading direction of each run is found from the DGPS recorded start and end positions of the run and the elapsed time.

c) The true wind velocity and direction for each Double Run is calculated.

d) Correction of power for resistance increase due to wind.

e) Correction of power for resistance increase due to waves.

f) Correction of power for resistance increase due to effect of water temperature and water density (salinity).

g) Correction of speed for current effect.

h) Check the current curve.

i) Correction of speed for shallow water effect.

j) Correction of power for the difference of displacement from the stipulated contractual and EEDI conditions.

k) Determine the final speed-power relationship at sea trial draught as follows: Use the speed/power curve from the tank tests for the specific ship design at the trial draught. Shift this curve along the power axis to find the best fit with all corrected speed/power points according to the least squares method. When more than three(3) power settings are obtained, it is acceptable to find the best fit with all corrected speed/power points using the 'least squares' method.

l) Intersect the curve at the specified power to derive the ship's speed at trial draught in the ideal conditions.

m) Apply conversions from the trial condition to other stipulated load conditions (see Annex I).

n) Apply corrections for the contractual weather conditions if these deviate from the ideal conditions.

## 14 Reporting

In the trial report, an overview shall be given of the trial conditions and all corrections that have been applied as necessary to arrive at the contract speed and the EEDI speed.

The trial report shall contain all relevant information to carry out the data analysis. It shall be written in such a way that all results can be reproduced.

The trial report shall contain the following sub clauses:

a) Trial Report Summary comprising details of:

   1) Ship particulars (including trial draughts and displacement).

   2) Propeller details.

   3) Engine data.

   4) Details of hull appendages and rudder(s).

b) Contract conditions including contract speed, power, and displacement.

c) EEDI conditions including EEDI speed, power and displacement.

d) A description of the instrumentation, describing: instrument set-up, calibration procedures, data acquisition interfacing details, location of sensors (e.g. anemometer), etc.

e) Description of the trial site. This gives information on geography, water depth, etc.

f) Environmental parameters. This shall list the measured/observed environmental conditions at the site during the S/P trials such as: wave height and period, wave direction, air pressure, wind direction, wind velocity, air temperature, water temperature, water density, etc.

g) S/P trial agenda. This gives a complete and chronological order of the trial programme (both planned and actual) with explanation of the duties of the different recording/monitoring stations on board.

h) Trial Results of each speed run:

   1) Date and time at start of speed run.

   2) Run number.

   3) Ship's positions.

   4) Ship's heading.

   5) Run duration.

   6) Mean value of measured ship's speed.

   7) Mean value and standard deviation of torque (per shaft).

   8) Mean value and standard deviation of shaft rpm (per shaft).

   9) Mean value and standard deviation of shaft power (per shaft).

   10) Relative wind velocity and direction.

11) Significant wave height, mean period and direction.

12) Water depth.

i) Analysis and Correction methods. The analysis and correction of the measured trial data shall be conducted in compliance with Clause 12.

j) Conclusions / Recommendations.

## 15 Example of speed trial data analysis

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date of Sea Trial | 2014/2/25 | Hull | | | | | | | | | | | | | |
| Ship builder's Name | SAJ Shipyard | $L_{OA}$ | Lpp | $L_{BWL}$ | B | $T_A$ | $T_{F1}$ | $T_{F2}$ | $\Delta_1$ | $\Delta_2$ | $k_{yy}$ | $A_M$ | $A_{XV}$ | $A_{YV}$ | $A_{OD}$ |
| Ship Number | 15016 | m | m | m | m | m | m | m | ton | ton | | $m^2$ | $m^2$ | $m^2$ | $m^2$ |
| Ship Name | M/V SAJ | - | 320,00 | 40,00 | 60,00 | 19,90 | 19,90 | - | 301 000 | 300 000 | - | 1 190,0 | 1 000,0 | - | - |
| Type of Ship | VLCC | Hull | | | | | | Propeller | Efficiency, etc. | | | | Heigh tfor Wind | | MCR |
| Draft Condition | Full(EEDI draught) | $H_C$ | $H_{BR}$ | $C_{MC}$ | $T_M$ | trim | $C_B$ | D | $\eta_T$ | $\eta_{R0}$ | $1\text{-}t_0$ | $1\text{-}w_{M0}$ | $Z_{ref}$ | $Z_a$ | $P_{MCR}$ |
| Trim Condition | Even keel | m | m | m | m | m | | m | | | | | m | m | kW |
| Sea Trial Site | ISO BAY | - | - | - | 19,90 | 0,0 | | 9,86 | 0,970 | - | - | - | 10,00 | 40,00 | 22 065 |
| Weather | Fine | Depth | Water Temperature | | Density | | Restrictions | | | | | | | | |
| Beaufort number | 4 | h | $T_w$ | | $\rho$ | $\rho_A$ | $(\Delta_1\text{-}\Delta_2)/\Delta_2$ | trim / $T_M$ | $T_{F1}$ - $T_{F2}$ | $h_{MIN}$ | $h_{MAX}$ | Beaufort number | | $V_W$ | $H_{1/3}$ |
| Method of measurement | Visual observations | m | °C | | kg/m³ | kg/m³ | % | % | m | | | | | m/s | m |
| Date of Print | 2014/7/9 17:53 | 500,0 | 15,00 | | 1 025,88 | 1,23 | 0,3% | -0,5% | - | - | - | 6 | | 13,80 | 2,68 |
| NK ID | | | | | | | | | | | | | | | |

| **Analysis method option** | |
|---|---|
| Wind correction | Annex C.1.1 & Annex C.2.2 |
| Wave correction | Annex D.1 |
| Current correction | Annex F.1 |

| **Measured or observed data** | | | | | | | | | | | | **Ref., Eq. No.** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Main engine output setting | | | 70% | | 85% | | 100% | | | | |
| 2 | Run number | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | |
| 3 | Course direction | (deg) | $\psi_0$ | 0,0 | 180,0 | 0,0 | 180,0 | 0,0 | 180,0 | | | measured |
| 4 | Mid time of each run | (hour) | $t_i$ | 15,07 | 17,40 | 19,67 | 21,85 | 23,98 | 26,07 | | | measured |
| 5 | Ship speed over the ground | (knots) | $V_G$ | 13,923 | 13,088 | 14,707 | 15,357 | 14,460 | 15,766 | | | measured |
| 6 | Propeller shaft speed | (rpm) | n | 66,03 | 66,26 | 70,31 | 70,62 | 73,95 | 74,41 | | | measured |
| 7 | Brake Power | (kW) | $P_{BM}$ | 15 513 | 15 425 | 18 790 | 18 777 | 21 918 | 22 074 | | | measured |
| 8 | Relative wind velocity at anemometer height | (m/s) | $V_{WR}$ | 13,68 | 3,56 | 14,07 | 3,95 | 13,95 | 4,06 | | | measured |
| 9 | Relative wind direction at anemometer height | (deg) | $\psi_{WR}$ | 14,8 | -79,1 | 14,4 | -62,3 | 14,5 | -59,7 | | | measured |
| 10 | True wind velocity at anemometer height | (m/s) | $V_{WT}$ | 7,00 | 7,00 | 7,00 | 7,00 | 7,00 | 7,00 | | | (C.2) |
| 11 | True wind direction at anemometer height | (deg) | $\psi_{WT}$ | 30,0 | 30,0 | 30,0 | 30,0 | 30,0 | 30,0 | | | (C.3) |
| 12 | True wind velocity at anemometer height (double run average) | (m/s) | $V'_{WT(i/i+1)}$ | 7,00 | 7,00 | 7,00 | 7,00 | 7,00 | 7,00 | | | (C.4) |
| 13 | True wind direction at anemometer height (double run average) | (deg) | $\psi'_{WT(i/i+1)}$ | 30,0 | 30,0 | 30,0 | 30,0 | 30,0 | 30,0 | | | (C.5) |
| 14 | Relative wind velocity at anemometer height (double run average) | (m/s) | $V'_{WR(i)}$ | 13,68 | 3,56 | 14,07 | 3,95 | 13,95 | 4,06 | | | (C.6) |
| 15 | Relative wind direction at anemometer height (double run average) | (deg) | $\psi'_{WR(i)}$ | 14,8 | -79,1 | 14,4 | -62,3 | 14,5 | -59,7 | | | (C.7) |
| 16 | True wind velocity at reference height | (m/s) | $V_{WTref}$ | 5,74 | 5,74 | 5,74 | 5,74 | 5,74 | 5,74 | | | (C.8) |
| 17 | Relative wind velocity at reference height | (m/s) | $V_{WRref}$ | 12,47 | 3,37 | 12,86 | 4,10 | 12,74 | 4,25 | | | (C.9) |
| 18 | Relative wind direction at reference height | (deg) | $\psi_{WRref}$ | 13,3 | -58,5 | 12,9 | -44,4 | 13,0 | -42,5 | | | (C.10) |
| 19 | Wind resistance coefficient | | $C_{AA}$ | 0,92 | 0,38 | 0,92 | 0,58 | 0,92 | 0,60 | | | Annex C.2 |
| 20 | Mean wave period (Seas) | (s) | $T_{wm}$ | | | | | | | | | measured |
| 21 | Significant wave height (Seas) (measured) | (m) | $H_{w1/3}$ | 0,7 | 0,7 | 0,7 | 0,7 | 0,7 | 0,7 | | | measured |
| 22 | Significant wave height (Seas) (used) | (m) | $H_{w1/3}$ | 0,7 | 0,7 | 0,7 | 0,7 | 0,7 | 0,7 | | | allowable |
| 23 | Incident angle of wave (Seas) | (deg) | $\chi_w$ | 30,0 | -150,0 | 30,0 | -150,0 | 30,0 | -150,0 | | | measured |
| 24 | Mean wave period (Swell) | (s) | $T_{Sm}$ | | | | | | | | | measured |
| 25 | Significant wave height (Swell) (measured) | (m) | $H_{s1/3}$ | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | | | measured |
| 26 | Significant wave height (Swell) (used) | (m) | $H_{s1/3}$ | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | | | allowable |
| 27 | Incident angle of wave (Swell) | (deg) | $\chi_s$ | 0,0 | 180,0 | 0,0 | 180,0 | 0,0 | 180,0 | | | measured |
| 28 | Significant wave height (measured) | (m) | $H_{1/3}$ | 1,22 | 1,22 | 1,22 | 1,22 | 1,22 | 1,22 | | | Synthetic H |
| 29 | Significant wave height (used) | (m) | $H_{1/3}$ | 1,22 | 1,22 | 1,22 | 1,22 | 1,22 | 1,22 | | | allowable |
| 30 | Delivered power | (kW) | $P_{DM}$ | 15 047 | 14 962 | 18 226 | 18 214 | 21 261 | 21 411 | | | (8) or (9) |
| 31 | Ship speed through the water | (knots) | $V_S$ | 13,506 | 13,506 | 15,032 | 15,032 | 15,113 | 15,113 | | | mean value of $V_G$ |
| 32 | Current velocity | (knots) | $V_C$ | 0,418 | 0,418 | -0,325 | -0,325 | -0,653 | -0,653 | | | $V_C$=$V_G$-$V_S$ |

| **Resistance data** | | | | | | | | | | | | **Ref., Eq. No.** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | Resistance increase due to wind | (kN) | $R_{AA}$ | 56,95 | -24,55 | 59,23 | -31,49 | 58,51 | -32,78 | | | (C.1) |
| 34 | Resistance increase due to waves | (kN) | $R_{AW}$ | 68,85 | 0,00 | 68,85 | 0,00 | 68,85 | 0,00 | | | (D.1) |
| 35 | Resistance increase due to deviation of water temp. and density | (kN) | $R_{AS}$ | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | | | (E.1) |
| 36 | Total resistance increase | (kN) | $\Delta R$ | 125,79 | -24,55 | 128,08 | -31,49 | 127,36 | -32,78 | | | (7) |

**Figure — Example of speed trial data analysis (Part 1)**

| **Direct Power Method** | | | | | | | | | | | | **Ref., Eq. No.** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 37 | Propulsive efficiency coefficient in ideal condition | | $\eta_{D0}$ | 0,694 | 0,673 | 0,717 | 0,696 | 0,685 | 0,665 | | | Tank Test |
| 38 | Load variation effect | | $\xi_P$ | -0,207 | -0,207 | -0,207 | -0,207 | -0,207 | -0,207 | | | Annex J |
| 39 | Delivered power | (kW) | $P_{DC}$ | 13 515 | 15 255 | 16 480 | 18 634 | 19 519 | 21 851 | | | (15) |
| 40 | Load variation effect | | $\xi_n$ | 0,248 | 0,248 | 0,248 | 0,248 | 0,248 | 0,248 | | | Annex J |
| 41 | Load variation effect | | $\xi_v$ | 0,193 | 0,193 | 0,193 | 0,193 | 0,193 | 0,193 | | | Annex J |
| 42 | Propeller shaft speed | (rpm) | $n_c$ | 64,23 | 66,57 | 68,52 | 71,01 | 72,35 | 74,78 | | | (18) |

| **Current correction (1) : specified in Annex F.1** | | | | | | | | | | | | **Ref., Eq. No.** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 43 | Avaraged ship speed | (knots) | $V_m$ | | 13,506 | | 15,032 | | 15,113 | | | mean value of $V_G$ |
| 44 | Avaraged brake power | (kW) | $P_m$ | | 14 830 | | 18 100 | | 21 325 | | | mean of $P_{DC}/\eta_T$ |
| 45 | Brake power on curve | (kW) | P' | 13 933 | 15 727 | 16 990 | 19 210 | 20 123 | 22 527 | | | $V_G$ → (F.2) |
| 46 | Avaraged brake power on curve | (kW) | $P'_m$ | | 14 830 | | 18 100 | | 21 325 | | | mean value of P' |
| 47 | Ship speed corrected for current | (knots) | $V'_S$ | 13,459 | 13,988 | 14,335 | 14,905 | 15,127 | 15,678 | | | (F.5) |
| 48 | Current velocity | (knots) | $V'_C$ | 0,465 | 0,899 | 0,372 | -0,451 | -0,667 | -0,089 | | | (F.4) |
| 49 | Current velocity on current curve | (knots) | $V_C$ | 0,465 | 0,899 | 0,372 | -0,451 | -0,667 | -0,089 | | | (F.1) |

| **Direct Power Method (2)** | | | | | | | | | | | | **Ref., Eq. No.** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50 | Delivered power | (kW) | $P_{DC}$ | 13 521 | 15 266 | 16 568 | 18 630 | 19 518 | 21 869 | | | (15) |
| 51 | Propeller shaft speed | (rpm) | $n_c$ | 64,24 | 66,59 | 68,61 | 71,01 | 82,35 | 74,80 | | | (18) |

| **Current correction (2) : specified in Annex F.1** | | | | | | | | | | | | **Ref., Eq. No.** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 52 | Ship speed corrected for current | (knots) | $V'_S$ | 13,446 | 13,980 | 14,351 | 14,899 | 15,122 | 15,681 | | | (F.5) |
| 53 | Current velocity | (knots) | $V'_C$ | 0,477 | 0,891 | 0,356 | -0,458 | -0,662 | -0,086 | | | (F.4) |
| 54 | Current velocity on current curve | (knots) | $V_C$ | 0,477 | 0,891 | 0,356 | -0,458 | -0,662 | -0,086 | | | (F.1) |

| **Shallow water correction** | | | | | | | | | | | | **Ref., Eq. No.** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 55 | Minimum water depth | (m) | $h_{MIN}$ | - | - | - | - | - | - | | | 8.4 |
| 56 | Maximum water depth | (m) | $h_{MAX}$ | - | - | - | - | - | - | | | 8.4 |
| 57 | Water depth (used) | (m) | h | | | | | | | | | 8.4 |
| 58 | Decrease of ship speed due to shallow water | (knots) | ΔV | | | | | | | | | Annex G |
| 59 | Ship speed through the water in deep water | (knots) | $V_S$ | | | | | | | | | (G.1) →$V_S$ |

| **Displacement correction** | | | | | | | | | | | | **Ref., Eq. No.** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 60 | Delivered power | (kW) | $P_{DC}$ | 13 491 | 15 232 | 16 532 | 18 589 | 19 474 | 21 821 | | | (H.1) |

| **Final performance** | | | | | | | | | | | | **Ref., Eq. No.** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 61 | Propeller shaft speed | (rpm) | $n_c$ | 64,24 | 66,59 | 68,61 | 71,01 | 72,35 | 74,80 | | | copied from 51 |
| 62 | Ship speed through the water | (knots) | $V_S$ | 13,446 | 13,980 | 14,351 | 14,899 | 15,122 | 15,681 | | | copied from 52 |
| 63 | Brake power | (kW) | $P_{BC}$ | 13 908 | 15 703 | 17 043 | 19 163 | 20 077 | 22 495 | | | $P_{DC}/\eta_T$ |

**Figure — Example of speed trial data analysis (Part 2)**

# Annex A
(normative)

# General information and trial log sheet

**GENERAL SHIP DATA**

| | | | |
|---|---|---|---|
| Ship name | | | |
| IMO Nr. | | | |
| Hull condition | | | |
| | Last date of hull cleaning | | [mm/yyyy] |
| | Roughness | | |
| | Area of wetted surface of hull only | | [$m^2$] |
| Hull appendages | | | |
| Description | | | |
| | Area of wetted surface bilge keels | | [$m^2$] |
| | Area of wetted surface rudder(s) | | [$m^2$] |
| | Area of wetted surface other appendages | | [$m^2$] |
| Propeller(s) | | | |
| | No. of Propellers | | [-] |
| | Type (FPP/CPP) | | [-] |
| | Diameter | | [m] |
| | Design pitch (FPP) | | [m] |
| | Direction of rotation (looking from aft) | | [R-L] |
| | Number of blades | | [-] |
| Shaft(s) | | | |
| | G modulus (default =82400 N/mm) | | [N/mm] |
| | Diameter (inside) | | [m] |
| | Diameter (outside) | | [m] |

**DATA AT S/P TRIALS**

| Draught | PS | SB | |
|---|---|---|---|
| $T_{FORE}$ | | | [m] |
| $T_{MID}$ | | | [m] |
| $T_{AFT}$ | | | [m] |
| Trim | | | [m] |
| Displacement | | | [Mtons] |

| | | |
|---|---|---|
| Vertical position of anemometer above waterline | | [m] |
| Transverse projected wind area | | [$m^2$] |
| Lateral projected wind area above waterline (Fujiwara) | | [$m^2$] |
| Lateral projected wind area of superstructures above upper deck. (Fujiwara) | | [$m^2$] |

| | | |
|---|---|---|
| $C_{mc}$ | | (m) |
| $H_c$ | | (m) |
| $H_{BR}$ | | (m) |

| | | | |
|---|---|---|---|
| Sea Trial Area | | | |
| | Weather condition | | Visual |
| | Latitude | | [dd-mm] |
| | Longitude | | [ddd-mm] |

| | | |
|---|---|---|
| $T_{AIR}$ | | [°C] |
| $T_{WATER}$ | | [°C] |
| $RHO_{WATER}$ | | [$kg/m^3$] |
| Atmospheric pressure | | [hPa, mbar] |
| Wave observation method | | Visual/Measured |

**S/P RUN DATA**

| Run Nr. | | [-] | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Power setting | | %MCR | | | | | | | | | | | | |
| Date | | yyyy-mm-dd | | | | | | | | | | | | |
| Start time of run | | hh:mm | | | | | | | | | | | | |
| Direction: Forward / Return | | [-] | | | | | | | | | | | | |
| Run duration | | mm:ss | | | | | | | | | | | | |
| Heading | | [°] | | | | | | | | | | | | |
| Measured Ship's Speed | | [knots] | | | | | | | | | | | | |
| Relative wind | Velocity | [m/s] | | | | | | | | | | | | |
| | Direction | [°] | | | | | | | | | | | | |
| Waves | Height | [m] | | | | | | | | | | | | |
| | Direction | [°] | | | | | | | | | | | | |
| | Period | [s] | | | | | | | | | | | | |
| Swell | Height | [m] | | | | | | | | | | | | |
| | Direction | [°] | | | | | | | | | | | | |
| | Period | [s] | | | | | | | | | | | | |
| Propeller PS | Power | [kW] | | | | | | | | | | | | |
| | Shaft Speed | [rpm] | | | | | | | | | | | | |
| | Pitch of CPP | [°] | | | | | | | | | | | | |
| Propeller SB | Power | [kW] | | | | | | | | | | | | |
| | Shaft Speed | [rpm] | | | | | | | | | | | | |
| | Pitch of CPP | [°] | | | | | | | | | | | | |
| Vert. G force at bow (STAWAVE-1) | | g | | | | | | | | | | | | |
| Water depth | | [m] | | | | | | | | | | | | |

# Annex B
(normative)

## Beaufort scale for wind velocity

This table is only intended as a guide to show roughly what may be expected in the open sea, remote from land. It shall never be used in the reverse way, i.e. for logging or reporting the state of the sea. In enclosed waters, or when near land, with an off-shore wind, wave heights will be smaller and the waves steeper. Figures in brackets indicate the probable maximum height of waves [7] .

| * | Descriptive term | Velocity equivalent at a standard height of 10 m above open flat ground | | | | Specifications | | | Probable wave height | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean velocity in knots | m s-1 | km h-1 | m.p.h. | Land | Sea | Coast | | |
| | | | | | | | | | m | ft |
| 0 | Calm | < 1 | 0–0,2 | < 1 | < 1 | Calm; smoke rises vertically | Sea like a mirror | Calm | - | - |
| 1 | Light air | 1–3 | 0,3–1,5 | 1–5 | 1–3 | Direction of wind shown by smoke drift but not by wind vanes | Ripples with the appearance of scales are formed, but without foam crests | Fishing smack just has steerage way | 0,1<br>(0,1) | 1/4<br>(1/4) |
| 2 | Light breeze | 4–6 | 1,6–3,3 | 6–11 | 4–7 | Wind felt on face; leaves rustle; ordinary vanes moved by wind | Small wavelets, still short but more pronounced; crests have a glassy appearance and do not break | of smacks which then travel at about 1–2 kn | 0,2<br>(0,3) | 1/2<br>(1) |
| 3 | Gentle breeze | 7–10 | 3,4–5,4 | 12–19 | 8–12 | Leaves and small twigs in constant motion; wind ex- tends light flag | Large wavelets; crests begin to break; foam of glassy appearance; perhaps scattered white horses | Smacks begin to careen and travel about 3–4 kn | 0,6<br>(1) | 2<br>(3) |
| 4 | Moderate breeze | 11–16 | 5,5–7,9 | 20–28 | 13–18 | Raises dust and loose paper; small branches are moved | Small waves, becoming longer;<br>fairly frequent white horses | Good working breeze, smacks carry all canvas with good list | 1<br>(1,5) | 31/2<br>(5) |
| 5 | Fresh breeze | 17–21 | 8,0–10,7 | 29–38 | 19–24 | Small trees in leaf begin to sway; crested wavelets form on inland waters | Moderate waves, taking a more pronounced long form; many white horses are formed (chance of some spray) | Smacks shorten sail | 2<br>(2,5) | 6<br>(81/2) |
| 6 | Strong breeze | 22–27 | 10,8–13,8 | 39–49 | 25–31 | Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty | Large waves begin to form; the white foam crests are more extensive everywhere (probably some spray) | Smacks have double reef in mainsail; care required when fishing | 3<br>(4) | 91/2<br>(13) |

* Beaufort number.

| * | Descrip-tive term | Velocity equivalent at a standard height of 10 m above open flat ground | | | | Specifications | | | Probable wave height | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean velocity in knots | m s-1 | km h-1 | m.p.h. | Land | Sea | Coast | | |
| 7 | Near gale | 28–33 | 13,9–17,1 | 50–61 | 32–38 | Whole trees in motion; inconvenience felt when walking against wind | Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind | Smacks remain in harbour and those at sea lie to | 4 (5,5) | 131/2 (19) |
| 8 | Gale | 34–40 | 17,2–20,7 | 62–74 | 39–46 | Breaks twigs off trees; generally impedes progress | Moderately high waves of greater length; edges of crests begin to break into the spindrift; the foam is blown in well-marked streaks along the direction of the wind | All smacks make for harbour, if near | 5,5 (7,5) | 18 (25) |
| 9 | Strong gale | 41–47 | 20,8–24,4 | 75–88 | 47–54 | Slight structural damage occurs (chimney pots and slates removed) | High waves; dense streaks of foam along the direction of the wind; crests of waves begin to topple, tumble and roll over; spray may affect visibility | - | 7 (10) | 23 (32) |
| 10 | Storm | 48–55 | 24,5–28,4 | 89–102 | 55–63 | Seldom experienced inland; trees uprooted; considerable structural damage occurs | Very high waves with long over- hanging crests; the resulting foam, in great patches, is blown in dense white streaks along the direction of the wind; on the whole, the surface of the sea takes on a white appearance; the tumbling of the sea becomes heavy and shock- like; visibility affected | - | 9 (12,5) | 29 (41) |
| 11 | Violent storm | 55–63 | 28,5–32,6 | 103–117 | 64–72 | Very rarely experienced; accompanied by widespread damage | Exceptionally high waves (small and medium-sized ships might be for a time lost to view behind the waves); the sea is completely covered with long white patches of foam lying along the direction of the wind; everywhere the edges of the wave crests are blown into froth; visibility affected | - | 11,5 (16) | 37 (52) |
| * | Beaufort number. | | | | | | | | | |

| * | Descrip-tive term | Velocity equivalent at a standard height of 10 m above open flat ground | | | | Specifications | | | Probable wave height | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean velocity in knots | m s-1 | km h-1 | m.p.h. | Land | Sea | Coast | | |
| 12 | Hurri-cane | 64 and over | 32,7 and over | 118 and over | 73 and over | - | The air is filled with foam and spray; sea completely white with driving spray; visibility very seriously affected | - | 14<br>(-) | 45<br>(-) |
| * Beaufort number. | | | | | | | | | | |

**State of the Sea**

| Code | Descriptive terms | Wave height* m | | |
|---|---|---|---|---|
| 0 | Calm (glassy) | 0 | — | — |
| 1 | Calm(rippled) | 0 | — | 0,1 |
| 2 | Smooth(wavelets) | 0,1 | — | 0,5 |
| 3 | Slight | 0,5 | — | 1,25 |
| 4 | Moderate | 1,25 | — | 2,5 |
| 5 | Rough | 2,5 | — | 4 |
| 6 | Very rough | 4 | — | 6 |
| 7 | High | 6 | — | 9 |
| 8 | Very high | 9 | — | 14 |
| 9 | Phenomenal | Over | 14 | |

NOTE 1 *These values refer to well-developed wind waves of the open sea. While priority shall be given to the descriptive terms, these height values may be used for guidance by the observer when reporting the total state of agitation of the sea resulting from various factors such as wind, swell, currents, angle between swell and wind, etc.

NOTE 2 The bound of the wave height shall be assigned for the lower code figure; e.g. a height of 4 m is coded as 5.

# Annex C
(normative)

# Resistance increase due to wind

The resistance increase due to wind is calculated by:

$$R_{AA} = 0{,}5\rho_A \cdot C_{AA}\left(\psi_{WRref}\right) \cdot A_{XV} \cdot V_{WRref}^2 - 0{,}5\rho_A \cdot C_{AA}(0) \cdot A_{XV} \cdot V_G^2 \quad (C.1)$$

where:

| | |
|---|---|
| $R_{AA}$ | is the resistance increase due to relative wind in newtons; |
| $A_{XV}$ | is the transverse projected area above the waterline including superstructures in square metres; |
| $C_{AA}$ | is the wind resistance coefficient; $C_{AA}(0)$ means the wind resistance coefficient in head wind; |
| $V_G$ | is the measured ship's speed over ground in metres per second; |
| $V_{WRref}$ | is the relative wind velocity at the reference height in metres per second; |
| $\psi_{WRref}$ | is the relative wind direction at the reference height in degrees; |
| $\rho_A$ | is the mass density of air in kilograms per cubic metre. |

The evaluation of wind data is explained in detail in C.1.

The wind resistance coefficient is based on the data derived from model tests in a wind tunnel. In cases where a database is available covering ships of similar type, such data may be used instead of carrying out wind tunnel model tests. Alternatively, statistical regression formulae concerning wind resistance coefficients of various ship types have been developed. The recommended methods are described in C.2.

## C.1 Evaluation of wind data

By nature wind velocity and direction vary in time and therefore they are defined by their mean value over a selected period.

For S/P trials it is assumed that the wind condition is steady, i.e. that velocity and direction are reasonably constant over the duration of each run. The mean values of direction and velocity recorded during every run are then used as the 'actual' values for that run.

### C.1.1 Averaging process for the true wind velocity and direction

Usually, the relative wind velocity and direction are measured by the on-board anemometer, which is generally located on the radar mast on top of the bridge. Both wind velocity and direction at this location may be affected by the geometry of the ship, in particular the shape of the superstructure.

The true wind vector for each speed run is found from the ship's heading and speed over the ground and the measured relative wind velocity and direction. By averaging the true wind vectors over both speed runs of the Double Run, the true wind vector for the run-set is found. This run-set averaged true wind vector shall be used to recalculate the relative wind vector for each speed run of the set.

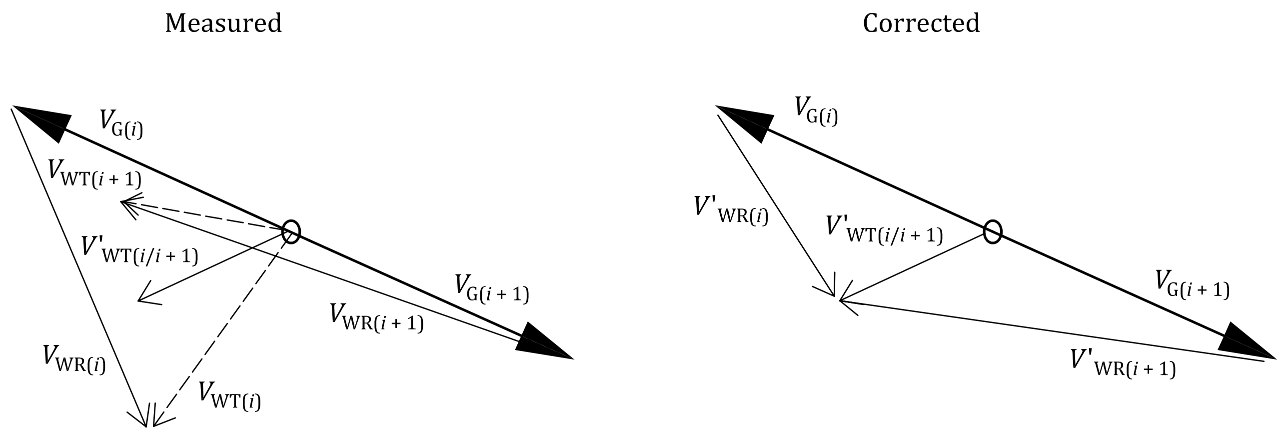



**Figure C.1 — True wind vectors and relative wind vectors**

The true wind velocity and direction at the vertical position of the anemometer are calculated by:

$$V_{WT} = \sqrt{V_{WR}^2 + {V_G}^2 - 2V_{WR}V_G\cos\psi_{WR}} \quad \text{(C.2)}$$

$$\psi_{WT} = \tan^{-1}\left\{\frac{V_{WR}\sin(\psi_{WR}+\psi) - V_G\sin(\psi)}{V_{WR}\cos(\psi_{WR}+\psi) - V_G\cos(\psi)}\right\} \text{for } V_{WR}\cos(\psi_{WR}+\psi) - V_G\cos(\psi) \geq 0,$$

$$\psi_{WT} = \tan^{-1}\left\{\frac{V_{WR}\sin(\psi_{WR}+\psi) - V_G\sin(\psi)}{V_{WR}\cos(\psi_{WR}+\psi) - V_G\cos(\psi)}\right\} + 180 \text{ for } V_{WR}\cos(\psi_{WR}+\psi) - V_G\cos(\psi) < 0 \quad \text{(C.3)}$$

where:

$V_G$ is the measured ship's speed over ground in meters per second;

$V_{WR}$ is the mean value of the measured relative wind velocity at the vertical position of the anemometer in metres per second;

$V_{WT}$ is the true wind velocity at the vertical position of the anemometer in metres per second;

$\psi$ is the ship's heading in degrees;

$\psi_{WR}$ is the mean value of the measured relative wind direction at the vertical position of the anemometer in degrees;

$\psi_{WT}$ is the true wind direction at the vertical position of the anemometer in degrees.

The true wind velocity and direction are corrected by an averaging process over both runs of the Double Run.

$$V'_{WT(i/i+1)} = \sqrt{\left(\frac{V_{WT(i)}\cos\psi_{WT(i)} + V_{WT(i+1)}\cos\psi_{WT(i+1)}}{2}\right)^2 + \left(\frac{V_{WT(i)}\sin\psi_{WT(i)} + V_{WT(i+1)}\sin\psi_{WT(i+1)}}{2}\right)^2}$$

(C.4)

$$\psi'_{WT(i/i+1)} = \tan^{-1}\left\{\frac{V_{WT(i)}\sin\psi_{WT(i)} + V_{WT(i+1)}\sin\psi_{WT(i+1)}}{V_{WT(i)}\cos\psi_{WT(i)} + V_{WT(i+1)}\cos\psi_{WT(i+1)}}\right\} \text{for}$$

$$V_{WT(i)}\cos\psi_{WT(i)} + V_{WT(i+1)}\cos\psi_{WT(i+1)} \geq 0,$$

$$\psi'_{WT(i/i+1)} = \tan^{-1}\left\{\frac{V_{WT(i)}\sin\psi_{WT(i)} + V_{WT(i+1)}\sin\psi_{WT(i+1)}}{V_{WT(i)}\cos\psi_{WT(i)} + V_{WT(i+1)}\cos\psi_{WT(i+1)}}\right\} + 180 \text{ for}$$

$$V_{WT(i)}\cos\psi_{WT(i)} + V_{WT(i+1)}\cos\psi_{WT(i+1)} < 0 \qquad \text{(C.5)}$$

$$V'_{WR(i)} = \sqrt{V'^2_{WT(i)} + V^2_{G(i)} + 2V'_{WT(i)}V_{G(i)}\cos(\psi'_{WT(i)} - \psi_{(i)})} \qquad \text{(C.6)}$$

$$\psi'_{WR(i)} = \tan^{-1}\left\{\frac{V'_{WT(i)}\sin(\psi'_{WT(i)} - \psi_{(i)})}{V_{G(i)} + V'_{WT(i)}\cos(\psi'_{WT(i)} - \psi_{(i)})}\right\} \text{for } V_{G(i)} + V'_{WT(i)}\cos(\psi'_{WT(i)} - \psi_{(i)}) \geq 0,$$

$$\psi'_{WR(i)} = \tan^{-1}\left\{\frac{V'_{WT(i)}\sin(\psi'_{WT(i)} - \psi_{(i)})}{V_{G(i)} + V'_{WT(i)}\cos(\psi'_{WT(i)} - \psi_{(i)})}\right\} + 180 \text{ for } V_{G(i)} + V'_{WT(i)}\cos(\psi'_{WT(i)} - \psi_{(i)}) < 0$$

(C.7)

where:

$V_G$ is the measured ship's speed over ground in metres per second;

$V_{WT}$ is the true wind velocity at the vertical position of the anemometer in metres per second;

$V'_{WT}$ is the averaged true wind velocity at the vertical position of the anemometer in metres per second;

$V'_{WR}$ is the corrected relative wind velocity at the vertical position of the anemometer in metres per second;

$\psi$ is the ship's heading in degrees;

$\psi_{WT}$ is the true wind direction at the vertical position of the anemometer in degrees;

$\psi'_{WT}$ is the averaged true wind direction at the vertical position of the anemometer in degrees;

$\psi'_{WR}$ is the corrected relative wind direction at the vertical position of the anemometer in degrees;

$(i)$ is the run number.

And then true wind velocity $V_{WT(i)}$, true wind direction $\psi_{WT(i)}$, relative wind velocity $V_{WR(i)}$ and relative wind direction $\psi_{WR(i)}$ are replaced by $V'_{WT(i)}$, $\psi'_{WT(i)}$, $V'_{WR(i)}$ and $\psi'_{WR(i)}$.

The true wind velocity and directions shall be checked by taking the following into consideration:

a) The consistency of the curves of true wind velocity and direction with time during each run.

b) The consistency of the curves of air temperature and atmospheric pressure with time during each run.

c) Publicly available weather information.

### C.1.2 Correction for the vertical position of the anemometer

The wind effect on the ship consists of two components: shear flow and uniform flow. Shear flow is the natural wind. Uniform flow is the relative speed between still air and the ship's own motion.

To calculate the wind resistance, the wind velocity and direction at the reference height of the wind tunnel tests on which the wind resistance coefficients are based, shall be used. Therefore the wind velocity and direction at the vertical position of the anemometer shall be corrected to those at the reference height.

The difference between the vertical position of the anemometer and the reference height for the wind resistance is to be corrected by means of the wind velocity profile given by:

$$V_{\text{WTref}} = V_{\text{WT}} \left( \frac{Z_{\text{ref}}}{Z_{\text{a}}} \right)^{\frac{1}{7}} \tag{C.8}$$

where:

$V_{\text{WTref}}$ is the true wind velocity at the reference height in metres per second;

$V_{\text{WT}}$ is the true wind velocity at the vertical position of the anemometer in metres per second;

$Z_{\text{ref}}$ is the reference height for the wind resistance coefficients in metres;

$Z_{\text{a}}$ is the vertical position of the anemometer in metres.

The reference height for the wind resistance coefficients, $Z_{\text{ref}}$ is selected as the corresponding height for the wind resistance coefficient from wind tunnel tests.

The relative wind velocity at the reference height is calculated by:

$$V_{\text{WRref}} = \sqrt{V_{\text{WTref}}{}^2 + V_{\text{G}}{}^2 + 2V_{\text{WTref}} V_{\text{G}} \cos(\psi_{\text{WT}} - \psi)} \tag{C.9}$$

The relative wind direction at the reference height is calculated by:

$$\psi_{\text{WRref}} = \tan^{-1} \left\{ \frac{V_{\text{WTref}} \sin(\psi_{\text{WT}} - \psi)}{V_{\text{G}} + V_{\text{WTref}} \cos(\psi_{\text{WT}} - \psi)} \right\} \text{ for } V_{\text{G}} + V_{\text{WTref}} \cos(\psi_{\text{WT}} - \psi) \geq 0 \,,$$

$$\psi_{\text{WRref}} = \tan^{-1} \left\{ \frac{V_{\text{WTref}} \sin(\psi_{\text{WT}} - \psi)}{V_{\text{G}} + V_{\text{WTref}} \cos(\psi_{\text{WT}} - \psi)} \right\} + 180 \text{ for } V_{\text{G}} + V_{\text{WTref}} \cos(\psi_{\text{WT}} - \psi) < 0 \tag{C.10}$$

where:

$V_{\text{G}}$ is the measured ship’s speed over ground in metres per second;

$V_{\text{WRref}}$ is the relative wind velocity at the reference height in metres per second;

$V_{\text{WTref}}$ is the true wind velocity at the reference height in metres per second;

$\psi$ is the ship’s heading in degrees;

$\psi_{\text{WRref}}$ is the relative wind direction at the reference height in degrees;

$\psi_{\text{WT}}$ is the true wind direction at the vertical position of the anemometer in degrees.

## C.2 Wind resistance coefficients

The wind resistance coefficients determined by the following methods shall be used.

### C.2.1 Wind tunnel test

If wind tunnel test results are available, the wind resistance coefficient evaluated by these tests shall be used.

### C.2.2 Data set on the wind resistance coefficient

A data set of wind resistance coefficients has been prepared by STA-JIP [6]. Data are available for; Tankers, LNG carriers, container ships, car carriers, ferry/cruise ships and general cargo ships as shown in Table C.1. The wind resistance coefficients, where $C_{AA} = -C_X$, for each ship type, are shown in Figure C.2.

Before making use of these coefficients, the ship type, shape and outfitting shall be carefully evaluated and compared with the geometry of the ship for which the data set has been prepared, as illustrated in Figure C.3. The data provided is limited to the present-day common ship types. The database is not suitable for special ships such as; tugs, offshore supply vessels, fishery vessels and fast craft, all of which have very individual geometries.

**Table C.1 — Ship types included in the data set**

| Ship type | Loading condition | Superstructure | Test ship |
|---|---|---|---|
| tanker conventional bow | laden | normal | 280 kDWT |
| tanker conventional bow | ballast | normal | 280 kDWT |
| tanker cylindrical bow | ballast | normal | 280 kDWT |
| LNG carrier | average | prismatic integrated | 125 k-$m^3$ |
| LNG carrier | average | prismatic extended deck | 138 k-$m^3$ |
| LNG carrier | average | spherical | 125k-$m^3$ |
| container ship | laden | with containers | 6 800 TEU |
| container ship | laden | without containers, with lashing bridges | 6 800 TEU |
| container ship | ballast | with lashing bridges | 6 800 TEU |
| container ship | ballast | without lashing bridges | 6 800 TEU |
| car carrier | average | normal | Autosky |
| ferry/cruise ship | average | normal | |
| general cargo ship | average | normal | |

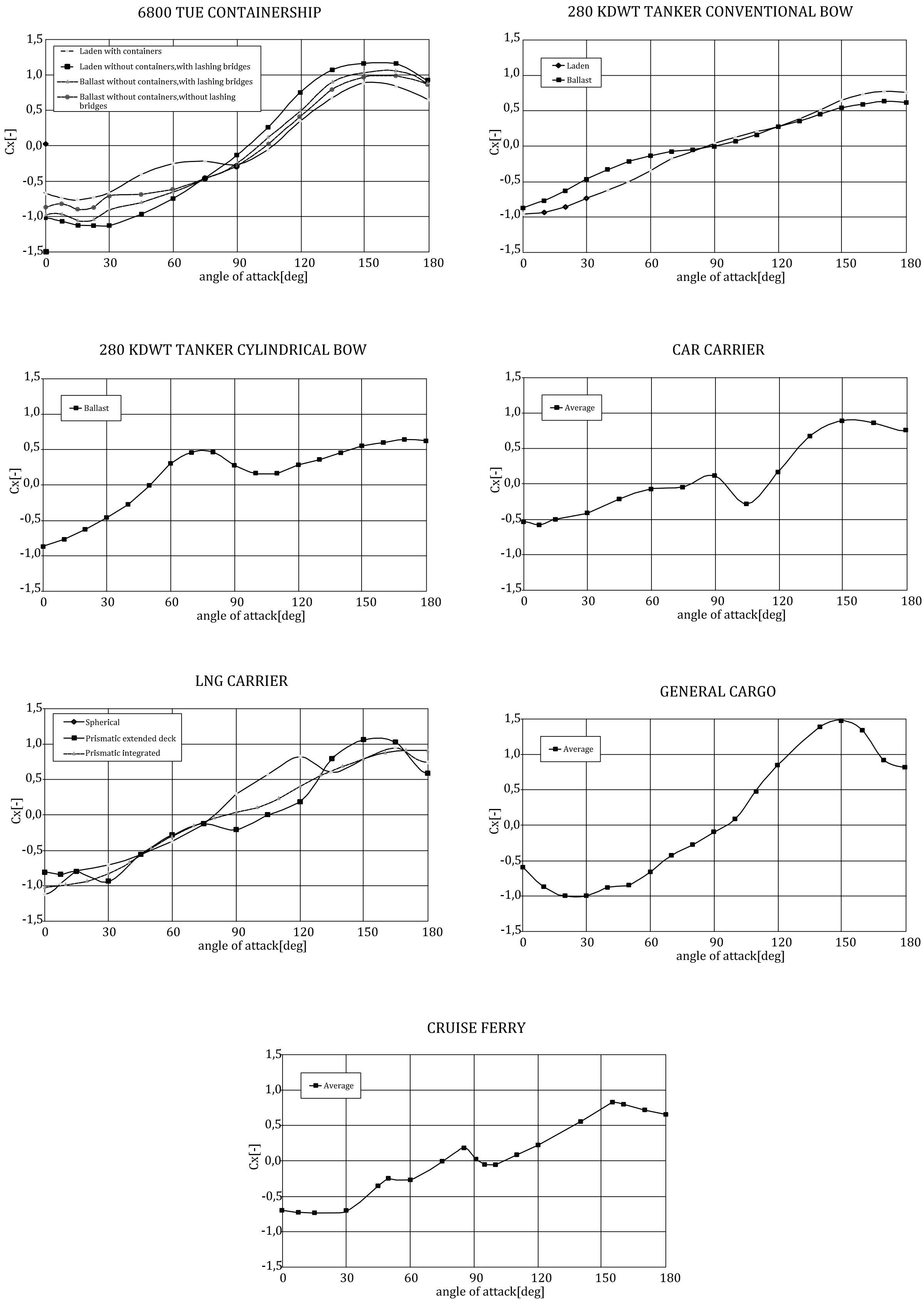



**Figure C.2 — Wind resistance coefficients for representative ship types [6]**

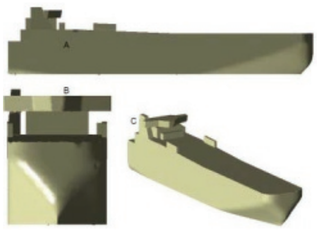

**a) Container ship, Laden with containers**


**b) Container ship, Ballast without containers**


**c) 280k DWT Tanker conventional bow, Laden**


**d) 280k DWT Tanker conventional bow, Ballast**


**e) 280k DWT Tanker cylindrical bow, Ballast**

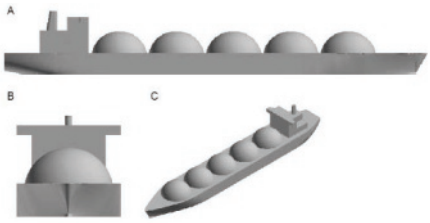


**f) Car carrier**

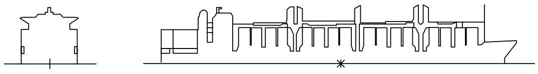
 


**g) LNG carrier prismatic extended deck**

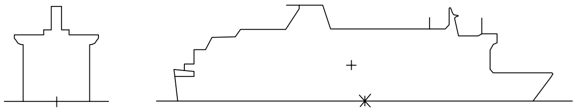

**h) LNG carrier prismatic integrated deck**




**i) LNG carrier spherical**



**j) General cargo ship**



**k) Cruise ferry**

**Figure C.3 — Ship profiles**

### C.2.3 Regression formula by Fujiwara et al.

Regression formula based on wind tunnel tests developed by Fujiwara et al.[8]:

$$C_{AA}(\psi_{WR}) = C_{LF}\cos\psi_{WR} + C_{XLI}\left(\sin\psi_{WR} - \frac{1}{2}\sin\psi_{WR}\cos^2\psi_{WR}\right)\sin\psi_{WR}\cos\psi_{WR} +$$
$$C_{ALF}\sin\psi_{WR}\cos^3\psi_{WR} \tag{C.11}$$

with:

for $0 \le \psi_{WR} < 90(\text{deg.})$

$$C_{LF} = \beta_{10} + \beta_{11} \frac{A_{LV}}{L_{OA}B} + \beta_{12} \frac{C_{MC}}{L_{OA}} \tag{C.12}$$

$$C_{XLI} = \delta_{10} + \delta_{11} \frac{A_{LV}}{L_{OA}H_{BR}} + \delta_{12} \frac{A_{XV}}{BH_{BR}} \tag{C.13}$$

$$C_{ALF} = \varepsilon_{10} + \varepsilon_{11} \frac{A_{OD}}{A_{LV}} + \varepsilon_{12} \frac{B}{L_{OA}} \tag{C.14}$$

for $90 < \psi_{WR} \leq 180(\text{deg.})$

$$C_{LF} = \beta_{20} + \beta_{21} \frac{B}{L_{OA}} + \beta_{22} \frac{H_C}{L_{OA}} + \beta_{23} \frac{A_{OD}}{L_{OA}^{\ 2}} + \beta_{24} \frac{A_{XV}}{B^2} \tag{C.15}$$

$$C_{XLI} = \delta_{20} + \delta_{21} \frac{A_{LV}}{L_{OA}H_{BR}} + \delta_{22} \frac{A_{XV}}{A_{LV}} + \delta_{23} \frac{B}{L_{OA}} + \delta_{24} \frac{A_{XV}}{BH_{BR}} \tag{C.16}$$

$$C_{ALF} = \varepsilon_{20} + \varepsilon_{21} \frac{A_{OD}}{A_{LV}} \tag{C.17}$$

for $\psi_{WR} = 90(\text{deg.})$

$$C_{AA}(90) = \frac{1}{2}\left\{C_{AA}(90-\mu) + C_{AA}(90+\mu)\right\} \tag{C.18}$$

where:

| | |
|---|---|
| $C_{AA}(\psi_{WR})$ | is the wind resistance coefficient; |
| $\psi_{WR}$ | is the relative wind direction in degrees; |
| $L_{OA}$ | is the ship's length overall in metres; |
| $B$ | is the ship's breadth in metres; |
| $A_{OD}$ | is the lateral projected area of superstructures above upper deck in square metres; |
| $A_{XV}$ | is the transverse projected area above the waterline including superstructures in square metres; |
| $A_{LV}$ | is the lateral projected area above the waterline including superstructures in square metres; |
| $C_{MC}$ | is the horizontal distance from midship section to centre of lateral projected area $A_{LV}$, where + means forward from midship in metres; |
| $H_{BR}$ | is the height of top of superstructure (bridge etc.) in metres; |
| $H_C$ | is the height from waterline to centre of lateral projected area $A_{LV}$ in metres; |
| $\mu$ | is the smoothing range in degrees, normally 10 (degrees.). |

The non-dimensional parameters $\beta_{ij}$, $\delta_{ij}$ and $\varepsilon_{ij}$ used in the formulae are shown in Table C.2.

**Table C.2 — Non-dimensional parameters**

| | *i* | *j* | | | | |
|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | 4 |
| $\beta_{ij}$ | 1 | 0,922 | −0,507 | −1,162 | - | - |
| | 2 | −0,018 | 5,091 | −10,367 | 3,011 | 0,341 |
| $\delta_{ij}$ | 1 | −0,458 | −3,245 | 2,313 | - | - |
| | 2 | 1,901 | −12,727 | −24,407 | 40,310 | 5,481 |
| $\varepsilon_{ij}$ | 1 | 0,585 | 0,906 | −3,239 | - | - |
| | 2 | 0,314 | 1,117 | - | - | - |

The coordinate system is shown in Figure C.4. and sign conventions are shown in Figure 4.

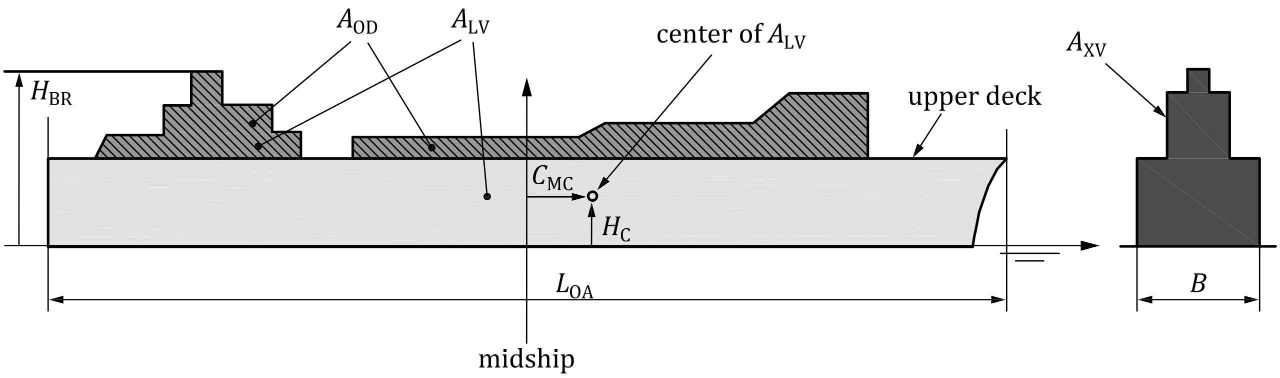



**Figure C.4 — Input parameters for regression formula by Fujiwara et al.**

# Annex D
(normative)

# Resistance increase due to waves

Irregular waves are represented as linear superposition of the components of regular waves. Therefore the mean resistance increase in short crested irregular waves $R_{AW}$ is calculated by linear superposition of the directional wave spectrum $E$ and the response function of the mean resistance increase in regular waves $R_{wave}$.

$$R_{AW} = 2\int_0^{2\pi}\int_0^{\infty}\frac{R_{wave}(\omega,\alpha,V_S)}{\zeta_A^2}E(\omega,\alpha)d\omega d\alpha \qquad \text{(D.1)}$$

where:

$R_{AW}$ is the mean resistance increase in short crested irregular waves in newtons;

$R_{wave}$ is the mean resistance increase in regular waves in newtons;

$\zeta_A$ is the wave amplitude in metres;

$\omega$ is the circular frequency of regular waves in radians per second;

$\alpha$ is the angle between ship's heading and component waves in radians; 0 means head waves;

$V_S$ is the ship's speed through the water in metres per second;

$E$ is the directional spectrum in square metre seconds.

If the directional spectrum is measured at sea trials by a sensor and the accuracy is confirmed, the measured directional spectrum shall be available. If the directional spectrum is not measured, it shall be calculated by the following relationship:

$$E = S_\eta(\omega)G(\alpha) \qquad \text{(D.2)}$$

where:

$S_\eta$ is the frequency spectrum in square metre seconds, as described in Formula (D.3);

$G$ is the angular distribution function.

The standard form of the frequency spectrum and the angular distribution function are assumed for the calculation. For wind waves the modified Pierson-Moskowitz type frequency spectrum of ITTC 1978, shown in Formula (D.3), shall be applied.

$$S_\eta(\omega) = \frac{A_{fw}}{\omega^5}\exp(-\frac{B_{fw}}{\omega^4}) \qquad \text{(D.3)}$$

$$A_{fw} = 173\frac{H_{1/3}^2}{T_{01}^4} \qquad \text{(D.4)}$$

$$B_{fw} = \frac{691}{T_{01}^4} \tag{D.5}$$

For the narrow band wave spectrum (e.g. North Sea), the JONSWAP frequency spectrum shown in Formula (D.6) is generally applied.

$$S_\eta(\omega) = \frac{A_{fs}}{\omega^5} \exp(-\frac{B_{fs}}{\omega^4}) 3,3^{\exp\left\{-0,5(1,3T_{01}\frac{\omega}{2\pi}-1)^2/\sigma_f{}^2\right\}} \tag{D.6}$$

$$A_{fs} = (2\pi)^4 \frac{0,072 H_{1/3}^2}{T_{01}^4} \tag{D.7}$$

$$B_{fs} = (2\pi)^4 \frac{0,44}{T_{01}^4} \tag{D.8}$$

$$\sigma_f = \begin{cases} 0,07 \quad \textit{for} \quad \omega \leq \frac{2\pi}{1,3T_{01}} \\ 0,09 \quad \textit{for} \quad \omega > \frac{2\pi}{1,3T_{01}} \end{cases} \tag{D.9}$$

where:

$$T_{01} = 2\pi \frac{m_0}{m_1} \tag{D.10}$$

and:

$H_{1/3}$ is the significant wave height in metres;

$\omega$ is the circular frequency of regular waves in radians per second;

$m_n$ is the $n^{th}$ moment of frequency spectrum.

For the angular distribution function the cosine-power type shown in Formula (D.11) is generally applied, e.g. $s = 1$ (for wind waves) and $s = 75$ (for swells) are used in practice.

$$G(\alpha) = \frac{2^{2s}}{\pi} \frac{\Gamma^2(s+1)}{\Gamma(2s+1)} \cos^{2s}(\alpha - \theta_m) \quad \text{for} \ (-\frac{\pi}{2} \leq \alpha - \theta_m \leq \frac{\pi}{2}) \tag{D.11}$$

where:

$s$ is the directional spreading parameter;

$\Gamma$ is the Gamma function;

$\alpha$ is the angle between ship's heading and component waves in radians; 0 means head waves;

$\theta_m$ is the primary wave direction in radians; 0 means head waves.

For wind waves and swells $R_{AW}$ is calculated for each with different wave height, period and direction.

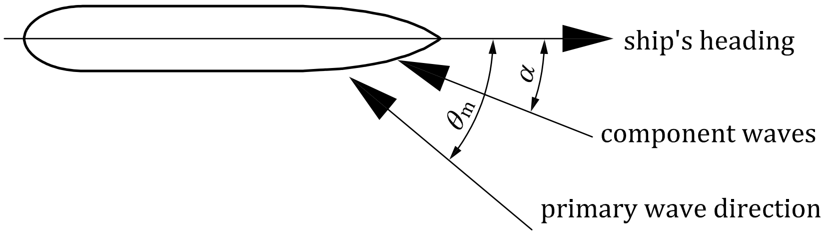



**Figure D.1 — Ship's heading and wave direction**

In calculating resistance increase due to waves, one of following methods shall be used:

In the event that the pitch and heave during a run have been small the 'simplified estimation method', prescribed in D.1, maybe used.

Otherwise, an 'empirical estimation method' for the frequency response function, prescribed in D.2, may be used for correction. This empirical transfer function covers both the mean resistance increase due to wave reflection and the motion induced resistance.

If the $C_P$ (longitudinal prismatic coefficient) and $C_{WP}$ (water plane area coefficient) curves are available, then the 'theoretical method with simplified tank tests in short waves', as prescribed in D.3, may be used.

The most reliable way to determine the decrease of ship's speed in waves is to carry out sea keeping tests, at various speeds, in regular waves of constant height but different wavelengths and directions. When the transfer functions of sea keeping tests, as prescribed in D.4, are available, they shall be used for correction of the S/P trials.

## D.1 Simplified correction method for ships with limited heave and pitch during the speed runs (STAWAVE-1)

A dedicated and simplified method to estimate the added resistance in waves with limited input data has been developed[6] specifically for speed trial conditions with present day ships.

Speed trials are conducted in low to mild sea states with restricted wave heights. In head waves the encounter frequency of the waves is high. In these conditions the effect of wave induced motions can be neglected and the added resistance is dominated by the wave reflection of the hull on the waterline. The water line geometry is approximated based on the ship beam and the length of the bow section on the water line (Figure D.2).

Formula (D.12) estimates the resistance increase in head waves provided that heave and pitch are small. The application is restricted to waves in the bow sector (less than ± 45 degrees off the bow). For wave directions outside this sector no wave correction is applied.

$$R_{\mathrm{AWL}} = \frac{1}{16}\rho_{\mathrm{S}} g H_{1/3}^{2} B \sqrt{\frac{B}{L_{\mathrm{BWL}}}} \quad \text{(D.12)}$$

where:

$R_{\mathrm{AWL}}$ is the mean resistance increase in long crested irregular waves in newtons, as substitute for $R_{\mathrm{AW}}$;

$\rho_{\mathrm{S}}$ is the water density in full scale in kilograms per cubic metre;

$g$ is the acceleration of gravity in metres per second squared;

$B$ is the ship's breadth in metres;

$H_{1/3}$ is the significant wave height in metres;

$L_{\mathrm{BWL}}$ is the distance of the bow to 95 % of maximum breadth on the waterline in metres, shown in Figure D.2.

with the following restriction:

1. significant wave height ($H_{1/3}$);

   $$H_{1/3} \leq 2{,}25\sqrt{L_{\mathrm{PP}} / 100}$$

2. heave and pitch during speed/power trial are small (vertical acceleration at bow < 0.05$g$);
3. wave direction is from ahead [within 0 to ± 45 (°)].

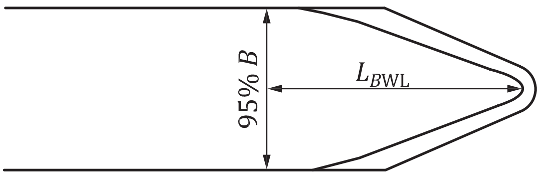



**Figure D.2 — Definition for the distance of the bow to 95 % of maximum beam on the waterline**

## D.2 Empirical correction method with frequency response function for ships which heave and pitch during the speed runs (STAWAVE-2)

An empirical method [6] has been developed to approximate the transfer function of the mean resistance increase in regular head waves by using the main parameters such as ship dimensions and speed (see Figure D.3).

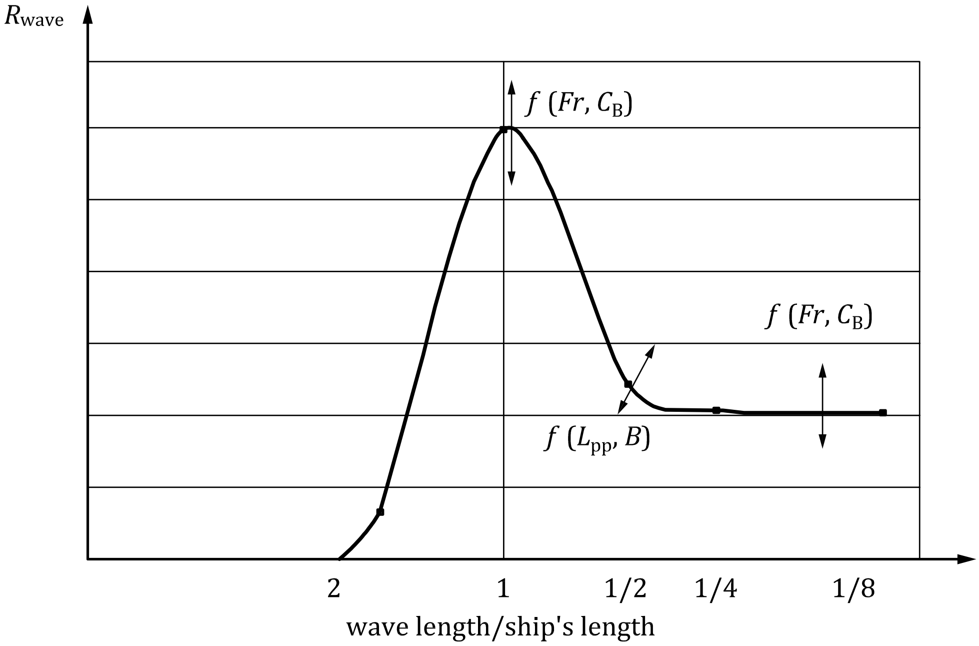



**Figure D.3 — Parametric transfer function of mean resistance increase in regular waves**

This empirical transfer function $R_{wave}$ covers both the mean resistance increase due to wave reflection $R_{AWRL}$ and the motion induced resistance $R_{AWML}$.

$$R_{wave} = R_{AWML} + R_{AWRL} \quad \text{(D.13)}$$

The components are calculated as shown in the following formulae.

$$R_{AWML} = 4\rho_S g \zeta_A^2 \frac{B^2}{L_{PP}} \overline{r_{aw}}(\omega) \quad \text{(D.14)}$$

with:

$$\overline{r_{aw}}(\omega) = \bar{\omega}^{b_1} \exp\left\{\frac{b_1}{d_1}\left(1 - \bar{\omega}^{d_1}\right)\right\} a_1 Fr^{1.50} \exp\left(-3{,}50 Fr\right) \quad \text{(D.15)}$$

$$\bar{\omega} = \frac{\sqrt{\frac{L_{PP}}{g}} \sqrt[3]{k_{yy}}}{1{,}17 Fr^{-0{,}143}} \omega \quad \text{(D.16)}$$

$$a_1 = 60{,}3 C_B^{1{,}34} \quad \text{(D.17)}$$

$$b_1 = \begin{cases} 11{,}0 & \text{for } \bar{\omega} < 1 \\ -8{,}50 & \text{elsewhere} \end{cases} \quad \text{(D.18)}$$

$$d_1 = \begin{cases} 14,0 & \text{for } \bar{\omega} < 1 \\ -566\left(\dfrac{L_{PP}}{B}\right)^{-2,66} & \text{elsewhere} \end{cases} \tag{D.19}$$

and:

$$R_{AWRL} = \frac{1}{2}\rho_S g \zeta_A^2 B \alpha_1(\omega) \tag{D.20}$$

$$\alpha_1(\omega) = \frac{\pi^2 I_1^2(1,5kT_M)}{\pi^2 I_1^2(1,5kT_M) + K_1^2(1,5kT_M)} f_1 \tag{D.21}$$

$$f_1 = 0,692\left(\frac{V_S}{\sqrt{T_M g}}\right)^{0,769} + 1,81 C_B^{6,95} \tag{D.22}$$

where:

| | |
|---|---|
| $\rho_S$ | is the water density in full scale in kilograms per cubic metre; |
| $g$ | is the acceleration of gravity in metres per second squared; |
| $\zeta_A$ | is the wave amplitude in metres; |
| $L_{PP}$ | is the ship's length between perpendiculars in metres; |
| $B$ | is the ship's breadth in metres; |
| $T_M$ | is the draught at midships in metres; |
| $C_B$ | is the block coefficient; |
| $Fr$ | is the Froude number; |
| $V_S$ | is the ship's speed through the water in metres per second; |
| $k_{yy}$ | is the non-dimensional radius of gyration in the lateral direction; |
| $I_1$ | is the modified Bessel function of the first kind of order 1; |
| $K_1$ | is the modified Bessel function of the second kind of order 1; |
| $k$ | is the wave number in radians per metre. |

With the following restrictions:

$$75(\text{m}) < L_{PP},$$

$$4,0 < \frac{L_{PP}}{B} < 9,0,$$

$$2,2 < \frac{B}{T_M} < 9,0,$$

$$0,10 < Fr < 0,30,$$

$$0,50 < C_B < 0,90 \text{ and}$$

wave direction is from ahead [within 0 to ± 45 (°)].

The method is applicable to the mean resistance increase in long crested irregular head waves $R_{AWL}$ [see Formula (D.23)]. The application is restricted to waves in the bow section to ± 45 (°) off bow waves which are treated as head waves for this method. Waves outside the ± 45 (°) sector are omitted from the wave correction in this method.

$$R_{\mathrm{AWL}} = 2\int_0^{\infty} \frac{R_{\mathrm{wave}}(\omega; V_{\mathrm{S}})}{\zeta_{\mathrm{A}}{}^2} S_{\eta}(\omega) d\omega \tag{D.23}$$

where:

$R_{AWL}$ is the mean resistance increase in long crested irregular waves in newtons, as substitute for $R_{AW}$;

$R_{wave}$ is the mean resistance increase in regular waves in newtons;

$\zeta_A$ is the wave amplitude in metres;

$\omega$ is the circular frequency of regular waves in radians per second;

$V_S$ is the ship's speed through the water in metres per second;

$S_\eta$ is the frequency spectrum in square metre seconds, for wind waves modified Pierson-Moskowitz type is known for the expression [see Formula (D.3)].

## D.3 Theoretical method with simplified tank tests in short waves

The application of this method is restricted to the certain ship types of container ship, bulk carrier, tanker or ro-ro cargo ship (vehicle carrier), whose length is more than 190 m.

The application is also restricted to waves encountered in the bow sector (less than ± 45 degrees off the bow). For wave directions outside this sector no wave correction is applied.

Applying the theoretical method, the mean resistance increase in regular waves $R_{wave}$ is calculated from the components of the mean resistance increase based on Maruo's theory [9] $R_{AWM}$ and its correction term which is primarily applicable to short waves $R_{AWR}$.

$$R_{\mathrm{wave}} = R_{\mathrm{AWM}} + R_{\mathrm{AWR}} \tag{D.24}$$

where:

$R_{AWM}$ is the mean resistance increase in regular waves based on Maruo's theory in newtons, which is calculated from the radiation and diffraction components;

$R_{AWR}$ is the correction term of $R_{AWM}$ in newtons.

$R_{AWR}$ shall be calculated with high accuracy because the mean resistance increase in short waves is the dominant factor for the evaluation of the mean resistance increase in irregular waves.

The expression of $R_{AWM}$ is given in the following formulae:

$$R_{\mathrm{AWM}} = 4\pi\rho_{\mathrm{S}}\left(-\int_{-\infty}^{m_{\mathrm{c}}} + \int_{m_{\mathrm{d}}}^{\infty}\right)\left|H_1(m)\right|^2 \frac{(m+k_0\tau)^2(m+k\cos\alpha)}{\sqrt{(m+k_0\tau)^4 - m^2k_0^2}} dm \text{ for } \tau \geq \frac{1}{4} \tag{D.25}$$

$$R_{\mathrm{AWM}} = 4\pi\rho_{\mathrm{S}}\left(-\int_{-\infty}^{m_{\mathrm{c}}} + \int_{m_{\mathrm{d}}}^{m_{\mathrm{b}}} + \int_{m_{\mathrm{a}}}^{\infty}\right)\left|H_1(m)\right|^2 \frac{(m + k_0\tau)^2(m + k\cos\alpha)}{\sqrt{(m + k_0\tau)^4 - m^2k_0^2}}\,dm \text{ for } \tau < \frac{1}{4} \tag{D.26}$$

where:

$$\tau = \frac{\omega_{\mathrm{E}} V_{\mathrm{S}}}{g} \tag{D.27}$$

$$k = \frac{\omega^2}{g} \tag{D.28}$$

$$k_0 = \frac{g}{V_{\mathrm{S}}^2} \tag{D.29}$$

$$\omega_{\mathrm{E}} = \omega + kV_{\mathrm{S}}\cos\alpha \tag{D.30}$$

$$m_{\mathrm{a}} = \frac{k_0\left(1 - 2\tau + \sqrt{1 - 4\tau}\right)}{2} \tag{D.31}$$

$$m_{\mathrm{b}} = \frac{k_0\left(1 - 2\tau - \sqrt{1 - 4\tau}\right)}{2} \tag{D.32}$$

$$m_{\mathrm{c}} = -\frac{k_0\left(1 + 2\tau + \sqrt{1 + 4\tau}\right)}{2} \tag{D.33}$$

$$m_{\mathrm{d}} = -\frac{k_0\left(1 + 2\tau - \sqrt{1 + 4\tau}\right)}{2} \tag{D.34}$$

$$H_1(m) = \int_L \sigma(x)e^{imx}dx \tag{D.35}$$

where:

$\rho_{\mathrm{S}}$ is the water density in full scale in kilograms per cubic metre;

$g$ is the acceleration of gravity in metres per second squared;

$V_{\mathrm{S}}$ is the ship's speed through the water in metres per second;

$\omega$ is the circular frequency of regular waves in radians per second;

$\omega_{\mathrm{E}}$ is the circular wave frequency of encounter in radians per second;

$\alpha$ is the encounter angle of incident waves in radians; 0 means head waves;

$H_1(m)$ is the function, in cubic metres per second, to be determined by the distribution of singularities $\sigma(x)$ which represents a periodical disturbance by the ship.

where the distribution of singularities $\sigma(x)$ is, as a practical treatment, calculated by the application of slender body theory, as shown in the following formula, in which the singularity is concentrated at a depth of $C_{Pv}T_M$, and the semi-infinite integration of $R_{AWM}$ is calculated paying attention to its convergence [10],[11],[12],[13].

$$\sigma(x) = -\frac{1}{4\pi}\left(i\omega_E - V_S \frac{\partial}{\partial x}\right)\left\{Z_\Gamma(x)B(x)\right\} \tag{D.36}$$

where:

$B(x)$ is the sectional breadth in metres;

$C_{Pv}$ is the vertical prismatic coefficient;

$T_M$ is the draught at midships in metres;

$x$ is the longitudinal coordinate in metres;

$\omega_E$ is the circular wave frequency of encounter in radians per second;

$V_S$ is the ship's speed through the water in metres per second;

$Z_\Gamma$ is the vertical displacement relative to waves in steady motion in metres.

The expression of $R_{AWR}$ is given by Tsujimoto et al[14]. The calculation method introduces an experimental coefficient in short waves into the calculation in terms of accuracy and takes into account the effect of the bow shape above the water.

$$R_{AWR} = \frac{1}{2}\rho_S g \zeta_A^2 B B_f \alpha_T (1 + C_U Fr) \tag{D.37}$$

where:

$\rho_S$ is the water density in full scale in kilograms per cubic metre;

$g$ is the acceleration of gravity in metres per second squared;

$\zeta_A$ is the wave amplitude in metres;

$B$ is the ship's breadth in metres;

$B_f$ is the bluntness coefficient, as calculated in Formula (D.41);

$C_U$ is the coefficient of advance speed;

$Fr$ is the Froude number;

$\alpha_T$ is the effect of draught and encounter frequency, as calculated in Formula (D.38).

and:

$$\alpha_T = \frac{\pi^2 I_1^2(k_e T_{deep})}{\pi^2 I_1^2(k_e T_{deep}) + K_1^2(k_e T_{deep})} \tag{D.38}$$

$$k_e = k(1 + \Omega \cos\alpha)^2 \tag{D.39}$$

$$\Omega = \frac{\omega V_S}{g} \tag{D.40}$$

$$B_{\mathrm{f}} = \frac{1}{B}\left\{\int_{I} \sin^2(\alpha + \beta_{\mathrm{W}})\sin\beta_{\mathrm{W}}dl + \int_{II}\sin^2(\alpha - \beta_{\mathrm{W}})\sin\beta_{\mathrm{W}}dl\right\} \tag{D.41}$$

where:

$I_1$ is the modified Bessel function of the first kind of order 1;

$K_1$ is the modified Bessel function of the second kind of order 1;

$k$ is the wave number in radians per metre;

$T_{deep}$ is the draught in metres; for a trim condition $T_{deep}$ is the deepest draught;

$g$ is the acceleration of gravity in metres per second squared;

$V_S$ is the ship's speed through the water in metres per second;

$\omega$ is the circular frequency of regular waves in radians per second;

$\alpha$ is the encounter angle of incident waves in radians; 0 means head waves;

$\beta_W$ is the slope of the line element $dl$ along the water line in radians.

and domains of the integration ($I$ and $II$) are shown in Figure D.4. When $B_{\mathrm{f}} < 0$ then $R_{\mathrm{wave}} = 0$ is assumed.

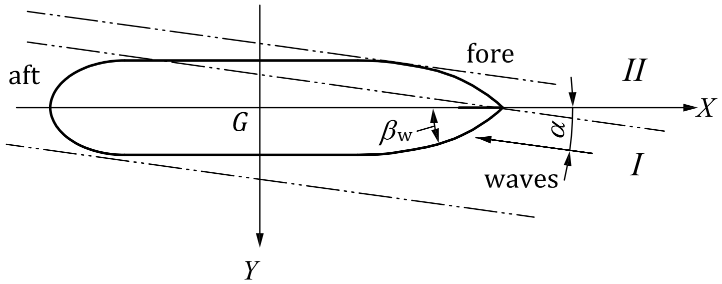



**Figure D.4 — Coordinate system for wave reflection**

The coefficient of the advance speed in oblique waves $C_U(\alpha)$ is calculated on the basis of the empirical relation line shown in Figure D.5, which has been obtained by tank tests of various ship types following the procedures in the next clause. When $C_U(\alpha = 0)$ is obtained by tank tests the relation used in oblique waves is shifted parallel to the empirical relation line, as Formulae (D.42) and (D.43). This is illustrated in Figure D.6 for both fine and blunt ships.

$$C_U = -310B_{\mathrm{f}} + 68 \text{ for } B_{\mathrm{f}} < 58\,/\,310 \tag{D.42}$$

$$C_U = 10 \text{ for } B_{\mathrm{f}} \geq 58\,/\,310 \tag{D.43}$$

NOTE The empirical relation line in Figure D.5 was obtained as follows. $C_U$ is derived from the result of tank tests and $R_{AWR}$, as Formula (D.44).

$$C_U = \frac{1}{Fr}\left\{\frac{R_{\text{wave}}^{\text{EXP}}(Fr) - R_{\text{AWM}}(Fr)}{\frac{1}{2}\rho_S g \zeta_A^2 B B_f \alpha_T} - 1\right\} \quad \text{(D.44)}$$

with

$R_{\text{wave}}^{\text{EXP}}$ is the mean resistance increase in regular waves measured in the tank tests in newtons;

$Fr$ is the Froude number;

$R_{\text{AWM}}$ is the mean resistance increase in regular waves based on Maruo's theory in newtons, which is calculated from the radiation and diffraction components;

$\rho_S$ is the water density in full scale in kilograms per cubic metre;

$g$ is the acceleration of gravity in metres per second squared;

$\zeta_A$ is the wave amplitude in metres, to be deleted;

$B$ is the ship's breadth in metres;

$B_f$ is the bluntness coefficient, as calculated in Formula D.41;

$\alpha_T$ is the effect of draught and encounter frequency, as calculated in Formula D.38.

The aforementioned coefficient $C_U(\alpha = 0)$ is determined by simplified tank tests which shall be carried out in short waves since $R_{\text{AWR}}$ is mainly affected by short waves. The tank tests shall be conducted for the specific ship geometry at the trial draughts and trim; and at contractual draughts if required. The number of wave frequencies is one in short waves. The length of short waves shall be 0,5$L_{\text{PP}}$ or less. The wave height corresponding to a sea state of Beaufort number[2)] 6, i.e. incident wave height: 3 m, is to be adopted. However, upper or lower limitation of the wave height can be set as the wave height to the ship's length ratio ($2\zeta_A / L_{pp}$) being 1/100 when reasonable restraint exists for suitable reasons, such as deck wetness etc. In any case the wave steepness (a ratio of the wave height to the wavelength) shall be 1/20 or less to avoid nonlinear wave behaviour. Incident waves are to be measured for 10 waves or more under steady conditions [17] . The test set-up and procedure shall follow ITTC 7.5-02 07-02.2.

The coefficient of advance speed $C_U$ is determined by the 'least squares' method through the origin against $Fr$ (see Figure D.7).

The tank tests shall be conducted for at least three different Froude Numbers ($Fr$). $Fr$ shall be selected such that the speeds during the sea trials lie between the lowest and the highest selected $Fr$.

2) The Beaufort Scale is given in Annex B.

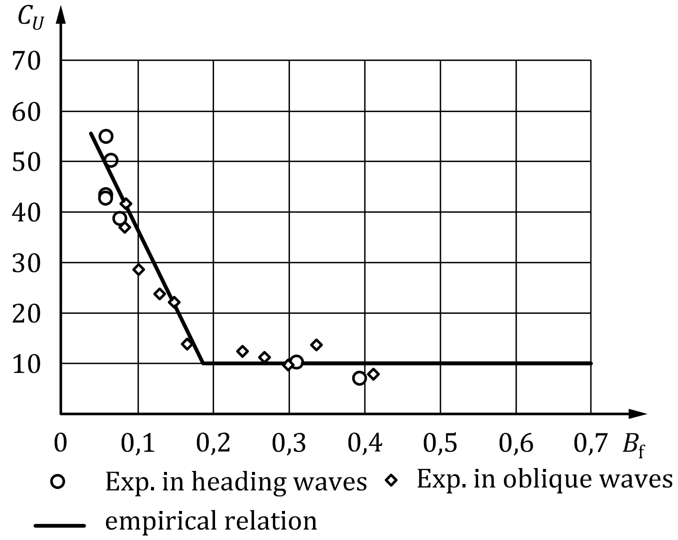



**Figure D.5 — Relation between the coefficient of advance speed on the added resistance due to wave reflection and the bluntness coefficient for a conventional hull form above water**

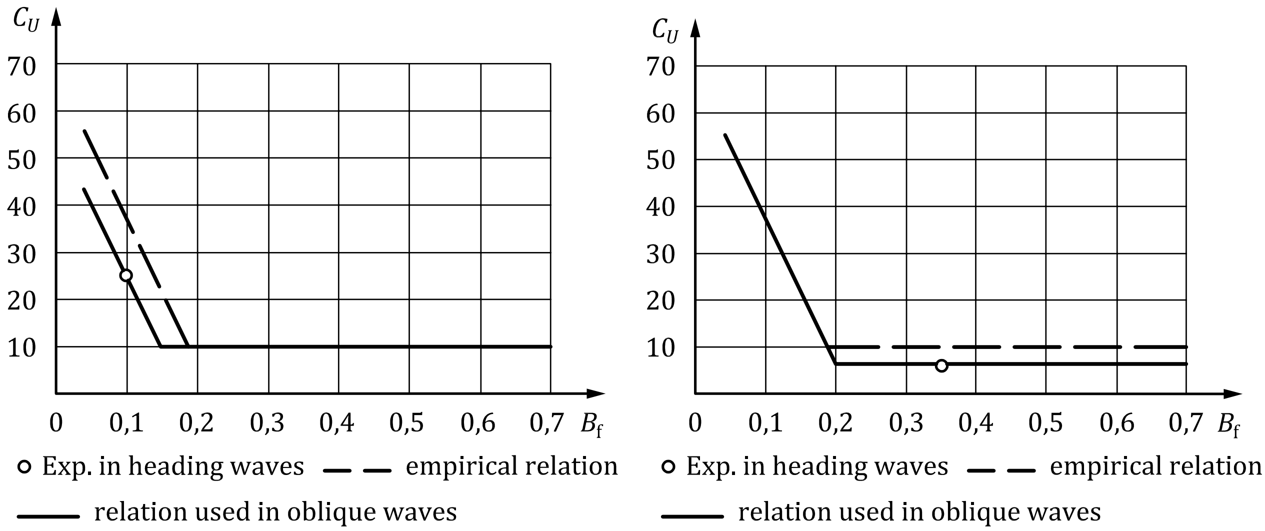



**Figure D.6 — Shift of the empirical relation in oblique waves (left; for fine ship $B_f < 58 / 310$, right; for blunt ship $B_f \geq 58 / 310$)**

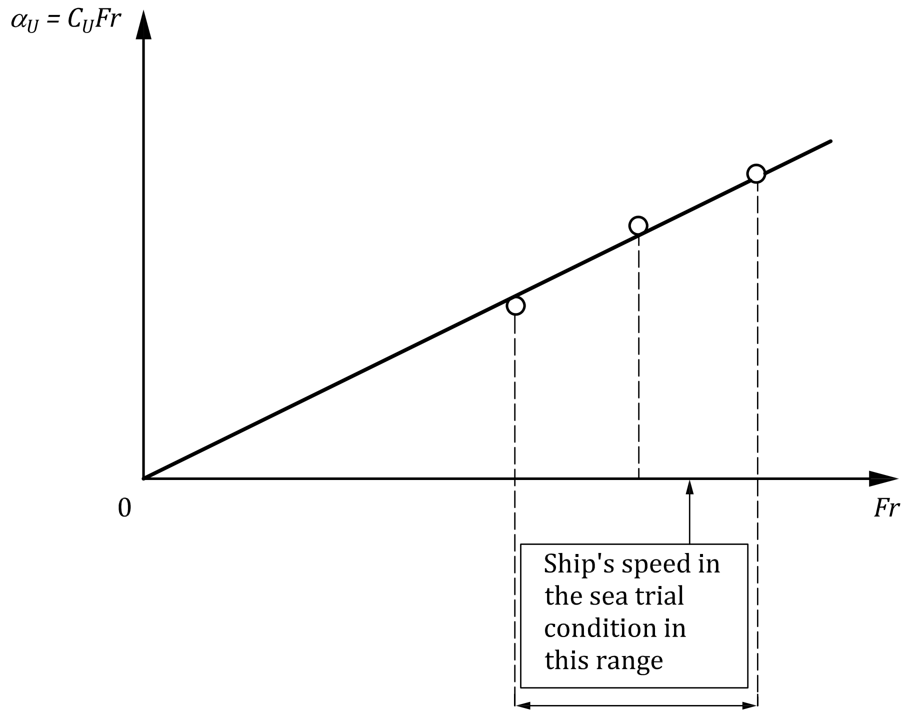



**Figure D.7 — Relation between effect of advance speed** $(\alpha_U = C_U Fr)$ **and Froude number** *Fr*

## D.4 Seakeeping model tests

Transfer functions of the resistance increase in waves ($R_{wave}$) may be derived from the tank tests in regular waves. The tank tests have to be conducted for the specific ship geometry at the trial draughts and trim; and at contractual draughts if required. A minimum of two different ship's speed ($V_S$) covering the speed range tested in the speed/power trials have to be tank tested.

If the trials are not conducted in head seas and following seas, the tank tests shall not only comprise head and following waves but also the relevant oblique wave conditions. A maximum interval of incident wave angle shall be 30 ° for head to beam seas (0° to 90°) but may be larger for beam to following seas (90° to 180°).

These tests shall be performed for a combination of circular frequency of regular waves ($\omega$), angle between ship heading and incident regular waves ($\alpha$) and ship's speed through the water ($V_S$) based on the following: A minimum of 5 wavelengths in the range of 0,5 $L_{PP}$ and less than 2,0 $L_{PP}$. The test set-up and procedure shall follow ITTC 7.5-02 07-02.2.

# Annex E
(normative)

# Effect of water temperature and water density

Both water temperature and water density affect the viscosity of the water and thus the ship resistance.

The prediction calculations of S/P trials are usually based on a temperature of the seawater of 15° C and a density of 1 026 kg/m$^3$. For EEDI correction, those base figures shall be used.

The effects of water temperature and water density are calculated as follows.

$$R_{AS} = R_{T0}\left(\frac{\rho_S}{\rho_{S0}} - 1\right) - R_F\left(\frac{C_{F0}}{C_F} - 1\right) \quad (E.1)$$

with:

$$R_F = \frac{1}{2}\rho_S S V_S^2 C_F \quad (E.2)$$

$$R_{F0} = \frac{1}{2}\rho_{S0} S V_S^2 C_{F0} \quad (E.3)$$

$$R_{T0} = \frac{1}{2}\rho_{S0} S V_S^2 C_{T0} \quad (E.4)$$

where:

$R_{AS}$ is the resistance increase due to deviation of water temperature and water density in newtons;

$C_F$ is the frictional resistance coefficient for the actual water temperature and water density;

$C_{F0}$ is the frictional resistance coefficient for the reference water temperature and water density;

$C_{T0}$ is the total resistance coefficient for the reference water temperature and water density;

$R_F$ is the frictional resistance for the actual water temperature and water density in newtons;

$R_{F0}$ is the frictional resistance for the reference water temperature and water density in newtons;

$R_{T0}$ is the total resistance for the reference water temperature and water density in newtons;

$S$ is the wetted surface area in square metres;

$V_S$ is the ship's speed through the water in metres per second;

$\rho_S$ is the water density for the actual water temperature and salt content in kilograms per cubic metre;

$\rho_{S0}$ is the water density for the reference water temperature and salt content in kilograms per cubic metre.

# Annex F
(normative)

# Effect of current

Considering the nature of currents, the current speed shall be estimated from the measured ship's speed at each run.

There are two methods to account for the effect of current.

— The 'Iterative' method, where the current speed is assumed as a semi durational phenomenon.

— The 'Mean of means' method, where current speed is assumed to vary parabolically [15] within a given power setting.

## F.1 'Iterative' method

In the 'Iterative' method, the current speed is assumed to vary with, *inter alia*, the semidiurnal period. A current curve is determined as a function of time as follows:

$$V_C = V_{C,C}\cos\left(\frac{2\pi}{T_C}t\right) + V_{C,S}\sin\left(\frac{2\pi}{T_C}t\right) + V_{C,T}t + V_{C,0} \quad \text{(F.1)}$$

where:

$V_C$ is the current speed in knots;

$T_C$ is the period of variation of current speed;

$t$ is the time for each run.

and unknown factors $V_{C,C}$, $V_{C,S}$, $V_{C,T}$ and $V_{C,0}$.

The most dominant period is the lunar semidiurnal period of 0,517 53 day (12 hours, 25 minutes and 12 seconds).

The ship's speed through the water $V_S$ is derived from a regression curve (F.2) which represents the relationship between the ship's speed through the water and its power corrected in accordance with 12.2.3 and is defined as follows:

**Stage 1: first approximation of ship's speed through the water**

$$P\left(V_S\right) = a + bV_S^q \quad \text{(F.2)}$$

Therefore:

$$V_S = \sqrt[q]{\frac{P\left(V_S\right) - a}{b}} \quad \text{(F.3)}$$

where:

$P(V_S)$ is the regression curve;

$V_S$ is the ship's speed through the water in knots.

and unknown factors $a$, $b$ and $q$.

The initial value of $V_S$ shall be taken as the average of the measured ship's speeds $V'_G$ of a Double Run. As a first approximation of the regression curve representing the relationship between ship's speed and power, a mean curve is derived by determining the unknown factors, $a$, $b$ and $q$ of Formula (F.2) by fitting the Formula (F.2) to combinations of the initial value of $V_S$ and averaged corrected power $P'_{id}$ by the 'least squares' method.

The ship's speed on the mean curve at the corrected power for each run is calculated as the updated ship's speed through the water $V_S$ from the Formula (F.3) applying the coefficients obtained as described above.

**Stage 2: calculation of current velocity**

Current speed at the time for each run $V'_C$ is calculated by subtracting the updated ship's speed through the water $V_S$ from the measured ship's speed over the ground $V_G$.

$$V_C' = V_G - V_S \tag{F.4}$$

A current curve is obtained by determining the unknown factors $V_{C,C}$, $V_{C,S}$, $V_{C,T}$ and $V_{C,0}$ of Formula (F.1) by fitting the Formula (F.1) to the combinations of time and current speed obtained from Formula (F.4) by the 'least squares' method.

The current speed on the current curve at the time for each run $V_C$ is calculated as the updated current speed from the Formula (F.1) and applying the coefficients obtained as described above.

**Stage 3: calculation of ship's speed through the water**

The ship's speed, corrected for current $V'_S$, is calculated by subtracting the updated current speed $V_C$ from the measured ship's speed over the ground $V_G$.

$$V_S' = V_G - V_C \tag{F.5}$$

The updated regression curve representing the relationship between ship's speed and power is obtained by determining new factors of Formula (F.2) by fitting the Formula (F.2) to the combination of ship's speed obtained from Formula (F.5) and corrected power by the 'least squares' method again.

The ship's speed through the water at the corrected power for each run $V_S$ is recalculated as the updated one from the Formula (F.3), and the processes of Stage 2 and Stage 3 are then repeated until $\sum\left(P\left(V_S'\right)_i - P_{\text{id}i}\right)^2$ is minimized:

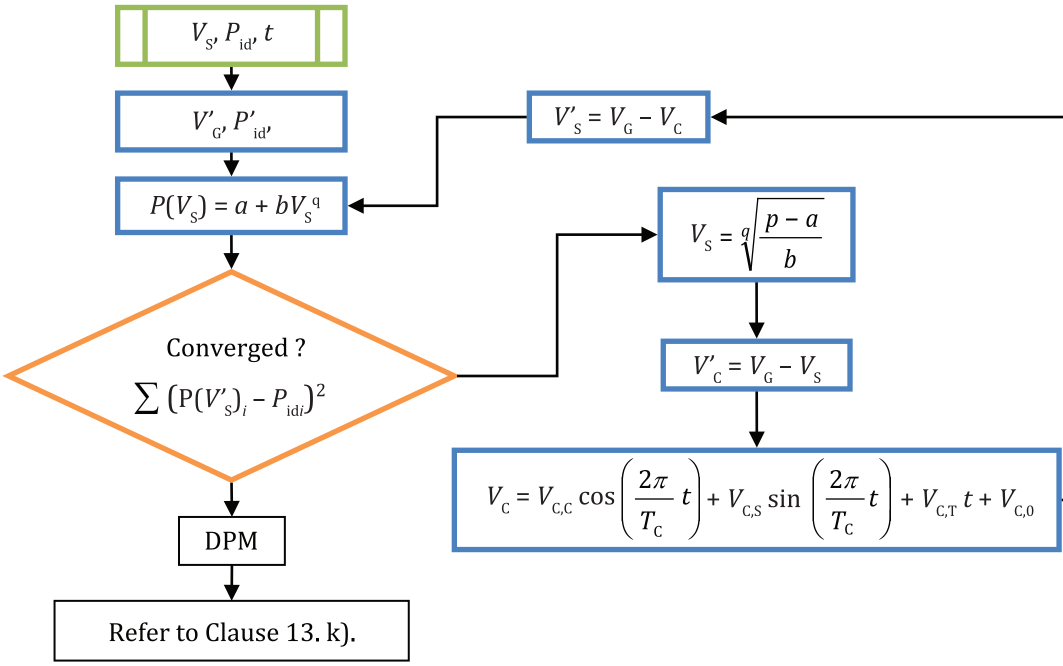



**Figure F.1 — Flow chart of the 'Iterative' method**

## F.2 'Mean of means' method

If two Double Runs, i.e. four runs, are carried out, the 'Mean of means' method can be used.

This method assumes that the current speed varies parabolically over the time, and the following formula is used to account for the current effect:

$$V_S = \frac{V_{G1} + 3V_{G2} + 3V_{G3} + V_{G4}}{8} \qquad \text{(F.6)}$$

where:

$V_S$ is the ship's speed through the water in knots;

$V_{G1}$ is the measured ship's speed over the ground on the first of four runs in knots;

$V_{G2}$ is the measured ship's speed over the ground on the second of four runs in knots;

$V_{G3}$ is the measured ship's speed over the ground on the third of four runs in knots;

$V_{G4}$ is the measured ship's speed over the ground on the fourth of four runs in knots.

If the current speed varies parabolically, a current curve is defined as a quadratic function of the time.[3)]

$$V_C = V_{C,2}t^2 - V_{C,1}t + V_{C,0} \qquad \text{(F.7)}$$

where:

$V_{C,0}$, $V_{C,1}$ and $V_{C,2}$ are unknown factors.

3) In case of three (3) Double Runs applied, Formula (F.7) is changed to quartic function.

If two Double Runs, i.e. four runs, are conducted, the following relationship is derived for each run from Formula (F.7).

$$V_{G1} = V_S + \left\{ V_{C,2}(t + 3\Delta t)^2 - V_{C,1}(t + 3\Delta t) + V_{C,0} \right\} \quad \text{(F.8)}$$

$$V_{G2} = V_S - \left\{ V_{C,2}(t + \Delta t)^2 - V_{C,1}(t + \Delta t) + V_{C,0} \right\} \quad \text{(F.9)}$$

$$V_{G3} = V_S + \left\{ V_{C,2}(t - \Delta t)^2 - V_{C,1}(t - \Delta t) + V_{C,0} \right\} \quad \text{(F.10)}$$

$$V_{G4} = V_S - \left\{ V_{C,2}(t - 3\Delta t)^2 - V_{C,1}(t - 3\Delta t) + V_{C,0} \right\} \quad \text{(F.11)}$$

where:

$V_S$ is the ship's speed through the water in knots;

$V_{G1}$ is the measured ship's speed over the ground on the first of four runs in knots;

$V_{G2}$ is the measured ship's speed over the ground on the second of four runs in knots;

$V_{G3}$ is the measured ship's speed over the ground on the third of four runs in knots;

$V_{G4}$ is the measured ship's speed over the ground on the fourth of four runs in knots;

$t$ is the start time of the first speed run of a power setting;

$\Delta t$ is half of the elapsed time between two successive runs.

The current effect is accounted for by substituting the above four Formulae (F.8) to (F.11) for Formula (F.6).

The ship's speed through the water is the 'Mean of means' of the two Double Runs.

The current speed for each individual speed run shall be checked by comparing the 'Mean of means' result at one power setting.

The propeller shaft speed and power shall be averaged over the two runs of each Double Run and then over the Double Runs for the same power setting.

# Annex G
(normative)

# Effect of shallow water

The following formula [16] shall be used to correct the ship's speed for shallow water effects:

$$\frac{\Delta V}{V_S} = 0{,}124\,2\left(\frac{A_M}{h^2} - 0{,}05\right) + 1 - \left(\tanh\frac{gh}{V_S^2}\right)^{1/2} \quad \text{for} \quad \frac{A_M}{h^2} \geq 0{,}05 \qquad \text{(G.1)}$$

where:

$\Delta V$ is the decrease of ship's speed due to shallow water in metres per second;

$V_S$ is the ship's speed through the water in metres per second;

$h$ is the water depth in metres;

$A_M$ is the midship section area under water in square metres;

$g$ is the acceleration of gravity in metres per second squared.

# Annex H
(normative)

# Effect of displacement

If the displacement of the ship at the S/P trial differs from the required displacement within the limit of 2 %, specified in 7.1, the following formula, based on the Admiral-formula, shall be applied to the power values:

$$P_2 = P_1 \cdot \left(\frac{\nabla_2}{\nabla_1}\right)^{2/3} \quad \text{at each speed} \tag{H.1}$$

where:

$P_1$ is the power in watts corresponding to displacement volume $\nabla_1$ during the S/P trial;

$P_2$ is the power in watts corresponding to displacement volume $\nabla_2$ used in the tank test;

$\nabla_1$ is the displacement volume during the S/P trial in cubic metres;

$\nabla_2$ is the displacement volume used in the tank test in cubic metres.

# Annex I
(normative)

# Conversion from trial condition to other stipulated load conditions

For ships whose S/P trials are not performed at full load or a stipulated condition, the S/P trials are performed in 'trial condition' and the S/P trial results are converted to that of other stipulated condition(s) by use of the tank test results.

The speed/power curve for other stipulated condition(s) is obtained from the results of the S/P trials at 'trial condition' by using the speed-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 S/P trials, and any other stipulated condition.

Using the speed/power curve obtained from the S/P trials in the trial condition, as defined in Clause 13 item k), the conversion of ship's speed from the trial condition to the other stipulated condition shall be carried out by the power ratio $\alpha_P$ defined in Formula (I.1).

The adjusted power at, e.g. full load condition ($P_{\text{Full,S}}$) shall be calculated by Formula (I.2).

$$\alpha_P = \frac{P_{\text{Trial,P}}}{P_{\text{Trial,S}}} \tag{I.1}$$

$$P_{\text{Full,S}} = \frac{P_{\text{Full,P}}}{\alpha_P} \tag{I.2}$$

where:

$P_{\text{Trial,P}}$ is the power at the trial condition predicted by the tank tests in watts;

$P_{\text{Trial,S}}$ is the power at the trial condition obtained by the S/P trials (see Clause 13, item k) in watts;

$P_{\text{Full,P}}$ is the power at full load/stipulated condition predicted by the tank tests in watts;

$P_{\text{Full,S}}$ is the power at full load/stipulated condition obtained by the S/P trials in watts;

$\alpha_P$ is the power ratio.

Figure I.1 shows an example of the scheme of the conversion to derive the resulting ship's speed at full load/stipulated condition $V_{\text{Full,S}}$ at 75 % MCR where MCR is the Maximum Continuous Rating.

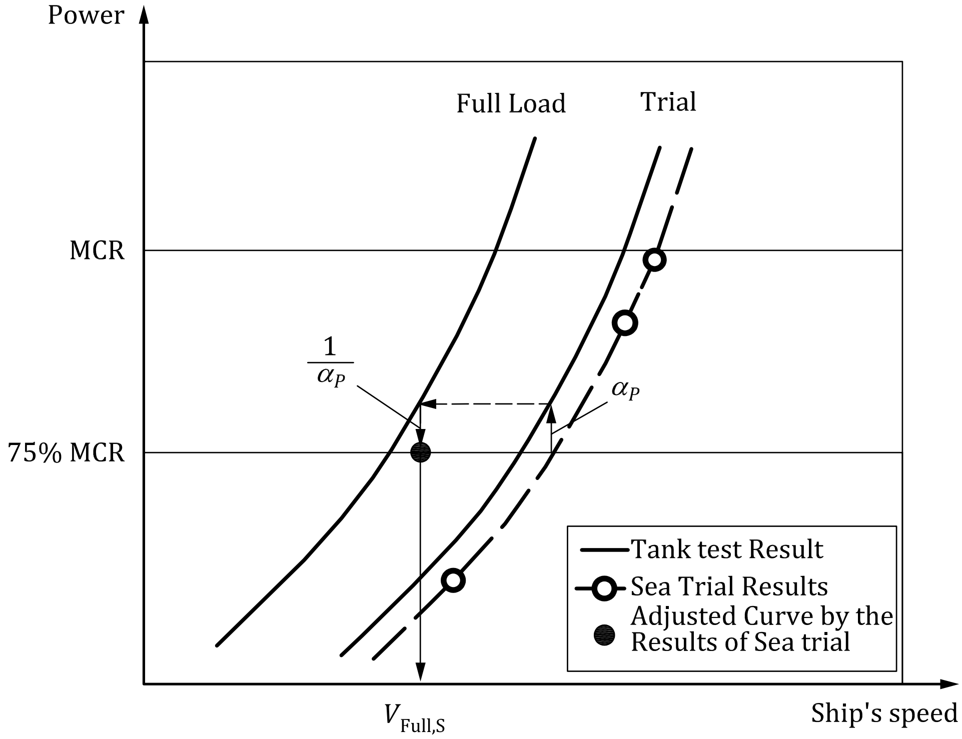



**Figure I.1 — Example of scheme of conversion from trial condition to other stipulated load condition at 75 % MCR**

# Annex J
(normative)

# Derivation of load variation coefficients

The load variation test includes at least four self-propulsion test runs, each one at a different propeller shaft speed while keeping the model's speed constant. The propeller shaft speeds are to be selected such that:

$$\frac{\Delta R}{R_{\mathrm{id}}} \approx \left[-0{,}1 \quad 0 \quad 0{,}1 \quad 0{,}2\right] \tag{J.1}$$

where:

$$\Delta R = (F_{\mathrm{D}} - F_{\mathrm{X}})\lambda^3 \frac{\rho_{\mathrm{S}}}{\rho_{\mathrm{M}}} \tag{J.2}$$

$\Delta R$ is the resistance increase in newtons;

$R_{\mathrm{id}}$ is the full scale resistance at the actual speed from resistance test in newtons;

$F_{\mathrm{X}}$ is the external tow force measured during load variation test in newtons;

$F_{\mathrm{D}}$ is the skin friction correction force same as in the normal self-propulsion tests in newtons;

$\lambda$ is the scale factor;

$\rho_{\mathrm{S}}$ is the water density in full scale in kilograms per cubic metre;

$\rho_{\mathrm{M}}$ is the water density in the model test in kilograms per cubic metre.

The "added resistance" in the load variation test has to be accounted for in the post processing. For example, if the standard self-propulsion test is carried out and processed according to ITTC 7.5–02–03–01.4 (1978 ITTC Performance Prediction Method) at tow force $F_{\mathrm{D}}$, the measured data are processed according to the mentioned procedure with one modification: from section 2.4.3 and onwards:

$C_{\mathrm{TS}}$ is replaced by $C_{\mathrm{TSadd}}$

where:

$$C_{\mathrm{TSadd}} = C_{\mathrm{TS}} + \frac{\Delta R}{1/2\rho_{\mathrm{S}} V_{\mathrm{S}}^2 S_{\mathrm{S}}} \tag{J.3}$$

$\rho_{\mathrm{S}}$ is the water density in full scale in kilograms per cubic metre;

$\Delta R$ is the resistance increase in newtons;

$V_{\mathrm{S}}$ is the full scale ship's speed in metres per second;

$S_{\mathrm{S}}$ is the full scale wetted surface in square metres, the same value as used in the normal self-propulsion test.

In this way the added resistance is reflected in the propeller load $K_T/J^2$, and as a consequence in $J_{TS}$, $n_{\mathrm{S}}$, $P_{\mathrm{DS}}$, $\eta_{\mathrm{OS}}$ and $\eta_{\mathrm{D}}$.

**Dependency of propulsive efficiency with resistance increase**

The propulsive efficiency coefficient in the ideal condition $\eta_{Did}$, is obtained from standard towing tank test and interpolated to the speed $V_S$.

The fraction between the propulsive efficiency $\eta_{Dms}$ from the load variation test and that from the normal self-propulsion test $\eta_{Did}$ is plotted against the added resistance fraction $\Delta R/R_{id}$ (with the ideal condition $R_{id}$ in the denominator). Each $\eta_{Dms}$ shall be treated as well as $\eta_{Did}$ in the verification process. The variable $\xi_P$ is the slope of the linear curve going through {0,1} and fitted to the data points by the 'least squares' method. (see example in Figure J.1)

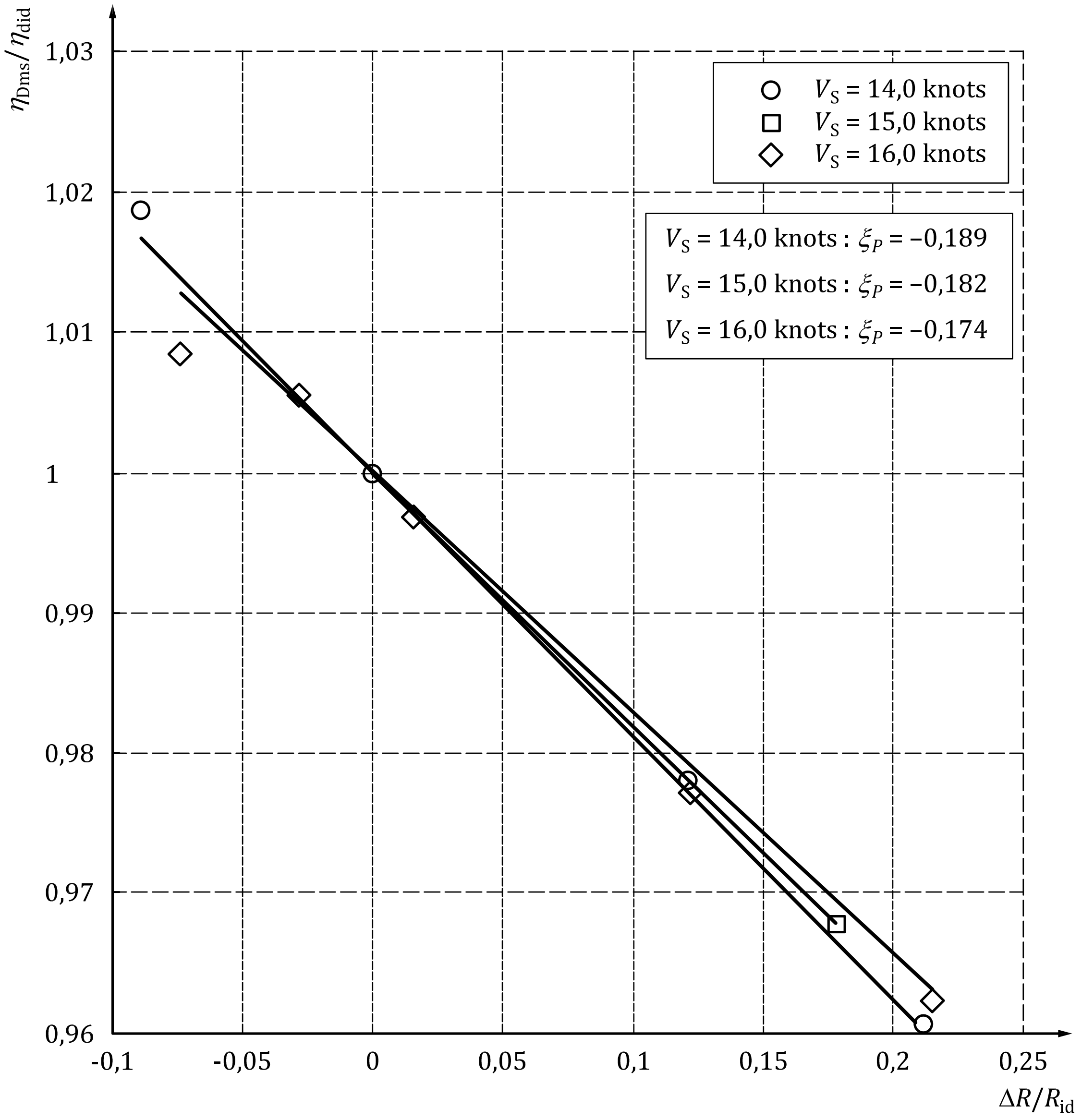



**Figure J.1 — Example of the approximate $\eta_{Dms}/\eta_{Did}$ - $\Delta R/R_{id}$ curve fitted by the 'least squares' method**

The propulsive efficiency is assumed to vary linearly with the added resistance according to:

$$\frac{\eta_{\mathrm{Dms}}}{\eta_{\mathrm{Did}}} = \xi_P \frac{\Delta R}{R_{\mathrm{id}}} + 1 \tag{J.4}$$

where:

$\eta_{\mathrm{Dms}}$ is the propulsive efficiency coefficient in the trial condition;

$\eta_{\mathrm{Did}}$ is the propulsive efficiency coefficient in the ideal condition;

$\xi_P$ is derived from the load variation test;

$\Delta R$ is the resistance increase in newtons;

$R_{\mathrm{id}}$ is the resistance in the ideal condition in newtons.

This leads to the expression for the corrected delivered power:

$$P_{\mathrm{Did}} = P_{\mathrm{Dms}} - \frac{\Delta R \cdot V_{\mathrm{S}}}{\eta_{\mathrm{Did}}} \cdot \left(1 - \frac{P_{\mathrm{Dms}}}{P_{\mathrm{Did}}} \cdot \xi_P\right) \tag{J.5}$$

$$P_{\mathrm{Did}} = \frac{1}{2}\left\{P_{\mathrm{Dms}} - \frac{\Delta R \cdot V_{\mathrm{S}}}{\eta_{\mathrm{Did}}} + \sqrt{\left(P_{\mathrm{Dms}} - \frac{\Delta R \cdot V_{\mathrm{S}}}{\eta_{\mathrm{Did}}}\right)^2 + 4P_{\mathrm{Dms}} \frac{\Delta R \cdot V_{\mathrm{S}}}{\eta_{\mathrm{Did}}} \cdot \xi_P}\right\} \tag{J.6}$$

where

$P_{\mathrm{Did}}$ is the delivered power in the ideal condition in watts;

$P_{\mathrm{Dms}}$ is the delivered power in the trial condition in watts;

$\Delta R$ is the resistance increase in newtons;

$V_{\mathrm{S}}$ is the ship's speed through the water in metres per second;

$\eta_{\mathrm{Did}}$ is the propulsive efficiency coefficient in the ideal condition;

$\xi_P$ is derived from the load variation test.

**Dependency of propeller shaft speed with power increase**

Similarly, the effect on propeller shaft speed $\Delta n/n_{\mathrm{id}}$ is plotted against $\Delta P_{\mathrm{D}}/P_{\mathrm{Did}}$ (with the ideal condition $n$ and $P_{\mathrm{Did}}$ in the denominators). The variable $\xi_n$ is the slope of the linear curve going through {0,0} and fitted to the data points with 'least squares' method (example in Figure J.2).

With the $P$ found as described above, the correction to propeller shaft speed is:

$$\frac{\Delta n}{n_{\mathrm{id}}} = \xi_n \frac{P_{\mathrm{Dms}} - P_{\mathrm{Did}}}{P_{\mathrm{Did}}} + \xi_V \frac{\Delta V}{V_{\mathrm{S}}} \tag{J.7}$$

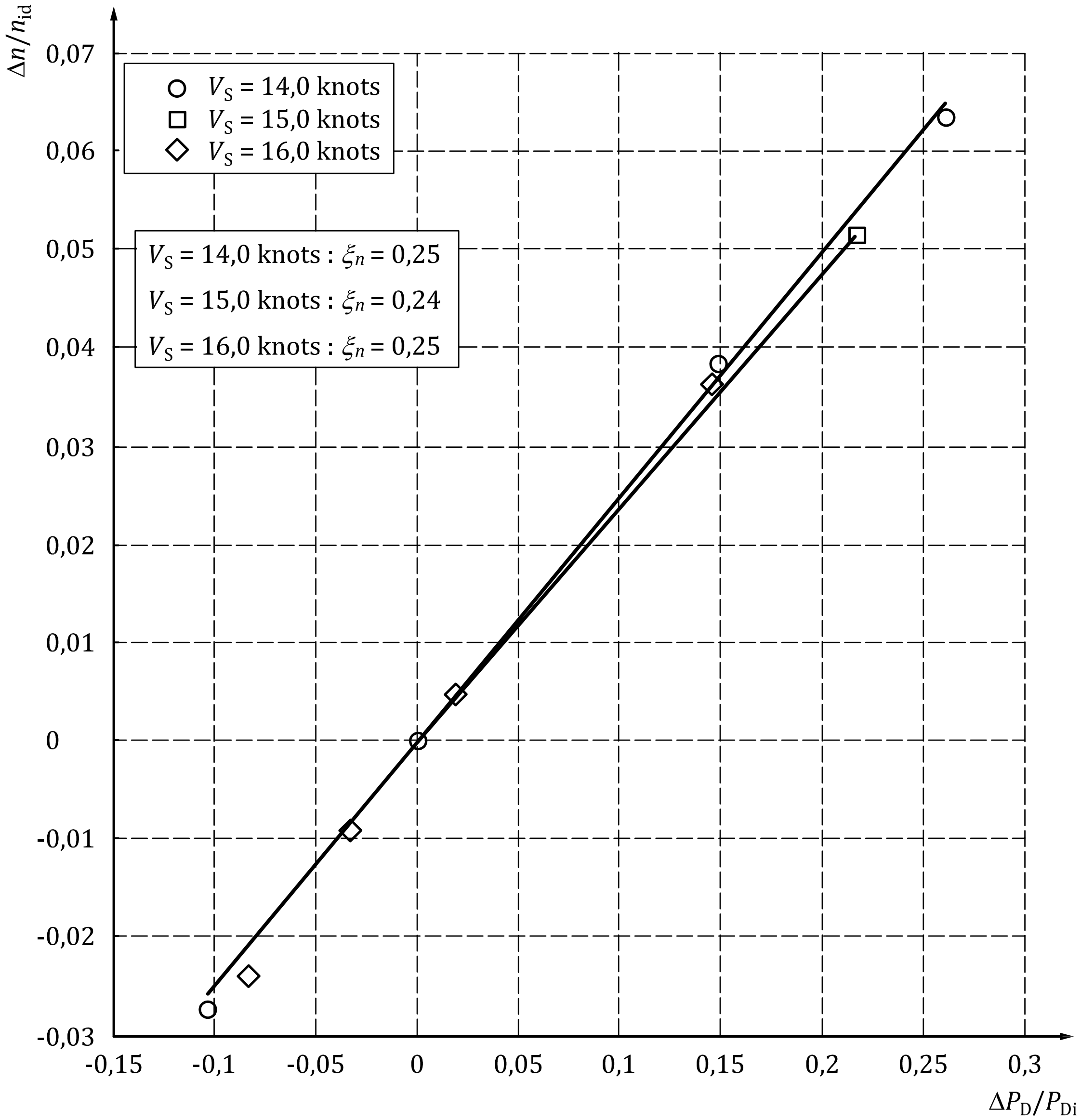
where:

$$n_{\mathrm{id}} = \frac{n_{\mathrm{ms}}}{\xi_n \cdot \frac{P_{\mathrm{Dms}} - P_{\mathrm{Did}}}{P_{\mathrm{Did}}} + \xi_V \cdot \frac{\Delta V}{V_{\mathrm{S}}} + 1} \tag{J.8}$$

$$\Delta n = n_{ms} - n_{id} \tag{J.9}$$

and:




| | |
|---|---|
| $n_{ms}$ | is the measured propeller shaft speed in revolutions per second; |
| $n_{id}$ | is the corrected propeller shaft speed in revolutions per second; |
| $P_{Did}$ | is the delivered power in the ideal condition in watts; |
| $P_{Dms}$ | is the delivered power in the trial condition in watts; |
| $\xi_n$, $\xi_V$ | are derived from load variation test; |
| $V_S$ | is the ship's speed through the water in metres per second; |
| $\Delta V$ | is the speed correction due to shallow water in metres per second, determined in Annex G. |

**Figure J.2 — Example of the approximate $\Delta n/n_{id}$ - $\Delta P_D/P_{Did}$ curve fitted using the 'least squares' method**

**Dependency of propeller shaft speed with speed change**

The propeller shaft speed $n$ from the load variation test is plotted against the resistance $R_{id}+\Delta R$. The corresponding curves for other speeds are assumed to be parallel to this line and go through the point $\{R_{id}, n\}$ from the calm water self-propulsion test. The intersection of these lines with a constant resistance gives the rpm dependency of speed. The slope of the $\Delta n/n$ - $\Delta V/V$ curve fitted using the 'least squares' method is $\xi_V$. (see example in Figure J.3)

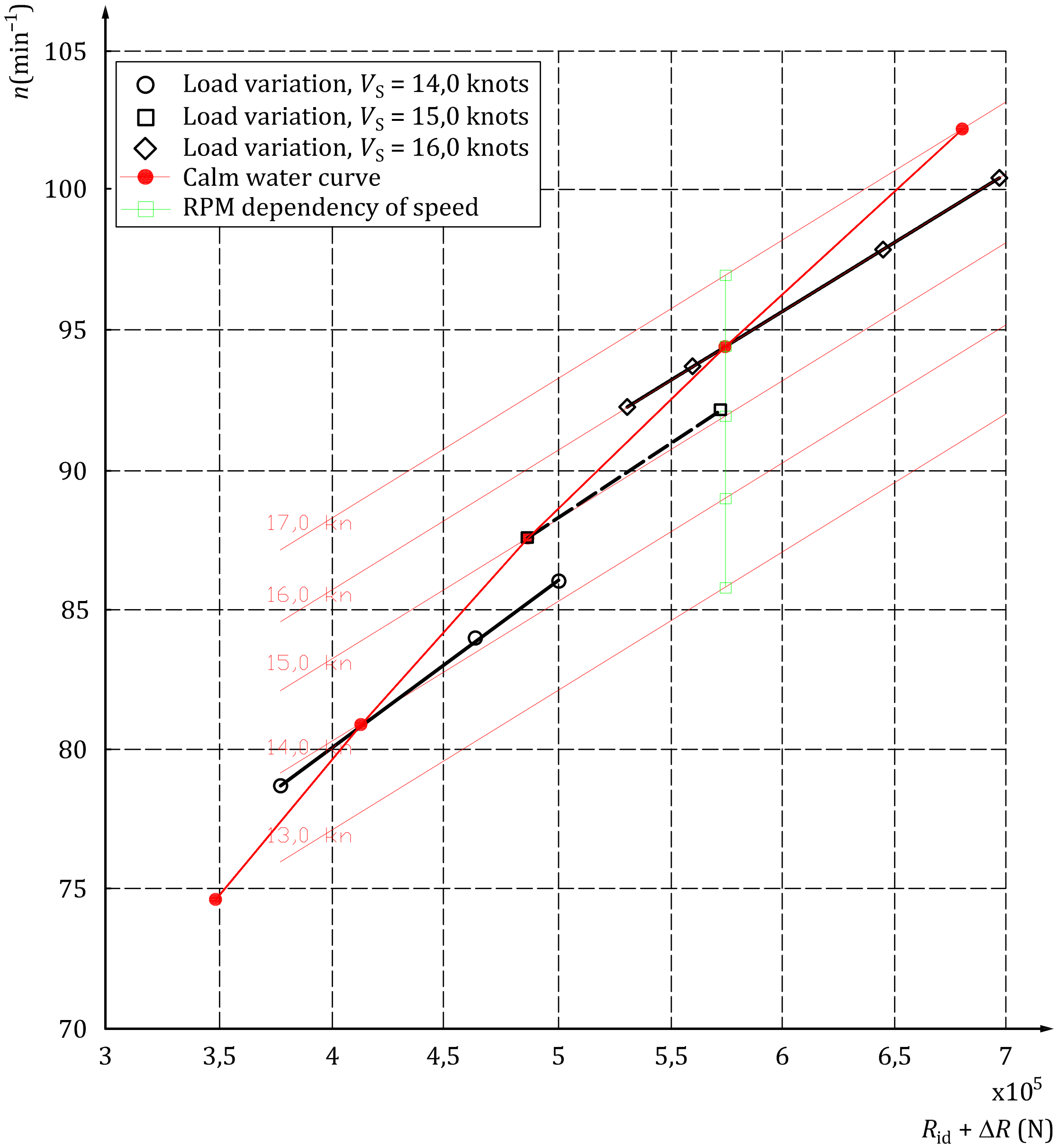



**Figure J.3 — Example of the effect of load variation and ship's speed on propeller shaft speed**

In case there is no load variation test available it is allowable that the self-propulsion factors considering load variation effect are assumed to be equal to the self-propulsion factors for the ideal condition. This is because deviations of self-propulsion factors due to load variation effect are negligibly small in comparison with the deviations of the propeller efficiency due to load variation effect. The variation of $\eta_O$ may be derived by ITTC 7.5-02-03-01.4 (2011).

# Annex K
(informative)

# Analysis of direct power method

## K.1 Propulsive efficiency correction

Propulsive efficiency coefficient $\eta_D$ is generally calculated using propeller efficiency $\eta_O$ and self-propulsion factors $\eta_R$, $t$ and $w_S$:

$$\eta_D = \eta_O \eta_R \frac{1-t}{1-w_S} \tag{K.1}$$

where:

$\eta_D$ is the propulsive efficiency coefficient;

$\eta_O$ is the propeller open water efficiency;

$\eta_R$ is the relative rotative efficiency;

$t$ is the thrust deduction factor;

$w_S$ is the full-scale wake fraction, which may be calculated according to ITTC procedure 7.5-02-03-01.4, 1978 ITTC Performance Prediction method.

The full-scale wake fraction $w_S$ is derived from model wake fraction $w_M$ by taking a scale correlation factor of the wake fraction $e_i$ into account.

$$1 - w_S = (1 - w_M) e_i \tag{K.2}$$

where:

$w_S$ is the full-scale wake fraction;

$w_M$ is the model wake fraction;

$e_i$ is the scale correlation factor of the wake fraction.

The self-propulsion factors $\eta_R$, $t$ and $w_S$ are obtained from the results of model self-propulsion tests.

Each self-propulsion factor for the trial condition $\eta_{Rms}$, $t_{ms}$ and $w_{Mms}$ is obtained by adding the deviation of each factor between the trial and the ideal condition $\Delta\eta_R$, $\Delta t$ and $\Delta w_M$ to each factor for the ideal condition $\eta_{Rid}$, $t_{id}$ and $w_{Mid}$ respectively. The deviations $\Delta\eta_R$, $\Delta t$ and $\Delta w_M$ are derived from the functions of $\Delta R/R_{id}$ based on the results of the self-propulsion test with load variation effect using resistance increase $\Delta R$ and total resistance in the ideal condition $R_{id}$.

$$\eta_{Rms} = \eta_{Rid} + \Delta\eta_R(\Delta R / R_{id}) \tag{K.3}$$

$$t_{ms} = t_{id} + \Delta t(\Delta R / R_{id}) \tag{K.4}$$

$$w_{Mms} = w_{Mid} + \Delta w_M(\Delta R / R_{id}) \tag{K.5}$$

where:

$\eta_{Rms}$ is the relative rotative efficiency in the trial condition;

$t_{ms}$ is the thrust deduction factor in the trial condition;

$w_{Mms}$ is the model wake fraction in the trial condition;

$\eta_{Rid}$ is the relative rotative efficiency in the ideal condition;

$t_{id}$ is the thrust deduction factor in the ideal condition;

$w_{Mid}$ is the model wake fraction in the ideal condition;

$\Delta\eta_R$ is the deviation of relative rotative efficiency;

$\Delta t$ is the deviation of thrust deduction factor;

$\Delta w_M$ is the deviation of wake fraction;

$\Delta R$ is the resistance increase in newtons;

$R_{id}$ is the resistance in the ideal condition in newtons.

The functions of $\Delta R/R_{id}$ representing the deviations of self-propulsion factors $\Delta\eta_R$, $\Delta t$ and $\Delta w_M$ are mentioned in K.2 in detail.

It is permitted that $\Delta\eta_R$, $\Delta t$ and $\Delta w_M$ are set to zero, because these values are negligibly small in comparison with the deviation of $\eta_0$ due to the load variation effect.

In applying the above Formulae (K.3) to (K.5), the total resistance $R_{id}$ required by the above formulae shall be derived from the measured data.

Propeller efficiency $\eta_0$ and full-scale wake fraction $w_S$ are determined using propeller open water characteristics for the ship's fitted propeller, i.e. curves of thrust coefficient, torque coefficient and load factor, according to the following procedure.

Thrust coefficient, torque coefficient and load factor are described by the following formulae:

$$K_T = a_T J^2 + b_T J + c_T \tag{K.6}$$

$$K_Q = a_Q J^2 + b_Q J + c_Q \tag{K.7}$$

$$\tau_P = a_T + b_T / J + c_T / J^2 \qquad \text{(K.8)}$$

where:

$K_T$ is the thrust coefficient;

$K_Q$ is the torque coefficient;

$\tau_P$ is the load factor equal to $K_T / J^2$;

$J$ is the propeller advance coefficient;

$a_T$, $b_T$, $c_T$ are the factors for the thrust coefficient curve;

$a_Q$, $b_Q$, $c_Q$ are the factors for the torque coefficient curve.

The torque coefficient in the trial condition $K_{Qms}$ is calculated by the following formula:

$$K_{Qms} = \frac{P_{Dms}}{2\pi\rho_S n_{ms}^3 D^5}\eta_{Rms} \qquad \text{(K.9)}$$

where:

$K_{Qms}$ is the torque coefficient in the trial condition;

$P_{Dms}$ is the delivered power in the trial condition in watts;

$\rho_S$ is the water density in kilograms per cubic metre;

$n_{ms}$ is the measured propeller shaft speed in revolutions per second;

$D$ is the propeller diameter in metres;

$\eta_{Rms}$ is the relative rotative efficiency in the trial condition.

The propeller advance coefficient $J_{ms}$ is determined by the Formula (K.10) using the torque coefficient $K_{Qms}$ obtained from Formula (K.9).

$$J_{ms} = \frac{-b_Q - \sqrt{b_Q^2 - 4a_Q(c_Q - K_{Qms})}}{2a_Q} \qquad \text{(K.10)}$$

where:

$J_{ms}$ is the propeller advance coefficient in the trial condition;

$K_{Qms}$ is the torque coefficient in the trial condition;

$a_Q$, $b_Q$, $c_Q$ are the factors for the torque coefficient curve.

The thrust coefficient in the trial condition $K_{Tms}$ is obtained by the Formula (K.6) using the propeller advance coefficient $J_{ms}$.

Therefore, the propeller efficiency $\eta_{0\mathrm{ms}}$ is:

$$\eta_{0\mathrm{ms}} = \frac{J_{\mathrm{ms}}}{2\pi} \frac{K_{T\mathrm{ms}}}{K_{Q\mathrm{ms}}} \quad \text{(K.11)}$$

where:

$\eta_{0\mathrm{ms}}$ is the propeller efficiency in the trial condition;

$J_{\mathrm{ms}}$ is the propeller advance coefficient in the trial condition;

$K_{T\mathrm{ms}}$ is the thrust coefficient in the trial condition;

$K_{Q\mathrm{ms}}$ is the torque coefficient in the trial condition.

The load factor $\tau_{\mathrm{Pms}}$ is:

$$\tau_{\mathrm{Pms}} = \frac{K_{T\mathrm{ms}}}{J_{\mathrm{ms}}^2} \quad \text{(K.12)}$$

where:

$\tau_{\mathrm{Pms}}$ is the load factor in the trial condition;

$J_{\mathrm{ms}}$ is the propeller advance coefficient in the trial condition;

$K_{T\mathrm{ms}}$ is the thrust coefficient in the trial condition.

The speed of flow into propeller $V_{\mathrm{A}}$ is:

$$V_{\mathrm{A}} = J_{\mathrm{ms}} n_{\mathrm{ms}} D \quad \text{(K.13)}$$

where:

$V_{\mathrm{A}}$ is the speed of flow into propeller in metres per second;

$J_{\mathrm{ms}}$ is the propeller advance coefficient in the trial condition;

$n_{\mathrm{ms}}$ is the measured propeller shaft speed in revolutions per second;

$D$ is the propeller diameter in metres.

And the full-scale wake fraction is:

$$1 - w_{\mathrm{Sms}} = \frac{V_{\mathrm{A}}}{V_{\mathrm{S}}} \quad \text{(K.14)}$$

where:

$w_{\mathrm{Sms}}$ is the full-scale wake fraction in the trial condition;

$V_{\mathrm{A}}$ is the speed of flow into propeller in metres per second;

$V_{\mathrm{S}}$ is the ship's speed through the water in metres per second.

The total resistance in the trial condition $R_{ms}$ is also estimated using the load factor in the trial condition $\tau_{Pms}$:

$$R_{ms} = \tau_{Pms}\left(1 - t_{ms}\right)\left(1 - w_{Sms}\right)^2 \rho_S V_S^2 D^2 \quad (K.15)$$

where:

$R_{ms}$ is the resistance in the trial condition in newtons;

$\tau_{Pms}$ is the load factor in the trial condition;

$t_{ms}$ is the thrust deduction factor in the trial condition;

$w_{Sms}$ is the full-scale wake fraction in the trial condition;

$\rho_S$ is the water density in kilograms per cubic metre;

$V_S$ is the ship's speed through the water in metres per second;

$D$ is the propeller diameter in metres.

The total resistance in the ideal condition $R_{id}$ is obtained by subtracting the resistance increase $\Delta R$ from the total resistance in the trial condition $R_{ms}$:

$$R_{id} = R_{ms} - \Delta R \quad (K.16)$$

where:

$R_{id}$ is the resistance in the ideal condition in newtons;

$R_{ms}$ is the resistance in the trial condition in newtons;

$\Delta R$ is the resistance increase in newtons.

Using Formulae (K.3), (K.4) and (K.5), the self-propulsion factors are calculated.

The load factor in the ideal condition $\tau_{Pid}$ is calculated by the following formula:

$$\tau_{Pid} = \frac{R_{id}}{\left(1 - t_{id}\right)\left(1 - w_{Sid}\right)^2 \rho_S V_S^2 D^2} \quad (K.17)$$

where:

$\tau_{Pid}$ is the load factor in the ideal condition;

$R_{id}$ is the resistance in the ideal condition in newtons;

$t_{id}$ is the thrust deduction factor in the ideal condition;

$w_{Sid}$ is the full-scale wake fraction in the ideal condition;

$\rho_S$ is the water density in kilograms per cubic metre;

$V_S$ is the ship's speed through the water in metres per second;

$D$ is the propeller diameter in metres.

The propeller advance coefficient $J_{id}$ is determined by the Formula (K.18) using the load factor $\tau_{Pid}$ obtained from Formula (K.17).

$$J_{id} = \frac{-b_T - \sqrt{b_T{}^2 - 4\left(a_T - \tau_{Pid}\right)c_T}}{2\left(a_T - \tau_{Pid}\right)} \tag{K.18}$$

where:

$J_{id}$ is the propeller advance coefficient in the ideal condition;

$\tau_{Pid}$ is the load factor in the ideal condition;

$a_T$, $b_T$, $c_T$ are the factors for the thrust coefficient curve.

The thrust coefficient $K_{Tid}$ and the torque coefficient $K_{Qid}$ are obtained by the Formulae (K.6) and (K.7) respectively using the propeller advance coefficient $J_{id}$.

Therefore, the propeller efficiency $\eta_{0id}$ is:

$$\eta_{0id} = \frac{J_{id}}{2\pi}\frac{K_{Tid}}{K_{Qid}} \tag{K.19}$$

where:

$\eta_{0ms}$ is the propeller efficiency in the ideal condition;

$J_{id}$ is the propeller advance coefficient in the ideal condition;

$K_{Tid}$ is the thrust coefficient in the ideal condition;

$K_{Qid}$ is the torque coefficient in the ideal condition.

The full-scale wake fraction in the ideal condition is calculated by the following formula:

$$1 - w_{Sid} = \left(1 - w_{Mid}\right)e_i \tag{K.20}$$

The scale correlation factor of wake fraction included in Formula (K.20) is obtained using the full-scale and model wake fractions in the trial conditions:

$$e_i = \frac{1 - w_{Sms}}{1 - w_{Mms}} \tag{K.21}$$

where:

$w_{Sid}$ is the full-scale wake fraction in the ideal condition;

$w_{Mid}$ is the model wake fraction in the ideal condition;

$w_{Sms}$ is the full-scale wake fraction in the trial condition;

$w_{Mms}$ is the model wake fraction in the trial condition;

$e_i$ is the scale correlation factor of the wake fraction.

Finally, the corrected propeller shaft speed $n_{id}$ is derived from the propeller advance coefficient in the ideal condition and the open water characteristics of the actual propeller.

$$n_{id} = \frac{V_S\left(1 - w_{Sid}\right)}{J_{id} D} \tag{K.22}$$

where:

$n_{id}$ is the propeller shaft speed in the ideal condition in revolutions per second;

$V_S$ is the ship's speed through the water in metres per second;

$w_{Sid}$ is the full-scale wake fraction in the ideal condition;

$J_{id}$ is the propeller advance coefficient in the ideal condition;

$D$ is the propeller diameter in metres.

Applying the analysis process in Figure K.1, the value of $V_S$, and thus the values of $\eta_{Rid}$, $t_{id}$ and $w_{Mid}$ are known after the analysis of the current velocity.

Additionally, the value of $\Delta R/R_{id}$, and thus the values of $\Delta\eta_R$, $\Delta t$ and $\Delta w_M$ are known after the analysis using the Direct Power Method. Therefore, the analysis by direct power method shall be repeated after the value of $V_S$ is obtained by the current analysis described in 12.2.4.

For the above evaluation by the direct power method, the mean value of $V_G$ for Double Run or 'Mean of means' value of $V_G$ for two Double Runs shall be used as the initial value, and the values of $\Delta\eta_R$, $\Delta t$ and $\Delta w_M$ are set to zero.

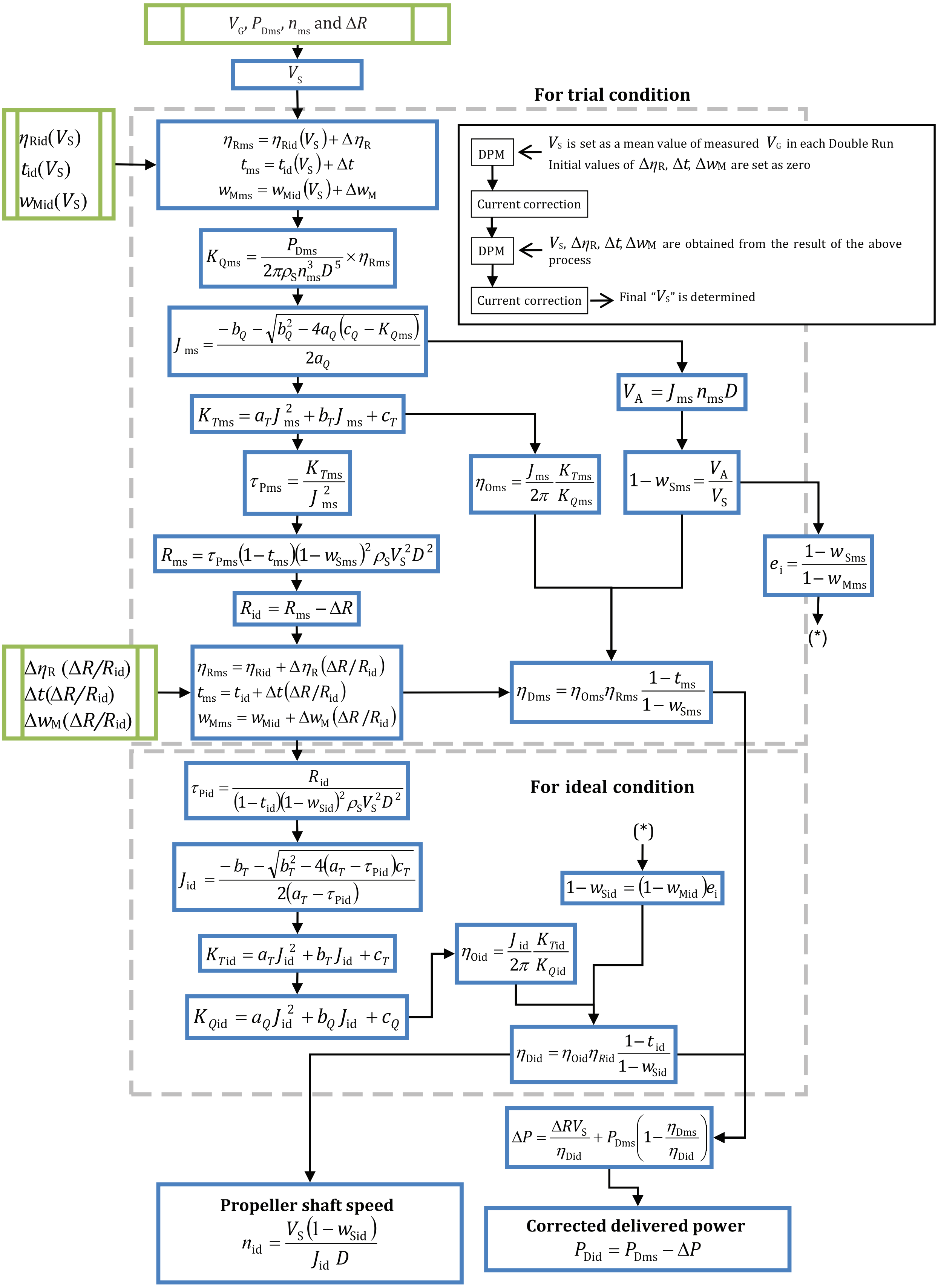



**Figure K.1 — Flow chart of evaluation based on Direct Power Method**

## K.2 Application of load variation test results

In order to determine each component of propulsive efficiency coefficient $\eta_D$, propeller open water tests, resistance and self-propulsion tests are carried out at trial draught and evaluated according to the tank's normal procedures. In addition, a self-propulsion test with load variation effect may be carried out at the trial draught and, as a minimum, one speed close to the predicted EEDI speed (75 % MCR). This speed shall be one of the speeds tested in the normal self-propulsion test.

The self-propulsion test with load variation effect includes at least four self-propulsion test runs, each one at a different propeller shaft speed while keeping the model's speed constant. The propeller shaft speed is to be selected such that:

$$\frac{\Delta R}{R_{\mathrm{id}}} \approx [-0{,}1 \quad 0 \quad 0{,}1 \quad 0{,}2] \tag{K.23}$$

where:

$$\Delta R = \left(F_{\mathrm{D}} - F_{\mathrm{X}}\right)\lambda^3 \frac{\rho_{\mathrm{S}}}{\rho_{\mathrm{M}}} \tag{K.24}$$

| | |
|---|---|
| $\Delta R$ | is the resistance increase in newtons; |
| $R_{\mathrm{id}}$ | is the full scale resistance at the actual speed from resistance test in newtons; |
| $F_{\mathrm{X}}$ | is the external tow force measured during load variation test in newtons; |
| $F_{\mathrm{D}}$ | is the skin friction correction force same as in the normal self-propulsion tests in newtons; |
| $\lambda$ | is the scale factor; |
| $\rho_{\mathrm{S}}$ | is the water density in full scale in kilograms per cubic metre; |
| $\rho_{\mathrm{M}}$ | is the water density in the model test in kilograms per cubic metre. |

Each self-propulsion factor obtained from the procedure mentioned above shall be expressed as a function of $\Delta R/R_{\mathrm{id}}$ as follows:

$$\Delta\eta_R = \xi_{\mathrm{R}}\left(\frac{\Delta R}{R_{\mathrm{id}}}\right)^2 + \zeta_{\mathrm{R}}\frac{\Delta R}{R_{\mathrm{id}}} \tag{K.25}$$

$$\Delta t = \xi_t\left(\frac{\Delta R}{R_{\mathrm{id}}}\right)^2 + \zeta_t\frac{\Delta R}{R_{\mathrm{id}}} \tag{K.26}$$

$$\Delta w = \xi_w\left(\frac{\Delta R}{R_{\mathrm{id}}}\right)^2 + \zeta_w\frac{\Delta R}{R_{\mathrm{id}}} \tag{K.27}$$

where:

| | |
|---|---|
| $\Delta\eta_{\mathrm{R}}$ | is the deviation of the relative rotative efficiency; |
| $\Delta t$ | is the deviation of the thrust deduction factor; |
| $\Delta w_{\mathrm{M}}$ | is the deviation of the wake fraction; |
| $\Delta R$ | is the resistance increase in newtons; |
| $R_{\mathrm{id}}$ | is the resistance in the ideal condition in newtons. |

and $\xi_R$, $\xi_t$, $\xi_w$, $\zeta_R$, $\zeta_t$ and $\zeta_w$ are unknown factors and determined by fitting the Formulae (K.25), (K.26) or (K.27) to the results of the load variation tests with the 'least squares' method.

# Bibliography

[1] ITTC 7.5-04-01-01.1, *ITTC recommended procedures and guidelines, Speed and power trials, Part-1 Preparation and conduct*

[2] ITTC 7.5-04-01-01.2, *ITTC recommended procedures and guidelines, Speed and power trials, Part-2 Analysis of Speed/Power trial data*

[3] ITTC Performance Committee: Hull Roughness, Report of the ITTC Performance Committee, 19th ITTC, 1990

[4] Sea Trial Analysis JIP. Recommended Practice for Speed Trials", Public document from www.marin.nl., 2006

[5] ITTC, "Recommendations and Guidelines for Resistance & Propulsion Model Tests", 23rd ITTC, 2002

[6] Sea Trial Analysis JIP. Recommended Analysis of Speed Trials. MARIN, 2006

[7] World Meteorological Organization: Manual on Codes, International Codes, Volume I.1, Part A-Alphanumeric Codes, WMO-No. 306 (1995 edition)

[8] Fujiwara T., Ueno M., Ikeda Y. Cruising performance of a large passenger ship in heavy sea", Proc. of Sixteenth International Offshore and Polar Engineering Conference, Vol. III, 2006

[9] Maruo H. "Resistance in Waves", Research on Sea keeping Qualities of Ships in Japan. SNAJ, **Vol. 8**, 1963

[10] Fujii H., & Takahashi T. Experimental Study on the Resistance Increase of a Ship in Regular Oblique Waves", Proc. of 14th ITTC, Vol.4 1975

[11] ITTC, "Report of the Seakeeping Committee", 16th ITTC, 1981, pp.226-227

[12] Hosoda R. The Added Resistance of Ships in Regular Oblique Waves. SNAJ, **Vol. 133**, 1973

[13] Kashiwagi M. Added Resistance, Wave-induced Steady Sway Force and Yaw Moment on an Advancing Ship", Ship Technology Research (Schiffstechnik), Vol.39, No.1, 1992

[14] Tsujimoto M., Shibata K., Kuroda M., Takagi K. A Practical Correction Method for Added Resistance in Waves. J. JASNAOE, **Vol. 8**, 2008

[15] van Manen J.D., & van Oossanen P. Propulsion, Principles of Naval Architecture. SNAME, **Vol. II**, 1988

[16] Lackenby H. The Effect of Shallow Water on Ship Speed", Shipbuilder, 70, No. 672, 1963

[17] ClassNK, "Guideline for the Technical Appraisal of Ship Performance in Actual Seas –10 Mode Performance Index for Ships-", 2009

[18] IMO Resolution MEPC.245(66), *2014 Guidelines on the method of calculation of the attained energy efficiency design index (EEDI) for new ships*

[19] IMO MEPC.1/Circ.816, *2013 Guidelines on survey and certification of the energy efficiency design index (EEDI)*

[20] ITTC 7.5-02-03-01.4, *ITTC Recommended Procedures and Guidelines, 1978 ITTC Performance Prediction Method*

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