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# 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
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# Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 15016 was prepared by Technical Committee ISO/TC 8, *Ships and marine technology*, Subcommittee SC 9, *General requirements*.

Annexes A to F form a normative part of this International Standard.

## Introduction

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

The primary purpose of speed trials is to determine ship performance in terms of speed, power and propeller revolutions under prescribed ship conditions, and thereby verify the satisfactory attainment of the contractually stipulated ship speed. Ship speed is that realized under the contractually stipulated conditions which usually are no wind, no waves, no current, deep water, smooth hull and propeller surfaces.

Such stipulated conditions cannot normally all be expected to be met during the actual trials. In practice, certain corrections for the environmental conditions have to be considered, as for water depth, wind, waves and current.

The purpose of this International Standard is to define basic requirements for the performance of speed trials, and to provide procedures for evaluation and correction of speed trials covering all influences which may be relevant for the individual trial runs based on sound scientific grounds, thus giving confidence to the customer with respect to the final results.

The procedure specified in this International Standard has been derived largely on the basis of published data on speed trials and on ship performance, the more important among them being listed in normative annexes A to F.

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

## 1 Scope

This International Standard specifies the procedure to be applied in analysing the results of speed trials for ships, with reference to the effects which may have an influence upon the speed-power-revolutions relationship.

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

The instrumentation to be used in the speed trials is not specifically indicated, nor is the method of conducting the trials. Calibrated instruments and their methods of use commonly adopted for such trials should be acceptable.

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 "kn" (knot) 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 standard, numerical values using the units of degree and knot are stated jointly at appropriate places.

## 2 Terms and definitions

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

**2.1**
**propeller pitch**
design pitch for controllable pitch propellers

**2.2**
**brake power**
power delivered by the output coupling of the propulsion machinery before passing through any speed-reducing and transmission devices and with all continuously operating engine auxiliaries in use

**2.3**
**shaft power**
net power supplied by the propulsion machinery to the propulsion shafting after passing through all speed-reducing and other transmission devices and after power for all attached auxiliaries has been taken off

## 3 Symbols and abbreviations

### 3.1 Symbols

$A_M$: area of midship section under water

$A_R$: rudder area

$A_{XV}$: area of maximum transverse section exposed to wind (area of portion of ship above waterline projected normally to the longitudinal direction of ship)

$B$ : breadth, moulded, of ship

$b_R$ : rudder span

$C_{AA}$ : wind resistance coefficient

$C_{AA0}$ : wind resistance coefficient in head wind

$C_B$ : block coefficient

$C_F$ : frictional resistance coefficient

$C_T$ : total resistance coefficient

$D$ : propeller diameter

$f$ : frequency

$F_n$ : Froude number

$g$ : acceleration due to gravity

$h$ : water depth

$H$ : total wave height

$H_{1/3}$ : significant wave height of seas

$H_{S1/3}$ : significant wave height of swell

$J$ : propeller advance ratio

$k$ : wave number

$K(\psi_{WR})$ : directional coefficient of wind resistance

$K_Q$ : torque coefficient

$K_{QO}$ : torque coefficient of propeller converted from behind to open water condition

$K_T$ : thrust coefficient

$L_{pp}$ : length of ship between perpendiculars

$m$ : mass in general

$n$ : propeller frequency of revolutions

$P$ : propeller pitch

$P_B$ : brake power

$P_D$ : delivered power

$P_S$ : shaft power ($= 2\pi nQ$)

$Q$ : shaft torque

$R$ : resistance in general

$R_{AA}$ : resistance increase due to wind

$R_{ADIS}$ : resistance increase due to displacement

$R_{AS}$ : resistance increase due to temperature and salt content

$R_F$ : frictional resistance

$R_T$ : total resistance

$R_{AW}$ : resistance increase due to waves

$R_{\beta\beta}$ : resistance increase due to drifting

$R_{\delta\delta}$ : resistance increase due to steering

$S(f)$ : spectral density function of unidirectional waves

$S_R$ : real slip ratio

$S_W$ : wetted surface area

$t$ : thrust deduction fraction

$T$ : period or temperature in general

$T_{01}$ : average period from zeroth and first moment

$T_{02}$ : average period from zeroth and second moment

$T_m$ : mean wave period of seas

$t_R$ : resistance deduction fraction due to steering

$T_{Sm}$ : mean wave period of swell

$T_W$ : water temperature

$V_{eff}$ : effective inflow velocity to rudder

$V_F$ : current velocity

$V_G$ : ship's speed over the ground

$V_S$ : ship's speed through the water

$V_{WR}$ : relative wind velocity

$V_{WT}$ : true wind velocity

$w$ : Taylor wake fraction in general

$\beta$ : drift angle

$\delta_R$ : rudder angle

$\Delta$ : displacement force

$\Delta R$ : total resistance increase

$\Delta r$ : response increase due to regular waves ( $= \Delta r_1 + \Delta r_2$ )

$\Delta r_1$ : resistance increase due to radiation in regular waves

$\Delta r_2$ : resistance increase due to diffraction in regular waves

$\zeta_A$ : wave amplitude

$\eta$ : efficiency in general

$\eta_R$ : relative rotative efficiency

$\eta_T$ : transmission efficiency: ratio $P_D / P_S$ or $P_D / P_B$

$\lambda_R$ : aspect ratio of rudder

$\pi$ : $= 3{,}141\ 592\ 6$

$\rho$ : mass density in general

$\rho_A$ : mass density of air

$\tau$ : load factor $\left( R / \rho D^2 V_S^2 (1-w)^2 (1-t) = K_T / J^2 \right)$

$\chi$ : incident angle of waves (head wave: $\chi = \pi$ rad)

$\psi_A$ : yaw amplitude

$\psi_0$ : course direction

$\psi_{WR}$ : relative wind direction: positive direction from which the wind is blowing; head wind = 0 (0°)

$\psi_{WA}$ : true wind direction: positive direction from which the wind is blowing; wind from the north = 0 (0°)

$\nu$ : kinematic viscosity

$\omega$ : circular frequency of incident waves

$\omega_e$ : circular frequency of encounter

### 3.2 Abbreviations

BSRA: The British Ship Research Association

ITTC: International Towing Tank Conference

JTTC: Japan Towing Tank Committee

KSNAJ: The Kansai Society of Naval Architects, Japan

RINA: Royal Institute of Naval Architects, UK

SNAJ: The Society of Naval Architects of Japan

SNAME: The Society of Naval Architects and Marine Engineers, USA

SRAJ: The Shipbuilding Research Association of Japan

WJSNAJ: The West — Japan Society of Naval Architects

## 4 Trial conditions

### 4.1 Wind

Wind speed and direction shall be measured as relative wind using the ship's wind indicator. Continuous recording of the relative wind during each run is recommended.

Whenever possible, wind force during the speed trials shall not be higher than

— Beaufort Number 6, $L_{pp} \geqslant 100$ m, or

— Beaufort Number 5, $L_{pp} < 100$ m.

### 4.2 Sea state

If possible, instruments should be used to determine the wave height, wave period and direction of seas and swell, as buoys or instruments onboard the ships (e.g. seaway analysis radar). Wave characteristics may be determined from observations by multiple observers, including the captain, preferably supported by hindcasting if the expected effect of the seaway is significant.

The total wave height, $H$, which is the sum of significant wave heights of seas $H_{1/3}$ and swell $H_{S1/3}$, shall satisfy the following:

$$L_{pp} \geqslant 100 \text{ m: the lower value of } H \leqslant 0{,}015 L_{pp} \text{ or } 3 \text{ m} \qquad (1)$$

$$L_{pp} < 100 \text{ m}: H \leqslant 1{,}5 \text{ m}$$

where

$$H = \sqrt{H_{1/3}^2 + H_{S1/3}^2} \text{ (m);} \qquad (2)$$

$L_{pp}$ is the length of ship between perpendiculars, in metres.

### 4.3 Water depth

Water depth in the trial area shall be obtained either from sea charts or by means of echo-sounder measurements.

To obtain satisfactory results, the water depth shall satisfy the following:

$$\Delta V_S / V_S \leqslant 0{,}02 \qquad (3)$$

where

$V_S$ is the ship's speed, in metres/second;

$\Delta V_S$ is the ship's speed loss due to shallow water, in metres/second

The ship's speed loss due to the effect of shallow water can be derived from normative annex F.

### 4.4 Current

Current speed and direction shall be obtained either as part of the evaluation of run and counter-run of each double run or by direct measurement with a current gauge buoy.

## 5 Speed and power measurement

### 5.1 Runs

All speed trials shall be carried out using double runs, i.e. each run followed by a return run in the exact opposite direction performed with the same engine settings. The number of such double runs shall not be less than three. Preferably runs should be performed in head and following winds.

Each run shall be preceded by an approach run, which shall be of sufficient length to attain steady running conditions.

### 5.2 Steering

The single amplitude of variation of heading angle, $\psi_A$, shall be within π/60 rad (3°).

The counter rudder to maintain a straight course shall be within π/36 rad (5°).

### 5.3 Measured and observed data

#### 5.3.1 General data

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

— date;

— area of trial;

— weather;

— mean water depth in area of trial;

— water temperature and density;

- air temperature;
- height of wind instrument above waterline;
- fore, midships and aft draughts;
- displacement;
- propeller pitch in the case of CPP.

It is recommended to retain a record of the following factors, which should prove useful for verifying the condition of the ship at the time of the speed trial:

- time elapsed since last hull and propeller cleaning;
- surface condition of hull and propeller.

### 5.3.2 Data on each run

The following data shall be monitored and recorded on each run:

- clock time at commencement;
- time elapsed over the measured distance;
- course direction;
- ship's speed over ground;
- propeller frequency of revolutions;
- propeller shaft torque and/or brake power;
- relative wind velocity and direction;
- mean wave period, significant wave height and direction of waves (seas);
- mean wave period, significant wave height and direction of waves (swell);
- rudder angle;
- drift angle.

There are two kinds of power, one is shaft power and the other is brake power. Shaft power shall be calculated by means of measuring shaft speed and torque of the shaft. Both types of power can be used to evaluate the speed and power performance. The analysis procedure in clause 6 uses shaft power.

Data such as ship's speed, frequency of revolutions of the propeller, torque, rudder angle, and drift angle to be used for analyses shall be the average values derived on the measured distance. If the draughts are needed for each run, they may be estimated using a loading computer, based on the data prior to the trial and the fuel consumption up to that time.

# 6 Analysis procedure

## 6.1 Flow of trial analysis

The analysis of trial data is basically divided into the following six steps, as shown in Figure 1.

a) Step 1: evaluation of acquired trial data.

b) Step 2: correction of ship's performance for resistance increase.

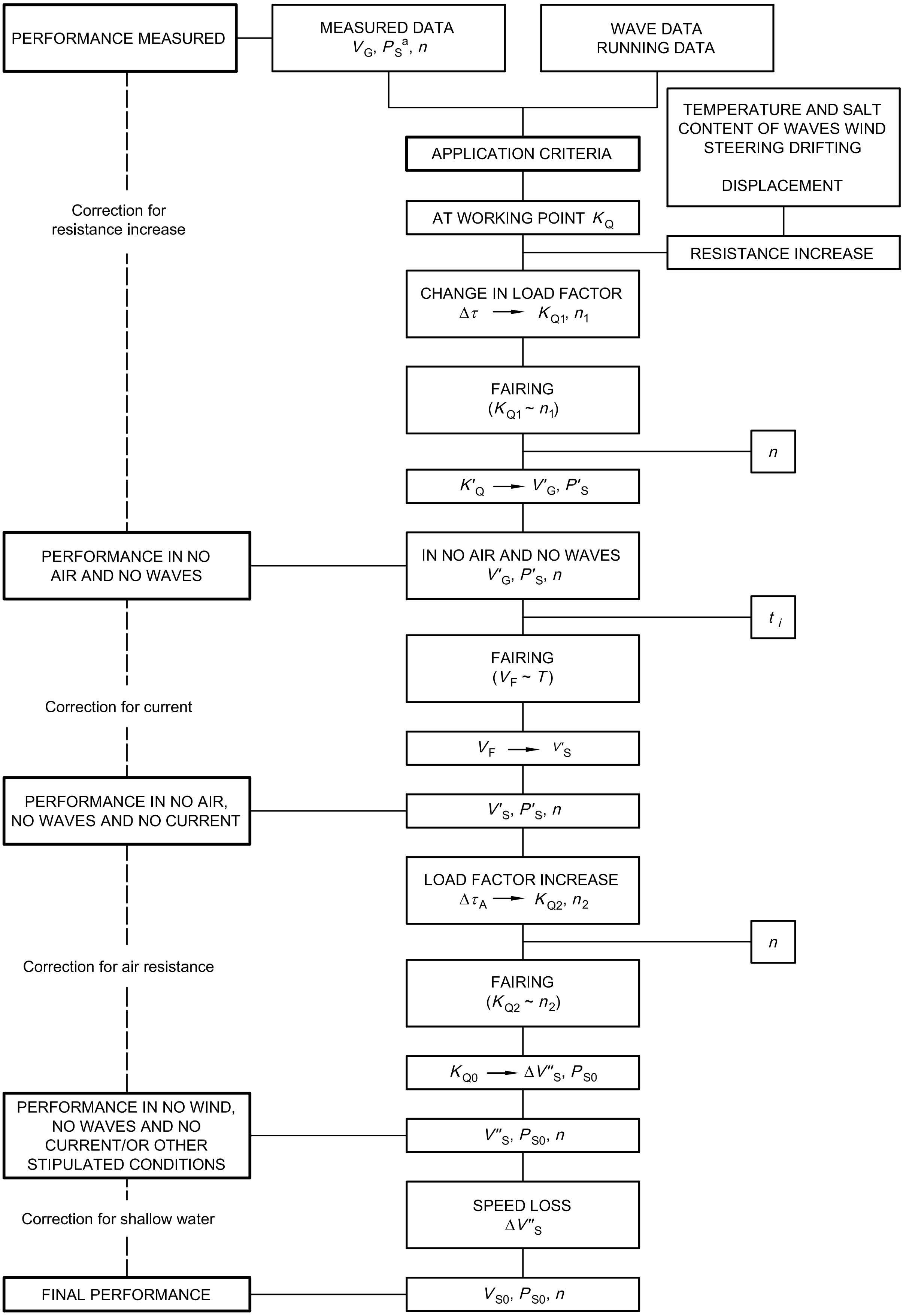
c) Step 3: correction of ship's performance for current.

d) Step 4: correction of ship's performance for air resistance.

e) Step 5: correction of ship's performance for shallow water.

f) Step 6: final ship's performance.

The procedure is described by reference to the numbered columns in Table 1.




a $P_B$ may be used alternatively.

**Figure 1 — Flowchart of speed trial analysis**

**Table 1 — Format of speed trial data analysis (Part 1)**

| Hull | | | | | | | | Rudder | | Propeller | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $L_{PP}$ | $B$ | $d$ | trim | $\Delta$ | $C_B$ | $A_M$ | $A_{XV}$ | $A_R$ | $b_R$ | $D$ | $P$ |
| | | | | | | | | | | | |

| Efficiency | | | Depth | Density | | Temperature |
|---|---|---|---|---|---|---|
| $\eta_T$ | $\eta_R$ | $1-t$ | $h$ | $\rho$ | $\rho_A$ | $T_W$ |
| | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | Main engine output setting | | | | | Remarks |
| 2 | Run number | | | $i$ | $i+1$ | |
| 3 | Course direction | (rad) | $\psi_0$ | | | |

## Measured or observed data

| | | | | | | |
|---|---|---|---|---|---|---|
| 4 | Ship's speed over ground | (m/s) | $V_G$ | | | |
| 5 | Propeller frequency of revolutions | (Hz) | $n$ | | | |
| 6 | Power measured | (kW) | $P_S$ | | | |
| 7 | Relative wind velocity | (m/s) | $V_{WR}$ | | | |
| 8 | Relative wind direction | (rad) | $\psi_{WR}$ | | | |
| 9 | Directional coefficient of wind resistance | | $K$ | | | |
| 10 | True wind velocity | (m/s) | $V_{WT}$ | | | $V_{WT} = \sqrt{V_{WR}^2 + V_G^2 - 2V_{WR} \cdot V_G \cdot \cos(\psi_{WR})}$ |
| 11 | True wind direction | (rad) | $\psi_{WT}$ | | | $\psi_{WT} = \tan^{-1}\left\{\frac{V_{WR}\sin(\psi_0+\psi_{WR}) - V_G\sin(\psi_0)}{V_{WR}\cos(\psi_0+\psi_{WR}) - V_G\cos(\psi_0)}\right\}$ |
| 12 | Mean wave period (Seas) | (s) | $T_m$ | | | In case of visual observations, the observed period value is to be used as $T_m$. When measured data are available, $T_{02}$ is to be used as $T_m$ |
| 13 | Significant wave height (Seas) | (m) | $H_{1/3}$ | | | |
| 14 | Incident angle of waves (Seas) | (rad) | $\chi$ | | | $\chi = \pi$ in head waves |
| 15 | Mean wave period (Swell) | (s) | $T_{Sm}$ | | | |
| 16 | Significant wave height (Swell) | (m) | $H_{S1/3}$ | | | |
| 17 | Incident angle of waves (Swell) | (rad) | $\chi_S$ | | | |
| 18 | Rudder angle | (rad) | $\delta_R$ | | | Mean value during the measurement of ship's speed |
| 19 | Drift angle | (rad) | $\beta$ | | | Mean value during the measurement of ship's speed |

**Analysed data** **(Part 2)**

| | | | | | | |
|---|---|---|---|---|---|---|
| 20 | Delivered power | (kW) | $P_D$ | | | $P_D = P_S \cdot \eta_T$ |
| 21 | Torque coefficient | | $K_Q$ | | | $K_Q = 500 P_D \cdot \eta_R / \pi / \rho / D^5 / n^3$ |
| 22 | Propeller advance ratio | | $J$ | | | $J(K_Q)$ in Figure 2 |
| 23 | Load factor | | $\tau$ | | | $\tau(J)$ in Figure 2 |
| 24 | Slip ratio | | $S_R$ | | | $S_R = 1 - DJ/P$ |
| 25 | Wake factor | | $1-w$ | | | $1-w = nDJ/V_G$ |
| 26 | Mean wake factor | | $(1-w)_m$ | | | Mean value of data in both runs of a double run |
| 27 | Mean speed through water | (m/s) | $V_S$ | | | $V_S = nDJ/(1-w)_m$ |
| 28 | Total resistance | (N) | $R_T$ | | | $R_T = \rho D^2 V_S^2 (1-w)_m^2 (1-t)\tau$ |

**Load correction**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 29 | Resistance increase due to wind | (N) | $R_{AA}$ | | | $R_{AA} = 0{,}5\rho_A \cdot C_{AA0} \cdot K(\psi_{WR}) \cdot A_{XV} \cdot V_{WR}^2$ | : see annex A |
| 30 | Resistance increase due to waves | (N) | $R_{AW}$ | | | | : see annex B |
| 31 | Resistance increase due to steering | (N) | $R_{\delta\delta}$ | | | $R_{\delta\delta} = 0{,}5\rho(1-t_R) f_a(\lambda_R) A_R V_{eff}^2 \delta_R^2$ | : see annex C |
| 32 | Resistance increase due to drift | (N) | $R_{\beta\beta}$ | | | $R_{\beta\beta} = 0{,}25\pi\rho d^2 V_S^2 \beta^2$ | : see annex C |
| 33 | Resistance increase due to temperature and salt content | (N) | $R_{AS}$ | | | | : see annex D |
| 34 | Resistance increase due to displacement | (N) | $R_{ADIS}$ | | | | : see annex E. |
| 35 | Total resistance increase | (N) | $\Delta R$ | | | $\Delta R = R_{AA} + R_{AW} + R_{\delta\delta} + R_{\beta\beta} + R_{AS} + R_{ADIS}$ | |
| 36 | Correction for load factor | | $\Delta\tau$ | | | $\Delta\tau = \Delta R / R_T \cdot \tau$ | $\tau$: see [23] |
| 37 | Load factor | | $\tau_1$ | | | $\tau_1 = \tau - \Delta\tau$ | |
| 38 | Propeller advance ratio | | $J_1$ | | | $J_1 = J(\tau_1)$ in Figure 2 | |
| 39 | Torque coefficient | | $K_{Q1}$ | | | $K_{Q1} = K_{Q(J_1)}$ in Figure 2 | |
| 40 | Propeller frequency of revolutions | (Hz) | $n_1$ | | | $n_1 = n J / J_1$ | |
| 41 | Torque coefficient | | $K'_Q$ | | | $K'_Q = K_{Q1}(n)$ in Figure 3 | |
| 42 | Propeller advance ratio | | $J'$ | | | $J' = J(K'_Q)$ in Figure 2 | |
| 43 | Load factor | | $\tau'$ | | | $\tau' = \tau(J')$ in Figure 2 | |
| 44 | Correction of ship's speed | (m/s) | $\Delta V_G$ | | | $\Delta V_G = aDn/(1-w)_m \cdot (K'_Q - K_Q)$ | |
| 45 | Speed over ground | (m/s) | $V'_G$ | | | $V'_G = V_G + \Delta V_G$ | |
| 46 | Delivered power | (kW) | $P'_D$ | | | $P'_D = P_D \cdot K'_Q / K_Q$ | |
| 47 | Shaft power | (kW) | $P'_S$ | | | $P'_S = P'_D / \eta_T$ | |

**Current (Part 3)**

| | | | | | | |
|---|---|---|---|---|---|---|
| 48 | Time of day at middle of run | | $t_i$ | | | $V'_{G(i+1)}$: Speed at $(i+1)$-th run with same power condition |
| 49 | Time at middle of serial runs | | $t$ | | | as $i$-th run |
| 50 | Speed correction for RPM difference | (m/sec) | $V''_{G(i+1)}$ | | | $V''_{G(i+1)} = V'_{G(i+1)} \cdot n_{(i)} / n_{(i+1)}$ $V'_{G(i)}$: Speed at $i$-th run |
| 51 | Mean current velocity | (m/sec) | $V_{FM}$ | | | $V_{FM} = \left(V''_{G(i+1)} - V'_{G(i)}\right)/2$ |
| 52 | Current during each run | (m/sec) | $V_F$ | | | $V_F = V_F(t_i)$ in Figure 4 |
| 53 | Speed without current | (m/sec) | $V'_S$ | | | $V'_S = V'_G + V_F$ |

**Wind correction**

| | | | | | | |
|---|---|---|---|---|---|---|
| 54 | Load factor increase | | $\Delta\tau_A$ | | | $\Delta\tau_A = 0{,}5\rho_A A_{XV} C_{AA0} / \rho / (1-t) / (1-w)_m^2 / D^2$ |
| 55 | Load factor | | $\tau_2$ | | | $\tau_2 = \tau' + \Delta\tau_A$ |
| 56 | Propeller advance ratio | | $J_2$ | | | $J_2 = J(\tau_2)$ in Figure 2 |
| 57 | Torque coefficient | | $K_{Q2}$ | | | $K_{Q2} = K_Q(J_2)$ in Figure 2 |
| 58 | Propeller frequency of revolutions | (Hz) | $n_2$ | | | $n_2 = n \cdot J' / J_2$ |
| 59 | Torque coefficient | | $K_{Q0}$ | | | $K_{Q0} = K_{Q2}(n)$ in Figure 3 |
| 60 | Correction of ship's speed | (m/sec) | $\Delta V'_S$ | | | $\Delta V'_S = aDn / (1-w)_m \cdot (K_{Q0} - K'_Q)$ $K'_Q$: see [41] |
| 61 | Ship's speed after correction | (m/sec) | $V''_S$ | | | $V''_S = V'_S - \Delta V'_S$ $V'_S$: see [53] |
| 62 | Delivered power | (kW) | $P_{D0}$ | | | $P_{D0} = P'_D \cdot K'_{Q0} / K_Q$ $K_Q$: see [21] |
| 63 | Shaft power | (kW) | $P_{S0}$ | | | $P_{S0} = P_{D0} / \eta_T$ |

**Shallow water**

| | | | | | | |
|---|---|---|---|---|---|---|
| 64 | Speed loss | (m/sec) | $\Delta V''_S$ | | | $\Delta V''_S = V''_S + \left(\Delta V''_S / V''_S\right)$ $\Delta V''_S / V''_S$: see annex F |
| 65 | Ship's speed after correction | (m/sec) | $V_{S0}$ | | | $V_{S0} = V''_S + \Delta V''_S$ |

## 6.2 Evaluation of acquired trial data

### 6.2.1 Performance data

Each item shall be filled in Table 1 as follows:

— [1]: main engine output;

— [2]: run number;

— [3]: course (direction) of run;

— [4] to [6]: ship performance data:

ship's speed over the ground, propeller frequency of revolutions, measured power;

— [7] to [9]: wind data:

relative wind velocity and direction, directional coefficient of wind resistance;

— [10]: true wind velocity.

True wind velocity, $V_{WT}$, in metres per second, is calculated by

$$V_{WT} = \sqrt{V_{WR}^2 + V_G^2 - 2V_{WR} \cdot V_G \cdot \cos(\psi_{WR})} \tag{4}$$

where

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

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

$\psi_{WR}$ is the relative wind direction, in radians;

— [11]: true wind direction.

True wind direction, $\psi_{WT}$, in radians, is calculated by

$$\psi_{WT} = \tan^{-1}\left\{\frac{V_{WR}\sin(\psi_0 + \psi_{WR}) - V_G \sin(\psi_0)}{V_{WR}\cos(\psi_0 + \psi_{WR}) - V_G \cos(\psi_0)}\right\} \tag{5}$$

where

$\psi_0$ is the ship's course direction, in radians

— [12] to [17]: wave data (seas and swell).

Significant height and mean period of waves for seas and swell shall be noted when appropriate. Wave data shall be determined as described in 4.2. When the measured data are available, the averaged period from zeroth and second moment, $T_{02}$, shall be noted and equation (B.6) shall be applied. The incident angle of waves, $\chi$, is defined in Figure B.2.

— [18] and [19]: Steering data:

rudder angle, drift angle.

### 6.2.2 Working point of propeller in measurement

[20] to [23]: power data shall be filled in Table 1 as follows.

The torque coefficient, $K_Q$, is calculated from the delivered power and propeller frequency of revolutions as follows:

$$K_Q = \frac{1\,000}{2\pi} \times \frac{P_D}{\rho n^3 D^5} \times \eta_R \tag{6}$$

where

$P_D = P_S \times \eta_T$, in kilowatts; (7)

$D$ is the propeller diameter, in metres;

$n$ is the propeller frequency of revolution, in hertz;

$P_S$ is the shaft power, in kilowatts;

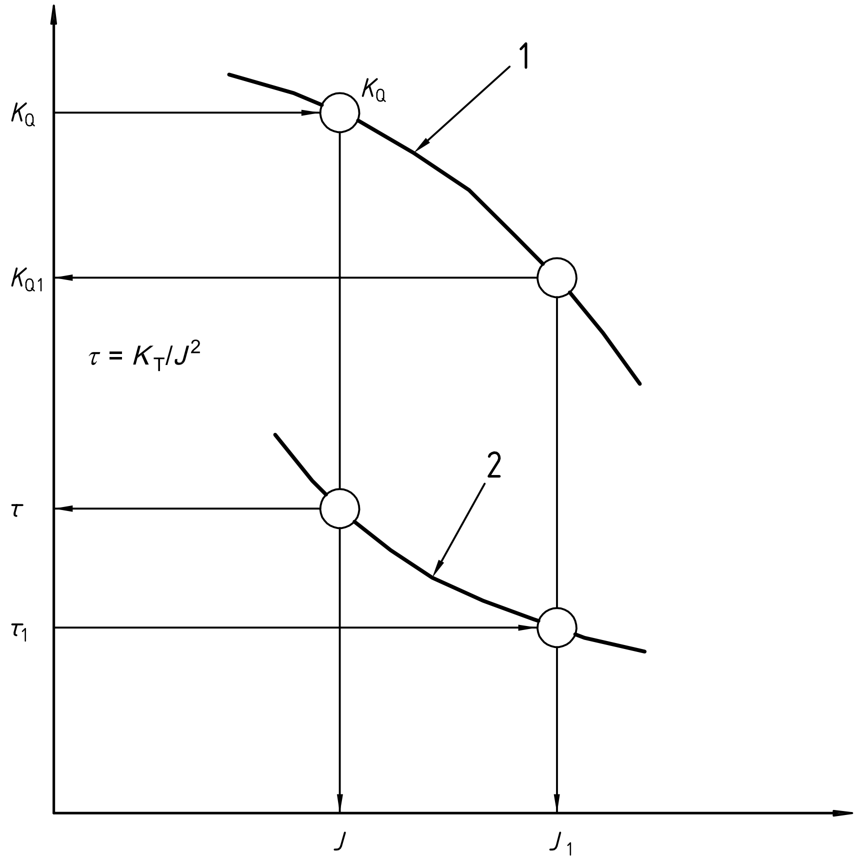
$P_D$ is the delivered power, in kilowatts;

$\eta_R$ is the relative rotative efficiency ( $\eta_R$ may be determined from either the design data base or preferably by model tests);

$\eta_T$ is the transmission efficiency ( $\eta_T$ may be determined from either the design data base or mechanical tests);

$\rho$ is the mass density of sea water, in kilograms per cubic metre.

The propeller advance ratio, $J$, and load factor, $\tau$, are then determined by making use of a diagram of propeller characteristics in open water as shown in Figure 2.




**Key**

1 Torque coefficient

2 Load factor

**Figure 2 — Propeller characteristic curves and working point**

### 6.2.3 Calculation of wake factor

Each item shall be filled in Table 1 as follows:

a) [24]: slip ratio.

The real slip ratio, $S_R$, from measurement is calculated by

$$S_R = 1 - \frac{DJ}{P} \quad (8)$$

where

$J$ is the propeller advance ratio;

$P$ is the propeller pitch, in metres.

b) [25]: wake factor.

For both runs of a double run, the wake factor $(1-w)$ is determined from the ship's speed over the ground, $V_G$, and the propeller advance ratio, $J$, based on the torque identity and on the open water diagram of the propeller.

$$1 - w = \frac{nD}{V_G} \times J \quad (9)$$

c) [26]: mean wake factor.

The mean wake factor $(1-w)_m$ is determined as the mean of the wake factors obtained for the individual runs of a double run.

d) [27]: ship's speed through the water.

The ship's speed, through the water, $V_S$, in metres per second, is approximated by

$$V_S = \frac{nD}{(1-w)_m} \times J \quad (10)$$

e) [28]: total resistance of ship.

The total resistance of a ship, $R_T$, in newtons, is calculated by

$$R_T = \rho \cdot D^2 \cdot V_S{}^2 (1-w)_m^2 (1-t) \cdot \tau \quad (11)$$

where

$1-t$ is the thrust deduction factor;

$\tau$ is the load factor;

$1-t$ may be determined from either the design data base or model tests.

## 6.3 Correction of ship performance for resistance increase

### 6.3.1 Effect of resistance increase on load factor

Environmental and external disturbances, such as sea water conditions, wind, waves and steering, increase the resistance of a ship, and corrections of the ship resistance for these disturbances should be made. The ship resistance should also be corrected for the deviation of the actual displacement from the specified displacement.

Resistance increases due to the disturbances and the deviations are calculated by the procedures specified in annexes A, B, C,D and E. The methods and procedures presented in these annexes are the latest available today. Other scientifically based methods may be adopted as agreed between the shipyard and owner. Some of these resistance increases can also be determined from model tests.

[29] to [35] in Table 1 concern the total resistance increase.

The total resistance increase, $\Delta R$, in newtons, is given by

$$\Delta R = R_{\mathrm{AA}} + R_{\mathrm{AW}} + R_{\delta\delta} + R_{\beta\beta} + R_{\mathrm{AS}} + R_{\mathrm{ADIS}} \tag{12}$$

where

$R_{\mathrm{AA}}$ is the resistance increase due to wind, in newtons;

$R_{\mathrm{AW}}$ is the resistance increase due to waves, in newtons;

$R_{\delta\delta}$ is the resistance increase due to steering, in newtons;

$R_{\beta\beta}$ is the resistance increase due to drifting, in newtons;

$R_{\mathrm{AS}}$ is the resistance increase due to water temperature and salt content, in newtons;

$R_{\mathrm{ADIS}}$ is the resistance increase due to deviation of displacement, in newtons.

[36] in Table 1 concerns the correction for load factor;

The effect of resistance increases on load factor $\Delta\tau$ is given by

$$\Delta\tau = \frac{\Delta R}{R_{\mathrm{T}}} \times \tau \tag{13}$$

### 6.3.2 Torque curve

[37] in Table 1 concerns the corrected load factor.

The load factor corrected by resistance increase, $\tau_1$, is given by

$$\tau_1 = \tau - \Delta\tau \tag{14}$$

[38] and [39] in Table 1 concern the propeller advance ratio and torque coefficient, respectively.

The propeller advance ratio, $J_1$, and torque coefficient, $K_{\mathrm{Q1}}$, are obtained by using a diagram of propeller characteristics in open water as shown in Figure 2.

[40] in Table 1 concerns the propeller frequency of revolutions.

The propeller frequency of revolutions, $n_1$, in hertz, is calculated by

$$n_1 = n \times \frac{J}{J_1} \tag{15}$$

A graph shall be plotted with the values of $n_1$ and $K_{Q1}$ as shown in Figure 3, and the mean curve $K_{Q1} \sim n_1(\bullet)$ is then determined using the least-squares method or alternatives.

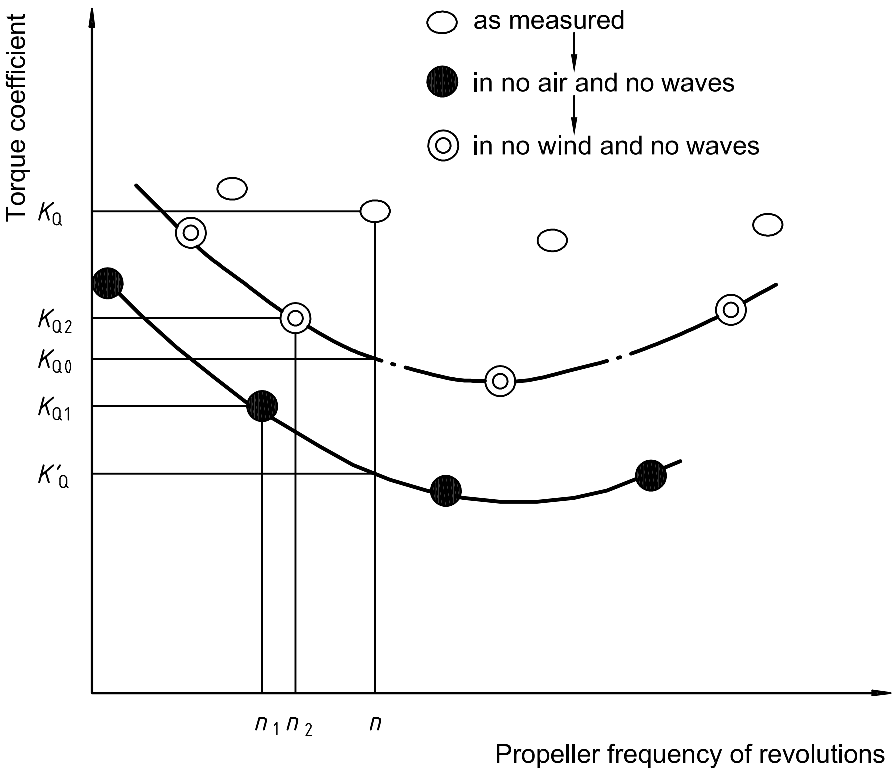



**Figure 3 — Torque coefficient curves and propeller frequency of revolutions**

### 6.3.3 Working point of the propeller taking account of resistance increase

[41] in Table 1 concerns the torque coefficients.

Making use of the mean curve of $K_{Q1} \sim n_1$, torque coefficient $K'_Q(n)$ is determined.

[42] and [43] in Table 1 concern the propeller advance ratio and load factor.

The propeller advance ratio $J'(K'_Q)$ and load factor $\tau'(K'_Q)$ are obtained from Figure 2.

### 6.3.4 Ship performance in no air and no waves

[44] in Table 1 concerns the correction of ship's speed.

The correction of ship's speed over the ground due to resistance increases $\Delta V_G$, in metres per second, is calculated using equations (16) and (17).

$$\Delta V_G = \frac{a \cdot D \cdot n \cdot (K'_Q - K_Q)}{(1-w)_m} \tag{16}$$

where

$$a = \frac{J_H - J_L}{(K_{QH} - K_{QL})} \quad (17)$$

where

$J_H$ is the propeller advance ratio at $K_{QH}$ obtained from a diagram of propeller characteristics;

$J_L$ is the propeller advance ratio at $K_{QL}$ obtained from a diagram of propeller characteristics;

$K_{QH}$ are higher values over the maximum measured value of $K_Q$;

$K_{QL}$ are lower values below the minimum measured value of $K_Q$.

[45] to [47] in Table 1 concern ship's speed over the ground, $V'_G$, in metres per second, delivered power at propeller, $P'_D$, in kilowatts, and shaft power, $P'_S$, in kilowatts, when a ship runs at $n$ in no air and no waves are calculated using equations (18), (19) and (20), respectively.

$$V'_G = V_G + \Delta V_G \quad (18)$$

$$P'_D = P_D \cdot \frac{K'_Q}{K_Q} \quad (19)$$

$$P'_S = \frac{P'_D}{\eta_T} \quad (20)$$

## 6.4 Correction of ship performance for current

### 6.4.1 Time history of current

[48] and [49] in Table 1 concern time.

The time at middle of run and time at middle of serial runs are noted.

[50] in Table 1, ship's speed at $(i+1)$th run, $V''_{G(i+1)}$, in metres per second, at the propeller frequency of revolutions $n_{(i)}$ is calculated by

$$V''_{G(i+1)} = V'_{G(i+1)} \times \frac{n_{(i)}}{n_{(i+1)}} \quad (21)$$

where

$n_{(i)}$ is the propeller frequency of revolutions at $(i)$th run, in hertz;

$n_{(i+1)}$ is the propeller frequency of revolutions at $(i+1)$th run, in hertz;

$V'_{G(i+1)}$ is the ship's speed over the ground at $(i+1)$th run, in metres per second.

Equation (21) is applicable if the engine(s) are not operated in constant frequency mode during double runs.

[51] in Table 1, the mean current velocity, $V_{FM}$, in metres per second, at the intermediate time of each series of measurements is calculated by

$$V_{FM} = \frac{V''_{G(i+1)} - V'_{G(i)}}{2} \tag{22}$$

where $V'_{G(i)}$ is the ship's speed over the ground at $(i)$ th run, in metres per second.

The time history of current is illustrated in Figure 4.

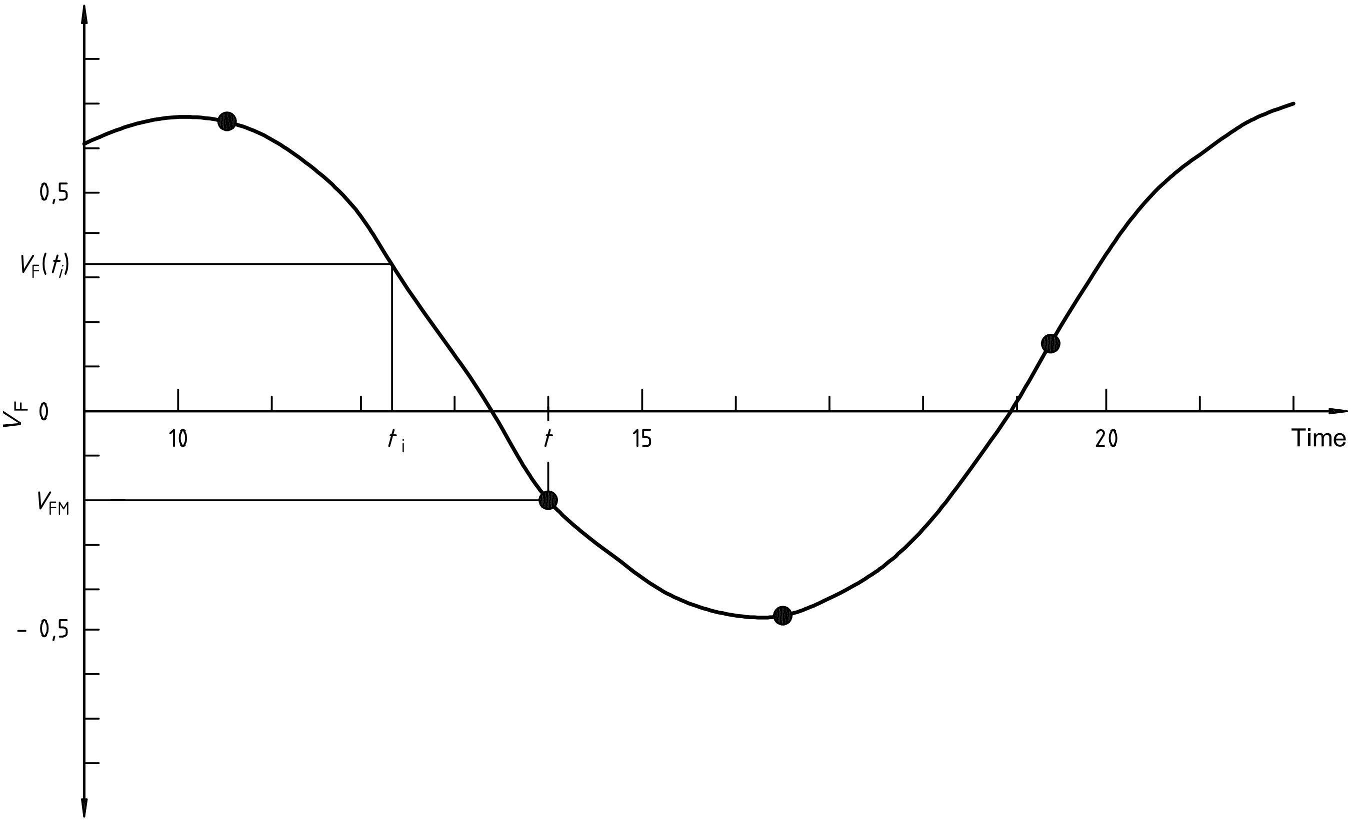



**Figure 4 — Tidal current curve**

### 6.4.2 Ship's speed corrected with current effect

[52] and [53] in Table 1:

The time history of current gives current velocity, $V_F$, at each intermediate time of running, $t_i$.

The ship's speed corrected with current effect, $V'_S$, in metres per second, is given by

$$V'_S = V'_G + V_F \tag{23}$$

When the current is measured by a current meter, the data can be used directly.

## 6.5 Correction of ship performance for air resistance

### 6.5.1 Torque curve

The ship's performance in no wind, no waves and no current is obtained by taking account of the effect of air resistance due to the ship running in no wind conditions on the load factor and torque coefficient.

[54] in Table 1: Change of load factor for a ship running in no wind.

$\Delta\tau_A$ is given by

$$\Delta\tau_A = \frac{\rho_A \cdot A_{XV} \cdot C_{AA0}}{2\rho \cdot D^2 (1-t)(1-w)_m^2} \tag{24}$$

where

$A_{XV}$ is the above-water cross-sectional area of the ship (area of portion of ship above waterline projected normally to the longitudinal direction of ship), in square metres;

$C_{AA0}$ is the wind resistance coefficient in a head wind;

$\rho_A$ is the mass density of air, in kilograms per cubic metre.

If the contract stipulates a certain head wind and/or wave conditions, equation (24) is modified accordingly.

[55] in Table 1: Load factor, $\tau_2$, is calculated using $\Delta\tau_A$ and $\tau'$:

$$\tau_2 = \tau' + \Delta\tau_A \tag{25}$$

[56] and [57] in Table 1: The propeller advance ratio, $J_2$, and torque coefficient, $K_{Q2}$, corresponding to $\tau_2$ is obtained from the propeller characteristic curves shown in Figure 2.

[58] in Table 1: The propeller frequency of revolutions, $n_2$, in hertz, corresponding to $J_2$ is calculated by

$$n_2 = n \times \frac{J'}{J_2} \tag{26}$$

and each calculated $n_2$ gives a point as shown in Figure 3, by which means a curve of torque coefficient versus propeller frequency of revolutions ( ◎ ) is determined using the least-squares method or alternatives.

### 6.5.2 Ship performance in no wind, no waves and no current, or other stipulated conditions

[59] in Table 1: The torque coefficient, $K_{Q0}$, which corresponds to the propeller frequency of revolutions, $n$, is determined from the torque coefficient curves as shown in Figure 3.

[60] in Table 1: Correction of ship's speed, $\Delta V'_S$, in metres per second, for a ship running in no wind is calculated by

$$\Delta V'_S = \frac{a \cdot D \cdot n \cdot (K_{Q0} - K'_Q)}{(1-w)_m} \tag{27}$$

[61] to [63] in Table 1: Ship's speed, $V''_S$, in metres per second, delivered power at propeller, $P_{D0}$, in kilowatts, and shaft power, $P_{S0}$, in kilowatts, when a ship runs at $n$ in no wind, no waves and no current are calculated by

$$V_S'' = V_S' - \Delta V_S' \tag{28}$$

$$P_{D0} = P_D \times \frac{K_{Q0}}{K_Q} \tag{29}$$

$$P_{S0} = \frac{P_{D0}}{\eta_T} \tag{30}$$

### 6.6 Correction of ship performance due to shallow water effects

[64]: Speed loss, $\Delta V_S''$, due to shallow-water effects is determined using Figure F.1 in normative annex F.

[65]: Ship's speed, $V_{S0}$, in metres per second, corrected for shallow water is calculated by

$$V_{S0} = V_S'' + \Delta V_S'' \tag{31}$$

### 6.7 Final ship performance

Ship performance for each run in no wind, no waves, no current and deep water is obtained by the above analysis; delivered power at propeller, $P_{D0}$, shaft power, $P_{S0}$, and ship's speed, $V_{S0}$, at propeller frequency of revolutions, $n$, are calculated by equations (29), (30) and (31), respectively.

The final ship performance is determined as the mean of the performance of the individual runs of a double run.

## 7 Example of method of analysis

This example is based on data obtained during speed trials with a single-screw, large, oil tanker (VLCC) in the full load condition. The ship dimensions are listed in Table 2.

Five double runs were carried out. A torsionmeter was used and an anemometer was equipped on the fore-mast in the trial. Wave data were obtained from observation by eye.

The data measured during the trial are listed in Table 2 (from item 1 to 19).

a) The measured shaft power and propeller frequency revolutions are plotted against the ship speed in Figure 5 ($\Delta$ mark).

b) The speed of the true wind during the trial varied from 8 m/s to 11 m/s, and it was a north wind. The wind direction changed from south to north one day before the trial, therefore the sea was slight (wave height: 0,5 m to speed of the 1,0 m). The resistance increase caused by the wind was calculated using the method specified in annex A.

c) The swell varied from 2 m to 3 m, which developed as a typhoon approached. The trial was stopped for a while after 6 runs were finished because the swell height became large, but it was resumed later. The resistance increase caused by the waves was calculated using the method specified in annex B.

d) The rudder angle and drift angle were less than 0,01 rad (0,6°), so that the resistance increases are negligible.

e) The actual displacement was about 500 tonnes larger than the specified value, and the actual water density was 0,1 % smaller than the specified value. The resistance increase due to these deviations is also negligible.

f) The depth of water was 500 m, so that the speed loss due to shallow water is negligible.

The analysed data are listed in Table 2 (from item 20 to item 65).

The load correction (from item 29 to 47 in Table 2) produced satisfactory results. Figure 6 shows the diagram of torque coefficient versus propeller frequency of revolutions.

The tide analysis (from item 48 to 53) also produced satisfactory results. Figure 7 shows the tidal current curve.

The final performance in still air conditions is plotted in Figure 5 (○ mark).

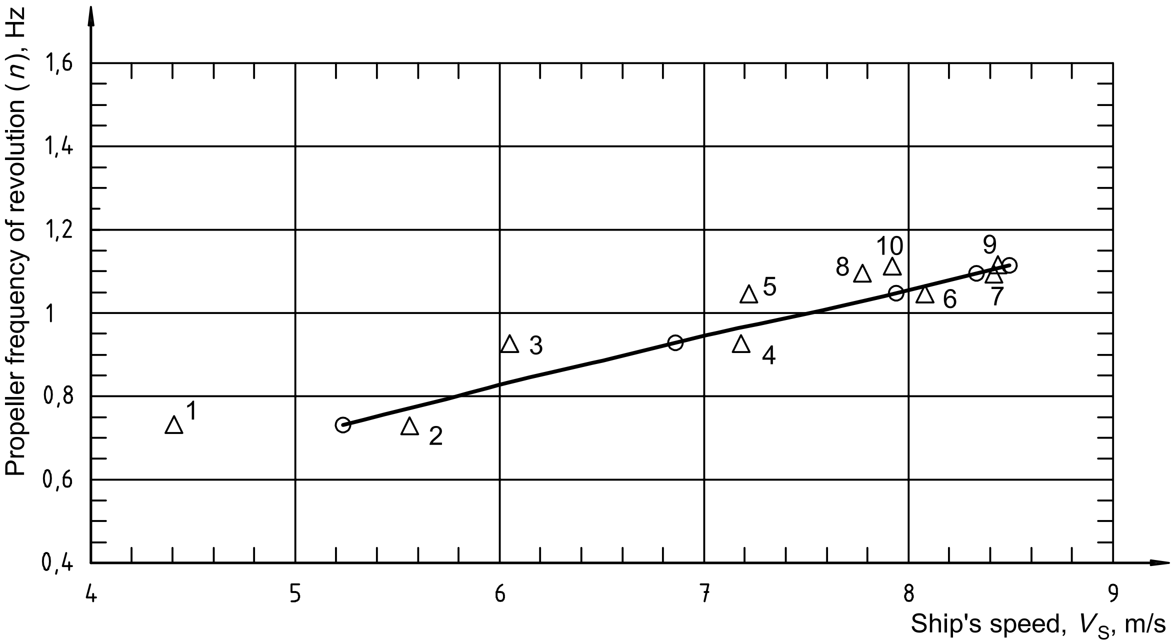
Other data used in the analysis are described below:

a) propeller open-water characteristics:

| | | | | |
|---|---|---|---|---|
| $J$ | 0,550 0 | 0,600 0 | 0,650 0 | 0,700 0 |
| $K_T$ | 0,211 9 | 0,190 7 | 0,168 9 | 0,146 5 |
| $10K_Q$ | 0,311 4 | 0,289 3 | 0,266 0 | 0,241 5 |

b) $C_{AA0} = 1{,}0$

c) Directional coefficient of wind resistance: Standard of JTTC (see Figure A.2)



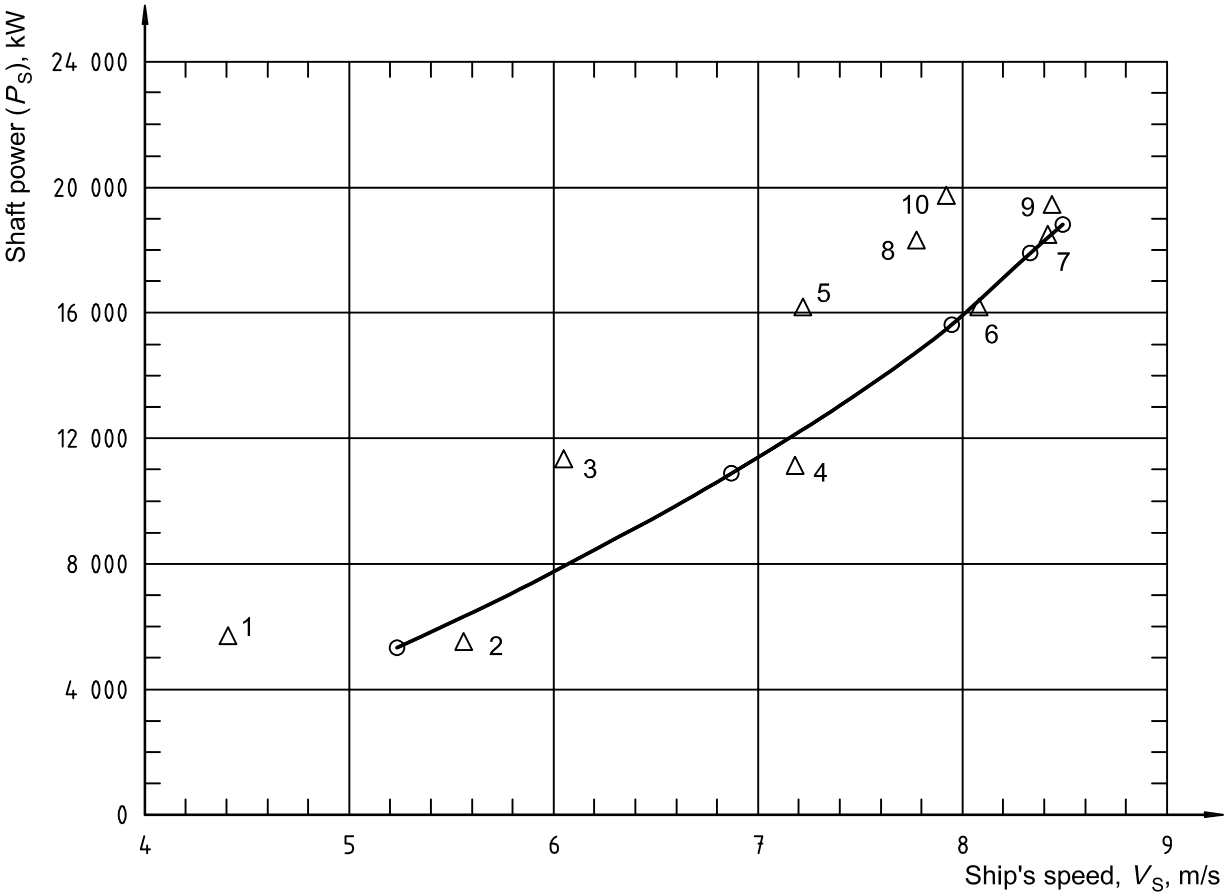




**Figure 5 — Examples of trial performance curves**

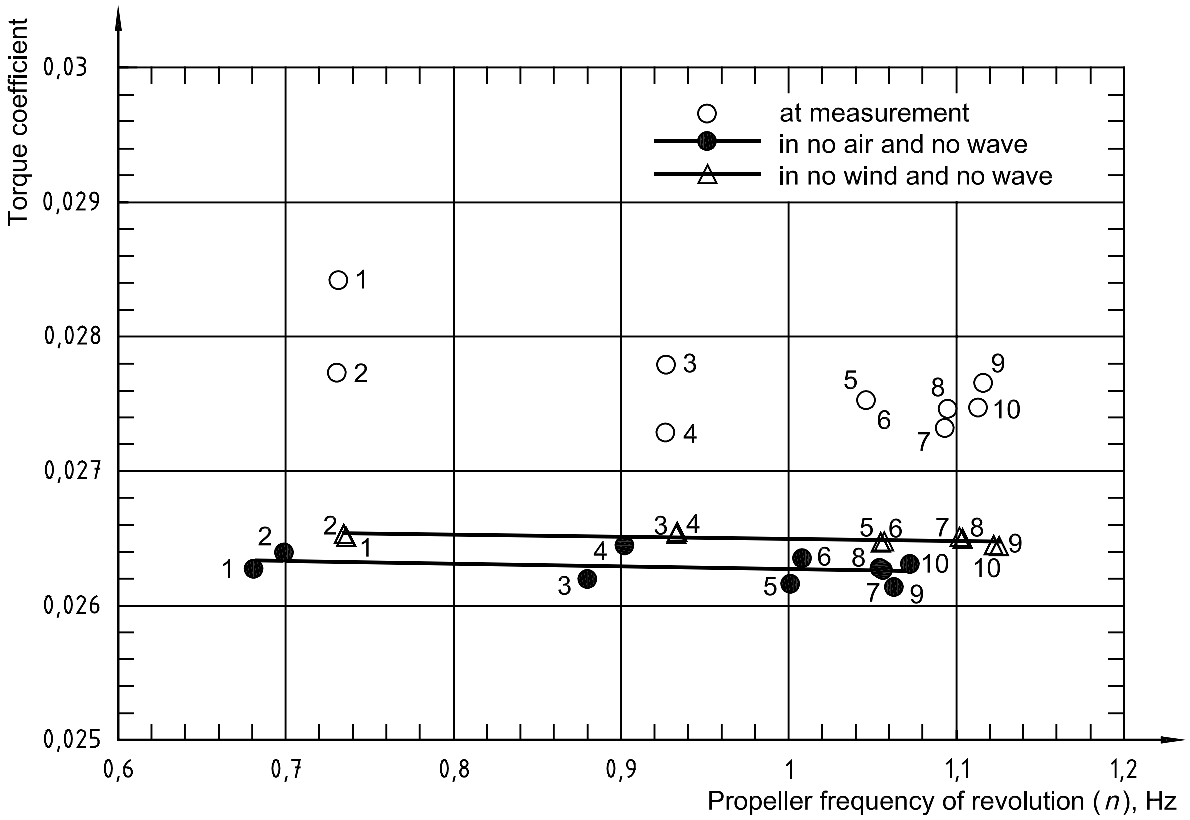



**Figure 6 — Example of torque coefficient curves and propeller frequency of revolution**

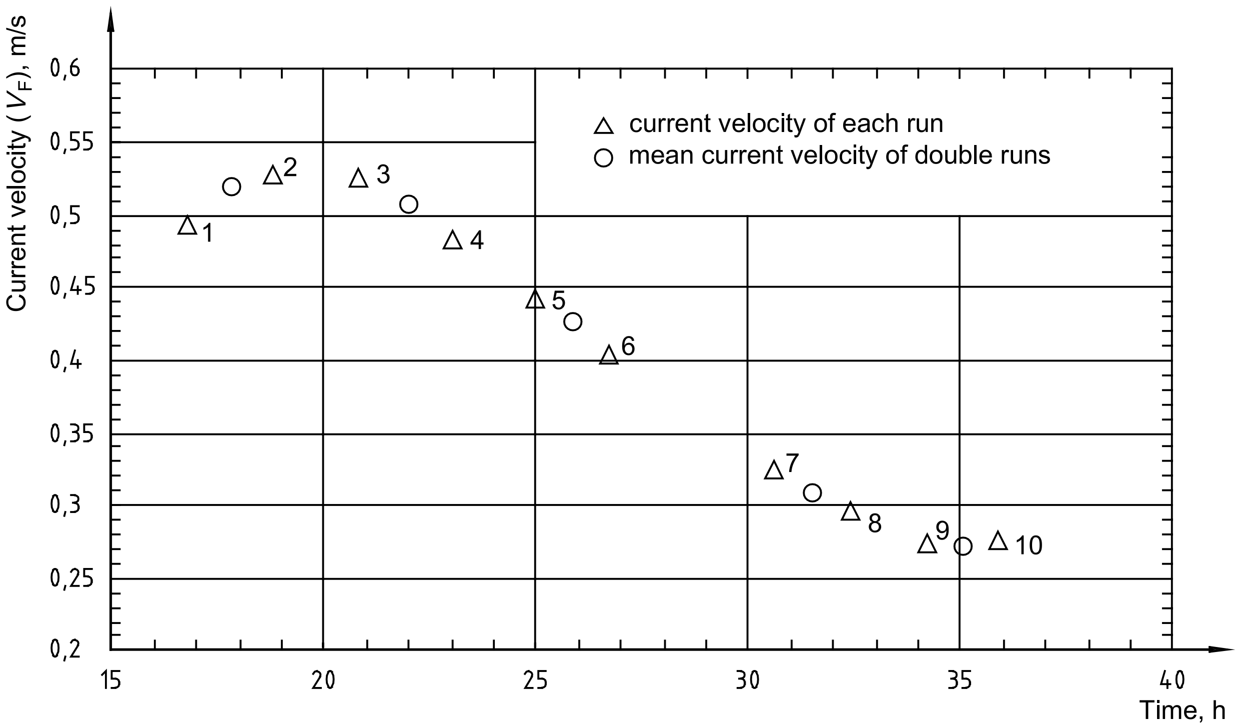



**Figure 7 — Example of tidal current curve**

## Table 2 — Example of speed trial data analysis

| Hull | | | | | | | | Rudder | | Propeller | | Efficiency, etc. | | | Depth | Density | | Temperature |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $L_{PP}$ | $B$ | $d$ | trim | $\Delta$ | $C_B$ | $A_M$ | $A_{XV}$ | $A_R$ | $b_R$ | $D$ | $P$ | $\eta_t$ | $\eta_R$ | 1-$t$ | $h$ | $\rho$ | $\rho_A$ | $T_W$ |
| m | m | m | m | ton | | m$^2$ | m$^2$ | m$^2$ | m | m | m | | | | m | kg/m$^3$ | kg/m$^3$ | °C |
| 318,0 | 58,0 | 18,5 | 0,0 | 273 740 | 0,78 | 1 070 | 1 132 | 95,5 | 14,2 | 9,5 | 8,3 | 0,971 | 1,0 | 0,87 | 500,0 | 1 024,0 | 1 225 | 20,0 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Main engine output setting | | | 25 % | | 50 % | | 75 % | | NOR | | MCR | |
| 2 | Run number | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 3 | Course direction | (°) | $\psi_0$ | 355,0 | 175,0 | 355,0 | 175,0 | 355,0 | 175,0 | 175,0 | 355,0 | 175,0 | 355,0 |
| | | (rad) | | 6,196 | 3,054 | 6,196 | 3,054 | 6,196 | 3,054 | 3,054 | 6,196 | 3,054 | 6,196 |
| **Measured or observed data** | | | | | | | | | | | | | |
| 4 | Ship's speed over ground | (kn) | $V_G$ | 8,57 | 10,81 | 11,76 | 13,96 | 14,03 | 15,71 | 16,36 | 15,11 | 16,40 | 15,40 |
| | | (m/s) | | 4,409 | 5,561 | 6,050 | 7,182 | 7,218 | 8,082 | 8,416 | 7,773 | 8,437 | 7,922 |
| 5 | Propeller frequency of revolutions | (Hz) | $n$ | 0,731 7 | 0,730 0 | 0,926 7 | 0,926 7 | 1,046 7 | 1,046 7 | 1,093 3 | 1,095 0 | 1,116 7 | 1,113 3 |
| 6 | Power measured | (kW) | $P_S$ | 5 711 | 5 533 | 11 349 | 11 140 | 16 200 | 16 190 | 18 500 | 18 330 | 19 450 | 19 756 |
| 7 | Relative wind velocity | (m/s) | $V_{WR}$ | 15,3 | 4,0 | 15,0 | 2,8 | 16,0 | 0,7 | 0,4 | 16,5 | 0,0 | 16,5 |
| 8 | Relative wind direction | (°) | $\Psi_{WR}$ | 10,0 | 215,0 | 10,0 | 225,0 | 355,0 | 210,0 | 225,0 | 355,0 | 215,0 | 10,0 |
| | | (rad) | | 0,174 5 | 3,752 5 | 0,174 5 | 3,927 0 | 6,195 9 | 3,665 2 | 3,927 0 | 6,195 9 | 3,752 5 | 0,174 5 |
| 9 | Directional coefficient of wind resistance | | $K$ | 1,040 | – 0,980 | 1,040 | – 0,820 | 1,020 | – 1,040 | – 0,820 | 1,020 | – 0,980 | 1,040 |
| 10 | True wind velocity | (m/s) | $V_{WT}$ | 10,98 | 9,13 | 9,10 | 9,37 | 8,83 | 8,70 | 8,70 | 8,78 | 8,44 | 8,81 |
| 11 | True wind direction | (rad) | $\Psi_{WT}$ | 0,157 0 | 0,166 7 | 0,202 9 | 0,125 6 | 6,037 4 | 6,236 2 | 6,228 4 | 6,031 4 | 6,195 9 | 0,244 1 |
| | | (°) | | 9,0 | 9,6 | 11,6 | 7,2 | 345,9 | 357,3 | 356,9 | 345,6 | 355,0 | 14,0 |
| 12 | Mean wave period (Seas) | (s) | $T_m$ | 3,90 | 3,90 | 3,90 | 3,90 | 3,90 | 3,90 | 2,80 | 2,80 | 2,80 | 2,80 |
| 13 | Significant wave height (Seas) | (m) | $H_{1/3}$ | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 0,50 | 0,50 | 0,50 | 0,50 |
| 14 | Incident angle of wave (Seas) | (°) | $x$ | 170,0 | 350,0 | 170,0 | 350,0 | 170,0 | 350,0 | 350,0 | 170,0 | 350,0 | 170,0 |
| | | (rad) | | 2,97 | 6,11 | 2,97 | 6,11 | 2,97 | 6,11 | 6,11 | 2,97 | 6,11 | 2,97 |
| 15 | Mean wave period (Swell) | (s) | $T_{Sm}$ | 10,59 | 10,59 | 10,59 | 10,59 | 11,32 | 11,32 | 11,32 | 11,32 | 11,32 | 11,32 |
| 16 | Significant wave height (Swell) | (m) | $H_{S1/3}$ | 2,0 | 2,0 | 2,0 | 2,0 | 2,5 | 2,5 | 2,5 | 2,5 | 3,0 | 3,0 |
| 17 | Incident angle of wave (Swell) | (°) | $X_S$ | 40,0 | 220,0 | 40,0 | 220,0 | 40,0 | 220,0 | 220,0 | 40,0 | 220,0 | 40,0 |
| | | (rad) | | 0,698 1 | 3,839 7 | 0,698 1 | 3,839 7 | 0,698 1 | 3,839 7 | 3,839 7 | 0,698 1 | 3,839 7 | 0,698 1 |
| 18 | Rudder angle | (°) | $\delta_R$ | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| | | (rad) | | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| 19 | Drift angle | (°) | $\beta$ | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| | | (rad) | | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |

**Table 2** (*continued*)

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Analysed data** | | | | | | | | | | | | | |
| 20 | Delivered power | (kW) | $P_D$ | 5 544 | 5 372 | 11 018 | 10 816 | 15 728 | 15 718 | 17 961 | 17 796 | 18 883 | 19 181 |
| 21 | Torque coefficient | | $K_Q$ | 0,028 410 | 0,027 72 | 0,027 79 | 0,027 28 | 0,027 53 | 0,027 52 | 0,027 33 | 0,027 46 | 0,027 65 | 0,027 47 |
| 22 | Propeller advance ratio | | $J$ | 0,611 3 | 0,626 4 | 0,624 7 | 0,635 6 | 0,630 3 | 0,630 7 | 0,634 6 | 0,631 9 | 0,627 8 | 0,631 7 |
| 23 | Load factor | | $\tau$ | 0,497 2 | 0,457 0 | 0,461 2 | 0,433 7 | 0,447 0 | 0,446 0 | 0,436 5 | 0,443 0 | 0,453 1 | 0,443 3 |
| 24 | Slip ratio | | $S_R$ | 0,297 7 | 0,280 3 | 0,282 3 | 0,269 8 | 0,275 9 | 0,275 4 | 0,270 9 | 0,274 0 | 0,278 7 | 0,274 2 |
| 25 | Wake factor | | $1-w$ | 0,963 8 | 0,781 1 | 0,909 0 | 0,779 1 | 0,868 3 | 0,776 0 | 0,783 2 | 0,845 6 | 0,789 4 | 0,843 3 |
| 26 | Mean wake factor | | $(1-w)_m$ | 0,872 5 | 0,872 5 | 0,844 1 | 0,844 1 | 0,822 1 | 0,822 1 | 0,814 4 | 0,814 4 | 0,816 4 | 0,816 4 |
| 27 | Mean speed through water | (m/s) | $V_S$ | 4,870 | 4 979 | 6 515 | 6 629 | 7 623 | 7 628 | 8 094 | 8 071 | 8 158 | 8 184 |
| 28 | Total resistance | (kN) | $R_T$ | 721,7 | 693,3 | 1 121,6 | 1 091,1 | 1 411,8 | 1 410,2 | 1 524,9 | 1 539,1 | 1 616,0 | 1 591,1 |
| **Load correction** | | | | | | | | | | | | | |
| 29 | Resistance increase due to wind | (kN) | $R_{AA}$ | 131,5 | – 10,9 | 162,3 | – 4,5 | 181,2 | – 0,3 | – 0,1 | 192,7 | 0,0 | 196,5 |
| 30 | Resistance increase due to waves | (kN) | $R_{AW}$ | 31,4 | 111,8 | 31,4 | 106,9 | 31,4 | 182,6 | 180,1 | 7,9 | 264,7 | 7,9 |
| 31 | Resistance increase due to steering | (kN) | $R_{\delta\delta}$ | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| 32 | Resistance increase due to drift | (kN) | $R_{\beta\beta}$ | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| 33 | Resistance increase due to temperature and salt content | (kN) | $R_{AS}$ | neg.[a] | neg.[a] | neg.[a] | neg.[a] | neg.[a] | neg.[a] | neg.[a] | neg.[a] | neg.[a] | neg.[a] |
| 34 | Resistance increase due to displacement | (kN) | $R_{ADIS}$ | neg.[a] | neg.[a] | neg.[a] | neg.[a] | neg.[a] | neg.[a] | neg.[a] | neg.[a] | neg.[a] | neg.[a] |
| 35 | Total resistance increase | (kN) | $\Delta R$ | 162,9 | 100,9 | 193,7 | 102,4 | 212,6 | 182,3 | 180,0 | 200,6 | 264,7 | 204,4 |
| 36 | Correction for load factor | | $\Delta\tau$ | 0,112 2 | 0,066 5 | 0,079 7 | 0,040 7 | 0,067 3 | 0,057 7 | 0,051 5 | 0,057 7 | 0,074 2 | 0,057 0 |
| 37 | Load factor | | $\tau_1$ | 0,385 0 | 0,390 5 | 0,381 6 | 0,393 0 | 0,379 7 | 0,388 3 | 0,385 0 | 0,385 3 | 0,378 9 | 0,386 4 |
| 38 | Propeller advance ratio | | $J_1$ | 0,656 7 | 0,654 2 | 0,658 2 | 0,653 0 | 0,659 1 | 0,655 0 | 0,656 7 | 0,656 5 | 0,659 4 | 0,656 0 |
| 39 | Torque coefficient | | $K_{Q1}$ | 0,026 27 | 0,026 39 | 0,026 20 | 0,026 45 | 0,026 16 | 0,026 35 | 0,026 27 | 0,026 28 | 0,026 14 | 0,026 31 |
| 40 | Propeller frequency of revolutions | (Hz) | $n_1$ | 0,681 1 | 0,699 0 | 0,879 5 | 0,902 0 | 1,000 9 | 1,007 8 | 1,056 5 | 1,054 0 | 1,063 2 | 1,072 1 |
| 41 | Torque coefficient | | $K'_Q$ | 0,026 33 | 0,026 33 | 0,026 32 | 0,026 32 | 0,026 24 | 0,026 24 | 0,026 26 | 0,026 26 | 0,026 20 | 0,026 20 |
| 42 | Propeller advance ratio | | $J'$ | 0,655 7 | 0,655 6 | 0,655 9 | 0,655 9 | 0,657 6 | 0,657 6 | 0,657 1 | 0,657 1 | 0,658 4 | 0,658 3 |
| 43 | Load factor | | $\tau'$ | 0,384 8 | 0,385 5 | 0,384 9 | 0,385 5 | 0,381 3 | 0,381 4 | 0,382 6 | 0,382 5 | 0,379 5 | 0,379 8 |
| 44 | Correction of ship's speed | (m/s) | $\Delta V_G$ | 0,360 | 0,236 | 0,328 | 0,211 | 0,334 | 0,330 | 0,290 | 0,326 | 0,405 | 0,351 |
| 45 | Speed over ground | (m/s) | $V'_G$ | 4,769 | 5,797 | 6,378 | 7,393 | 7,552 | 8,412 | 8,706 | 8,099 | 8,842 | 8,274 |
| 46 | Delivered power | (kW) | $P'_D$ | 5 139 | 5 102 | 10 436 | 10 435 | 14 991 | 14 987 | 17 258 | 17 018 | 17 893 | 18 294 |
| 47 | Shaft power | (kW) | $P'_S$ | 5 293 | 5 256 | 10 749 | 10 748 | 15 441 | 15 437 | 17 776 | 17 529 | 18 430 | 18 843 |
| **Current** | | | | | | | | | | | | | |
| 48 | Time of day at middle of run | | $t_i$ | 16,792 | 18,830 | 20,826 | 23,053 | 24,986 | 26,682 | 30,597 | 32,433 | 34,231 | 35,849 |
| 49 | Time at middle of serial runs | | $t$ | 17,811 | 17,811 | 21,939 | 21,939 | 25,834 | 25,834 | 31,515 | 31,515 | 35,040 | 35,040 |
| 50 | Speed correction for revolution difference | (m/s) | $V''_{G(i+1)}$ | 4,769 | 5,810 | 6,378 | 7,393 | 7,552 | 8,412 | 8,706 | 8,087 | 8,842 | 8,299 |
| 51 | Mean current velocity | (m/s) | $V_{FM}$ | 0,521 | 0,521 | 0,508 | 0,508 | 0,430 | 0,427 | 0,310 | 0,310 | 0,272 | 0,272 |
| 52 | Current at each run | (m/s) | $V_F$ | 0,494 | – 0,527 | 0,525 | – 0,484 | 0,442 | – 0,404 | – 0,324 | 0,296 | – 0,273 | 0,275 |
| 53 | Speed without current | (m/s) | $V'_S$ | 5,263 | 5,269 | 6,902 | 6,909 | 7,994 | 8,008 | 8,382 | 8,395 | 8,570 | 8,549 |

**Table 2** (*continued*)

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Wind correction** | | | | | | | | | | | | | |
| 54 | Load factor increase | | $\Delta\tau_A$ | 0,011 3 | 0,011 3 | 0,012 1 | 0,012 1 | 0,012 8 | 0,012 8 | 0,013 0 | 0,013 0 | 0,012 9 | 0,012 9 |
| 55 | Load factor | | $\tau_2$ | 0,396 1 | 0,396 8 | 0,397 0 | 0,397 6 | 0,394 1 | 0,394 2 | 0,395 6 | 0,395 5 | 0,392 4 | 0,392 7 |
| 56 | Propeller advance ratio | | $J_2$ | 0,651 8 | 0,651 4 | 0,651 4 | 0,651 0 | 0,652 5 | 0,652 5 | 0,651 9 | 0,651 9 | 0,653 2 | 0,6531 |
| 57 | Torque coefficient | | $K_{Q2}$ | 0,026 51 | 0,026 53 | 0,026 53 | 0,026 55 | 0,026 47 | 0,026 47 | 0,026 51 | 0,026 50 | 0,026 44 | 0,026 45 |
| 58 | Propeller frequency of revolution | (Hz) | $n_2$ | 0,736 0 | 0,734 7 | 0,933 1 | 0,933 6 | 1,054 8 | 1,054 8 | 1,102 1 | 1,103 7 | 1,125 6 | 1,122 2 |
| 59 | Torque coefficient | | $K_{Q0}$ | 0,026 52 | 0,026 52 | 0,026 54 | 0,026 54 | 0,026 48 | 0,026 48 | 0,026 51 | 0,026 51 | 0,026 45 | 0,026 45 |
| 60 | Correction of ship's speed | (m/s) | $\Delta V'_S$ | 0,032 | 0,032 | 0,050 | 0,049 | 0,062 | 0,062 | 0,067 | 0,067 | 0,069 | 0,069 |
| 61 | Ship's speed after correction | (m/s) | $V''_S$ | 5,230 | 5,238 | 6,852 | 6,861 | 7,932 | 7,946 | 8,315 | 8,327 | 8,501 | 8,480 |
| 62 | Delivered power | (kW) | $P_{D0}$ | 5 176 | 5 139 | 10 523 | 10 522 | 15 128 | 15 124 | 17 422 | 17 180 | 18 064 | 18 468 |
| 63 | Shaft power | (kW) | $P_{S0}$ | 5 331 | 5 293 | 10 839 | 10 838 | 15 582 | 15 578 | 17 945 | 17 696 | 18 606 | 19 022 |
| **Shallow water** | | | | | | | | | | | | | |
| 64 | Speed loss | (m/s) | $\Delta V''_S$ | neg.[a] | neg.[a] | neg.[a] | neg.[a] | neg.[a] | neg.[a] | neg.[a] | neg.[a] | neg.[a] | neg.[a] |
| 65 | Ship's speed after correction | (m/s) | $V_{S0}$ | 5,230 | 5,238 | 6,852 | 6,861 | 7,932 | 7,946 | 8,315 | 8,327 | 8,501 | 8,480 |
| **Final performance** | | | | | | | | | | | | | |
| 5 | Propeller frequency of revolution | (Hz) | $n$ | 0,731 7 | 0,730 0 | 0,926 7 | 0,926 7 | 1,046 7 | 1,046 7 | 1,093 3 | 1,095 0 | 1,116 7 | 1,113 3 |
| | Mean propeller frequency of revolution | (Hz) | | 0,730 8 | | 0,926 7 | | 1,046 7 | | 1,094 2 | | 1,115 0 | |
| 65 | Ship's speed | (m/s) | $V_{S0}$ | 5,230 | 5,238 | 6,852 | 6,861 | 7,932 | 7,946 | 8,315 | 8,327 | 8,501 | 8,480 |
| | Mean ship's speed | (m/s) | | 5,234 | | 6,857 | | 7,939 | | 8,321 | | 8,490 | |
| | | (kn) | | 10,17 | | 13,33 | | 15,43 | | 16,17 | | 16,50 | |
| 63 | Shaft power | (kW) | $P_{S0}$ | 5 331 | 5 293 | 10 839 | 10 838 | 15 582 | 15 578 | 17 945 | 17 696 | 18 606 | 19 022 |
| | Mean shaft power | (kW) | | 5 312 | | 10 838 | | 15 580 | | 17 820 | | 18 814 | |

[a] Negligible.

# Annex A
(normative)

## Resistance increase due to wind

The resistance increase due to wind, in newtons, is calculated by

[29] in Table 1: $R_{AA} = 0{,}5\rho_A \cdot C_{AA}(\psi_{WR}) \cdot A_{XV} \cdot V_{WR}^2$ (A.1)

using

$$C_{AA}(\psi_{WR}) = C_{AA0} \times K(\psi_{WR}) \tag{A.2}$$

where

| | |
|---|---|
| $A_{XV}$ | is the area of maximum transverse section exposed to the wind, in square metres; |
| $C_{AA}(\psi_{WR})$ | is the wind resistance coefficient; |
| $C_{AA0}$ | is the wind resistance coefficient in head wind; |
| $K(\psi_{WR})$ | is the directional coefficient of wind resistance; |
| $V_{WR}$ | is the relative wind velocity, in metres per second; |
| $\psi_{WR}$ | is the relative wind direction, in radians; |
| $\rho_A$ | is the mass density of air, in kilograms per cubic metre. |

The wind resistance coefficient in head wind and the directional coefficient of wind resistance shall be based on data derived from model tests in a wind tunnel. For guidance, data obtained from model tests are given in Figures A.1 and A.2.

In cases where data are available covering ships of similar type, such data may be used instead of carrying out model tests. When such data are not available, and for ships of unusually shaped superstructures, use of data from model tests is recommended.

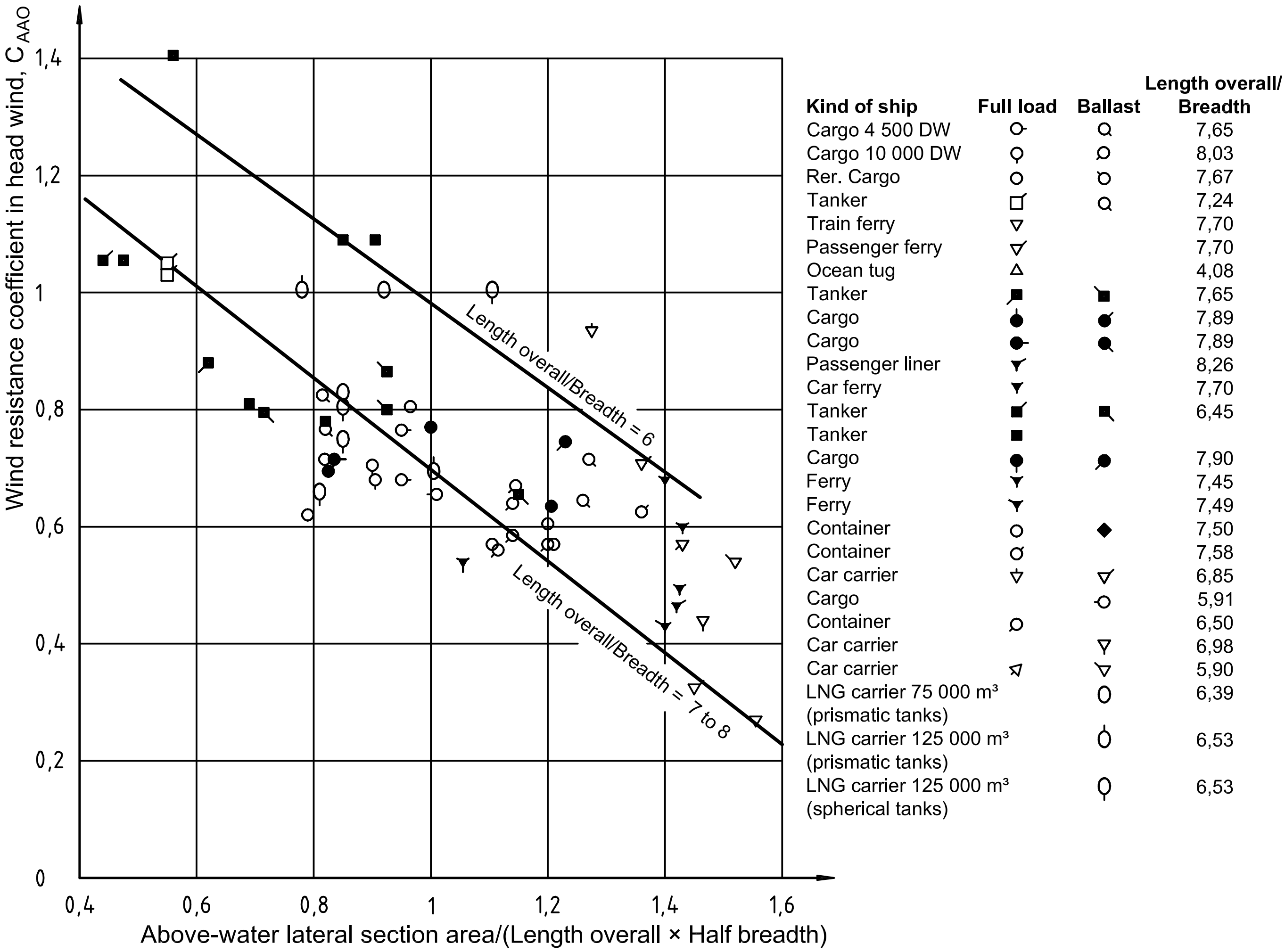



**Figure A.1 — Wind resistance coefficient in head wind**

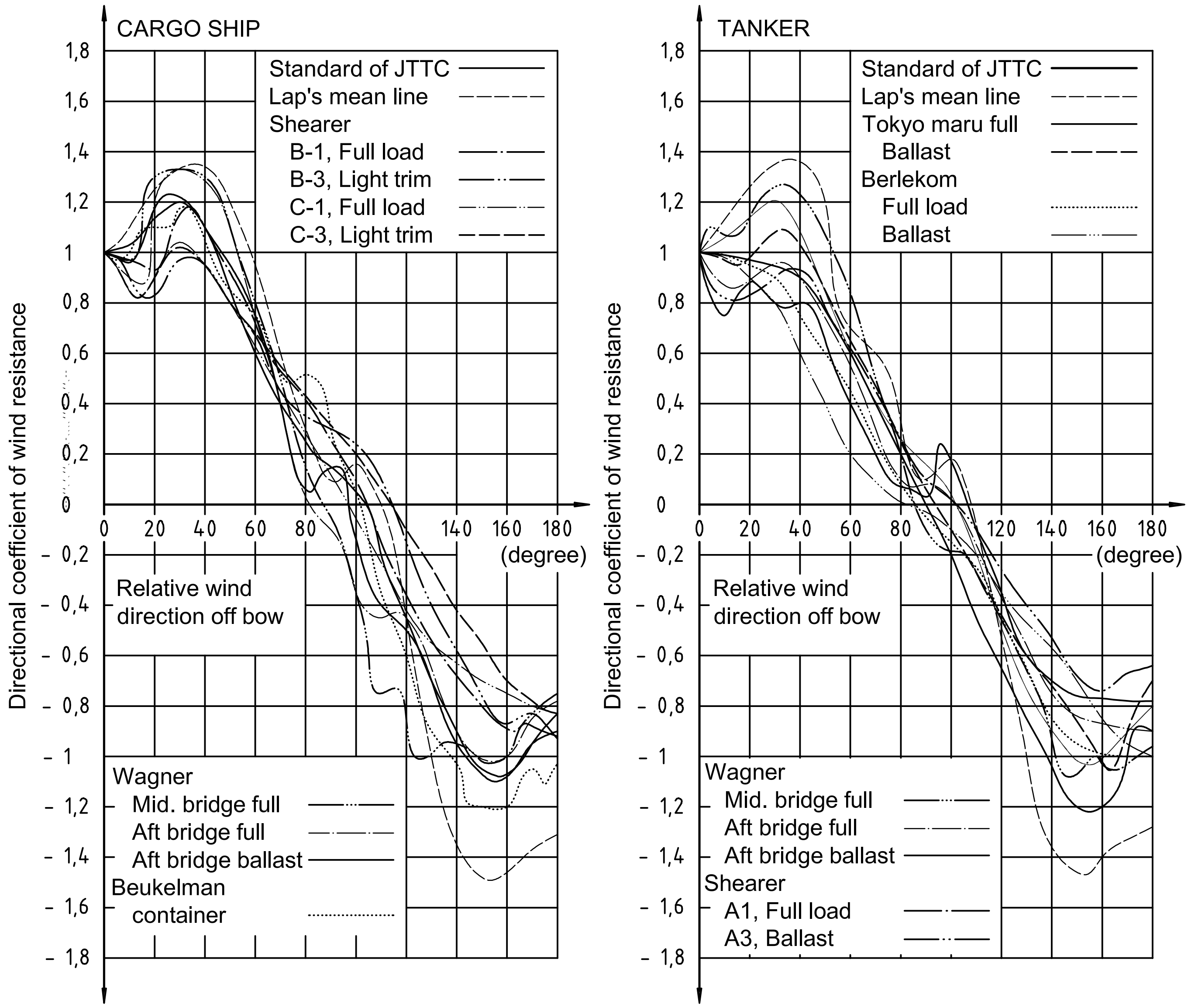



**Figure A.2 — Directional coefficient of wind resistance**

# Annex B
(normative)

# Resistance increase due to waves

## B.1 Calculation of resistance increase due to waves

### B.1.1 Calculation method

Calculation of resistance increase due to waves is divided into two stages, basic calculations made beforehand and calculations to be made on board as shown in Figure B.1.

Wave data shall be determined from observations by eye performed by multiple observers, including the captain. If instruments can be used, the wave characteristics are determined either by measurement with buoys or from instruments on the ship.

When both seas and swell are observed and are to be taken into account, the total resistance increase is given by the sum of resistance increases due to seas and swell calculated independently.

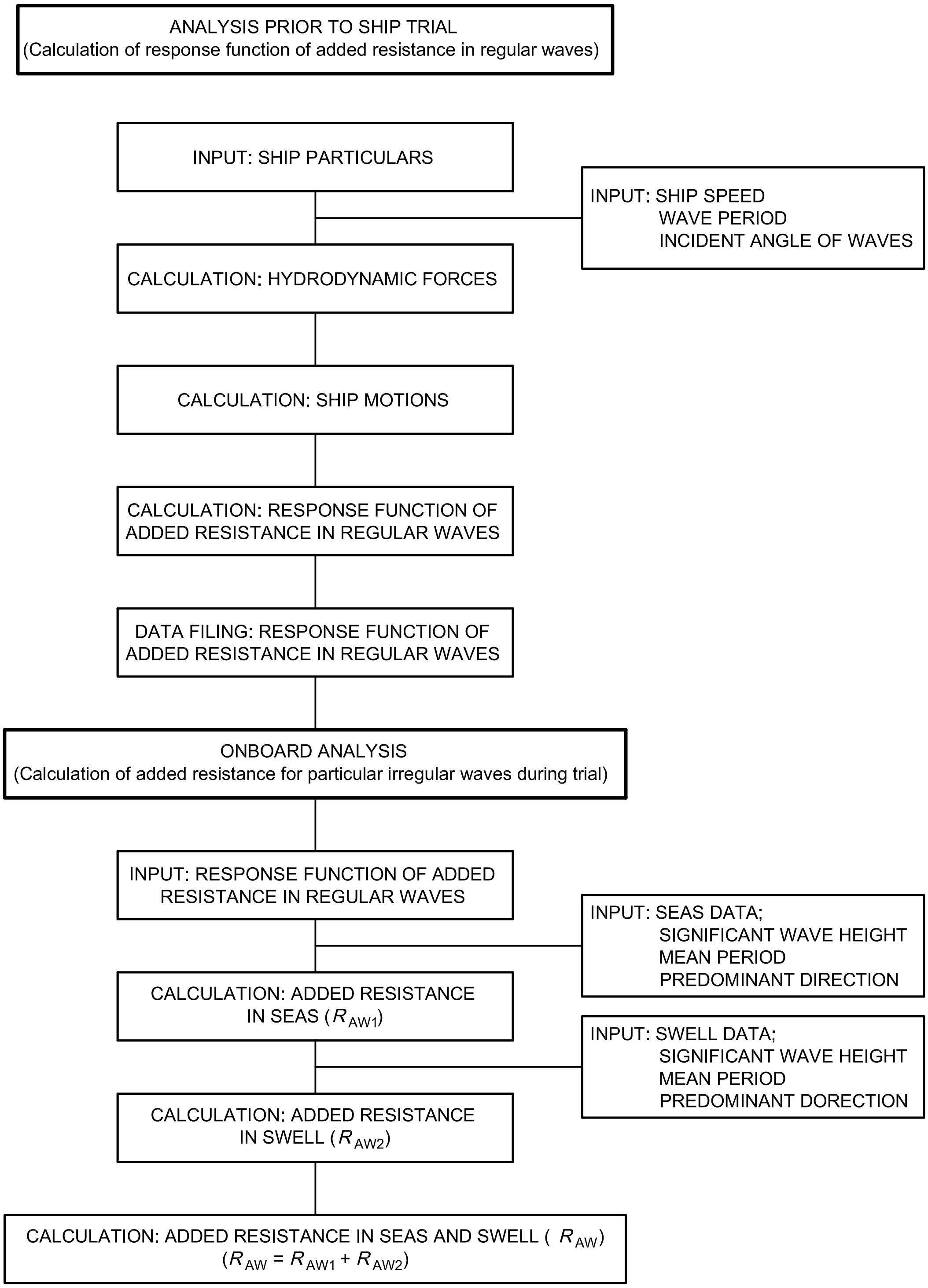



**Figure B.1 — Flowchart for calculation of resistance increase in waves**

## B.1.2 Response function of resistance increase due to waves

The most common response function of resistance increase due to waves, expressed in newtons per square metre, is given by Maruo's theory ([3] in the bibliography) as follows:

$$\frac{\Delta r_1}{\zeta_A^2} = \frac{\rho}{4\pi\zeta_A^2}\left[ -\int_{-\infty}^{m_1} + \int_{m_2}^{m_3} + \int_{m_4}^{\infty} \right] \frac{k_u(m)(m - k\cos\chi)}{\sqrt{k_u^2(m) - m^2}} \left( \left| C(m) \right|^2 + \left| S(m) \right|^2 \right) dm \text{ (N/m}^2\text{)} \quad \text{(B.1)}$$

$$\left.\begin{matrix} m_1 \\ m_2 \end{matrix}\right\} = -\frac{k_0}{2}\left(1 + 2\tau \pm \sqrt{1 + 4\tau}\right)$$

$$\left.\begin{matrix} m_3 \\ m_4 \end{matrix}\right\} = \frac{k_0}{2}\left(1 - 2\tau \mp \sqrt{1 - 4\tau}\right)$$

$$k_u(m) = \frac{(m + k_0\tau)^2}{k_0}$$

$$\tau = \frac{V_S\omega_e}{g}$$

where

$g$ is the acceleration due to gravity, in metres per second squared;

$k$ is the wave number $\left( = \omega^2/g \right)$, in 1/metre;

$k_0$ is the wave number $\left( = g/V_S^2 \right)$, in 1/metre;

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

$\Delta r_1$ is the resistance increase due to radiation in regular waves, in newtons;

$\zeta_A$ is the wave amplitude, in metres;

$\rho$ is the mass density of sea water, in kilograms per cubic metre;

$\omega_e$ is the circular frequency of encounter, in radians per second;

$C(m)$ is the symmetric Kochin function, in cubic metres per second;

$S(m)$ is the asymmetric Kochin function, in metres per second.

It is assumed that $m_3 = m_4$ for $\tau > 1/4$.

The Kochin functions are determined from singularity distributions which express the flow field of a ship as follows;

$$C(m) = \int_L Q(x) e^{imx} dx \quad \text{(B.2)}$$

$$S(m) = \int_L D(x) e^{imx} dx$$

where $Q(x)$ and $D(x)$ are the intensity of source and doublet distributions on the $x$-axis, respectively. These singularity distributions shall be obtained by a strip method, unified theory or other alternative methods.

In short waves, in particular, marked diffraction of incident waves is observed around the bow, and this causes the main resistance increase in waves. The method based on an assumption of a slender ship cannot take exact account of the effect of wave diffraction around a blunt bow. As for the correction of this effect according to equation (B.1), Fujii-Takahashi's formula ([10] in the bibliography), Faltinsen's formula [12] and Kwon's formula [14] are recommended. These formulae can be used to calculate the response function of resistance increase due to diffraction in regular waves, $\Delta r_2 / \zeta_A^2$.

Faltinsen's formula is as follows:

$$\frac{\Delta r_2}{\zeta_A^2} = \frac{1}{2}\rho g \alpha_1 \Big[ \int_{\mathrm{I}} [\sin^2(\chi - \theta) - \frac{2\omega V_S}{g}\{\cos\chi - \cos\theta\cos(\chi - \theta)\}] \sin\theta \, \mathrm{d}\ell$$

$$+ \int_{\mathrm{II}} [\sin^2(\chi + \theta) - \frac{2\omega V_S}{g}\{\cos\chi - \cos\theta\cos(\chi + \theta)\}] \sin\theta \, \mathrm{d}\ell \Big] \ (\mathrm{N/m^2}) \tag{B.3}$$

where

$d$ is the draught of ship, in metres;

$I_1, K_1$ are the modified Bessel functions;

$\ell$ is the coordinate along waterline, in metres;

$\alpha_1$ is the draught influence factor;

$$= \frac{\pi^2 I_1^2(1{,}5kd)}{\pi^2 I_1^2(1{,}5kd) + K_1^2(1{,}5kd)}$$

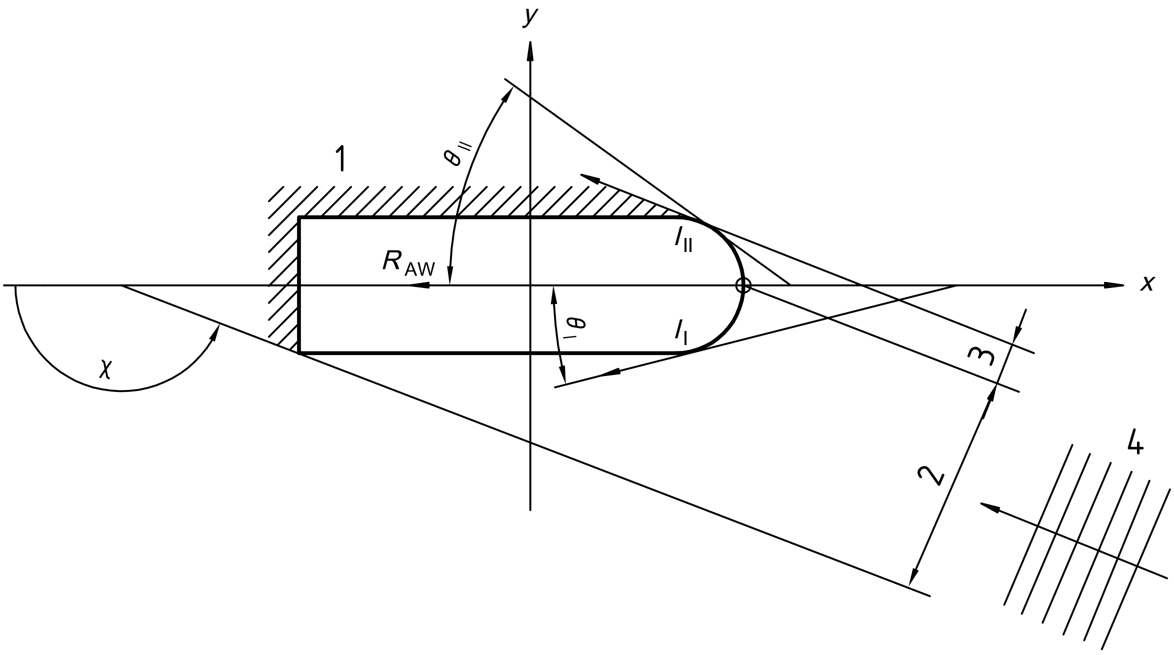
$\Delta r_2$ is the resistance increase due to diffraction in regular waves, in newtons;

$\theta$ is the angle between water-line tangent and body axis, in radians;

$\omega$ is the circular frequency of incident waves, in radians per second.

Kwon's formula is applicable for all directions of waves. Fujii-Takahashi's formula and Faltinsen's formula, however, should be applied only for the cases of head to beam waves. An assumption that waves are reflected along a ship's water line, under which the correction formulae are introduced, collapses in the case of following waves ($\chi < \pi/2$ rad). If the formulae are used, it is recommended that the resistance increase due to diffraction ($\Delta r_2$) equals zero when $\chi < \pi/2$.

The coordinate system, etc. are shown in Figure B.2.




**Key**

1 Shadow region
2 Region I
3 Region II
4 Waves

**Figure B.2 — Coordinate system**

## B.1.3 Calculation of resistance increase due to waves in the trial condition

Ships usually encounter irregular waves during trials. By making use of the response function of ships in regular waves, the resistance increase of ships in short-crested irregular waves, $R_{AW}$, in newtons, is obtained by

[30] in Table 1: $$R_{AW}(\chi) = 2\int_{-\pi}^{\pi} G(\alpha-\chi)\left[\int_0^\infty S(f)\frac{\Delta r(f,\alpha)}{\zeta_A^2}\mathrm{d}f\right]\mathrm{d}\alpha \quad \text{(B.4)}$$

where

$f$ is the frequency of the elementary incident wave, in 1/second;

$G$ is the direction distribution of incidence waves;

$S(f)$ is the frequency distribution of incident waves, in square metres per second;

$\alpha$ is the direction of the elementary incident wave, in radians;

$\frac{\Delta r}{\zeta_A^2}$ is the response function of resistance increase in regular waves, in newtons per square metre

$$= \frac{\Delta r_1}{\zeta_A^2} + \frac{\Delta r_2}{\zeta_A^2}$$

When measured wave data are not available, significant wave height and mean period of waves are estimated by observations, and the following ITTC standard spectrum for seas shall be applied for the frequency distribution of incident waves.

$$S(f) = \frac{0{,}11 H_{1/3}^2 T_{01}}{(T_{01} f)^5} \exp\left\{ -\frac{0{,}44}{(T_{01} f)^4} \right\} \ (\mathrm{m}^2 \cdot \mathrm{s}) \tag{B.5}$$

where

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

$T_{01}$ is the mean wave period, in seconds.

$$= \frac{\int_0^\infty S(f)\mathrm{d}f}{\int_0^\infty S(f) f \mathrm{d}f}$$

When wave data are determined by measurement, the wave spectrum is given by

$$S(f) = \frac{0{,}08 H_{1/3}^2 T_{02}}{(T_{02} f)^5} \exp\left\{ -\frac{0{,}32}{(T_{02} f)^4} \right\} \ (\mathrm{m}^2 \cdot \mathrm{s}) \tag{B.6}$$

where $T_{02}$ is the mean wave period, in seconds.

$$= \sqrt{\frac{\int_0^\infty S(f)\mathrm{d}f}{\int_0^\infty S(f) f^2 \mathrm{d}f}}$$

Directional distribution of waves for seas is standardized by $\cos^2$ type distribution. The directional distribution $G(\alpha)$ is given by

$$G(\alpha) = \frac{2}{\pi}\cos^2 \alpha \qquad \text{at} \left( -\frac{\pi}{2} < \alpha < \frac{\pi}{2} \right) \tag{B.7}$$

The frequency distribution for swell is described by a narrow band spectrum. The JONSWAP spectrum is commonly applied for swell as follows:

$$S(f) = \frac{0{,}072 H_{1/3}^2 T_{01}}{(T_{01} f)^5} \exp\left\{ -\frac{0{,}44}{(T_{01} f)^4} \right\} \times 3{,}3^{\exp\left\{ -0{,}5 (1{,}3 T_{01} f - 1)^2 / \sigma^2 \right\}} \ (\mathrm{m}^2 \cdot \mathrm{s}) \tag{B.8}$$

$$\sigma = \begin{cases} 0{,}07 \text{ for} & f \leqslant (1{,}3 T_{01})^{-1} \\ 0{,}09 \text{ for} & f > (1{,}3 T_{01})^{-1} \end{cases}$$

$$G(\alpha) = 2{,}447 \left( \cos \frac{\alpha}{2} \right)^{150} \quad \text{at } (-\pi < \alpha < \pi) \tag{B.9}$$

## B.2 Other prediction methods for resistance increase due to waves

The resistance increase due to waves may be obtained by other theoretical methods than those of clause B.1 or from model tests. One such typical method is the modified Townsin-Kwon method ([15] in the bibliography).

# Annex C
(normative)

# Effect of steering

## C.1 Steering required for course keeping

The resistance increase due to steering required by course keeping, $R_{\delta\delta}$, in newtons, is calculated by

[31] in Table 1: $R_{\delta\delta} = 0{,}5\rho\left(1 - t_\mathrm{R}\right) \cdot f_\alpha\left(\lambda_\mathrm{R}\right) \cdot A_\mathrm{R} \cdot V_\mathrm{eff}^2 \cdot \delta_\mathrm{R}^2$ (C.1)

where

$$f_\alpha\left(\lambda_\mathrm{R}\right) = \frac{6{,}13\lambda_\mathrm{R}}{2{,}25 + \lambda_\mathrm{R}} \qquad \text{(C.2)}$$

$A_\mathrm{R}$ is the rudder area, in square metres;

$t_\mathrm{R}$ is the resistance deduction fraction due to steering;

$V_\mathrm{eff}$ is the effective inflow velocity to rudder, in metres per second;

$\delta_\mathrm{R}$ is the rudder angle, in radians;

$\lambda_\mathrm{R}$ is the aspect ratio of rudder.

The resistance deduction fraction due to steering, $t_\mathrm{R}$, is shown in Figure C.1.

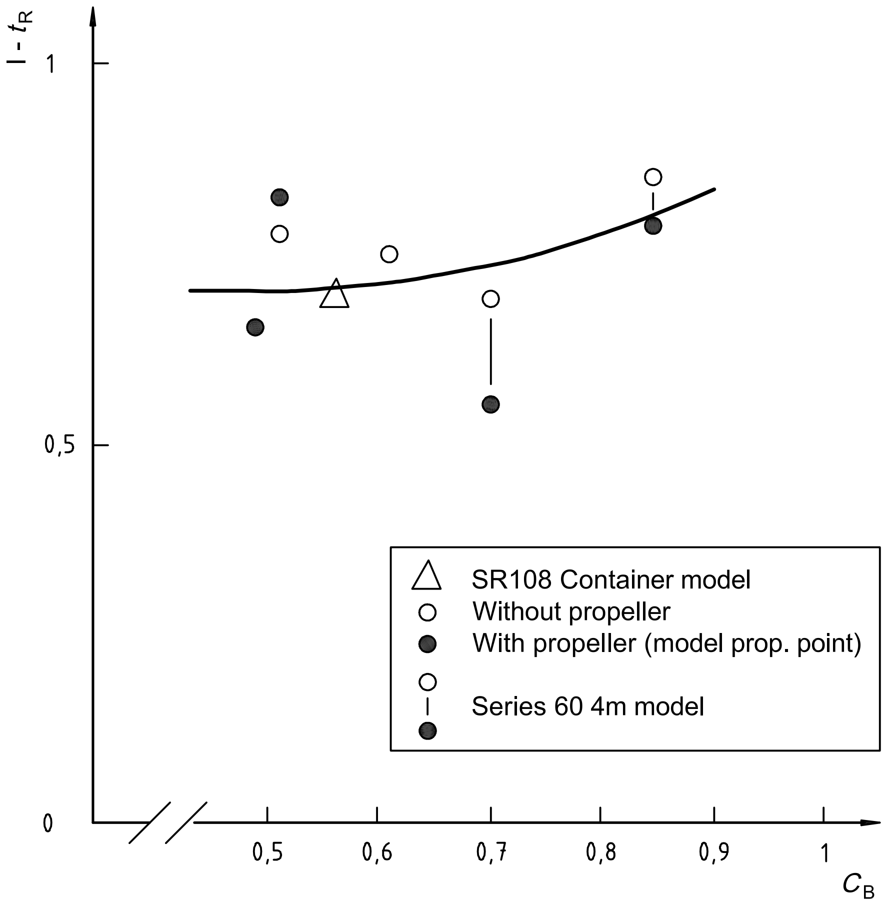



**Figure C.1 — Resistance deduction fraction due to steering ([20] in the bibliography)**

The effective inflow velocity to the rudder, $V_{eff}$, in metres per second, is given by

$$V_{eff} = \frac{0{,}75 V_S}{(1 - S_R)} \sqrt{1 - 2(1 - c_1 c_2) S_R + \{1 - c_1 c_2 (2 - c_2)\} S_R^2} \tag{C.3}$$

where

$$c_1 = \frac{D}{b_R} \tag{C.4}$$

$$c_2 = 0{,}8(1 - w)_m \tag{C.5}$$

$b_R$ is the rudder span, in metres;

$S_R$ is the real slip ratio.

## C.2 Effect of drifting

The resistance increase due to drifting, $R_{\beta\beta}$, in newtons, is calculated by

[32] in Table 1: $R_{\beta\beta} = 0{,}25\pi \times \rho \cdot d^2 \cdot V_S^2 \cdot \beta^2$ (C.6)

where $\beta$ is the drift angle, in radians.

The drift angle can be estimated by theoretical or alternative methods.

# Annex D
(normative)

# Effect of water temperature and salt content

There may be differences in water temperature and salt content due to the trial area and season. Since conditions may differ significantly between contracts or the ITTC reference conditions of the model test and actual trial, corrections may be necessary.

If trials have to be performed in a trial area where the water temperature and/or salt content deviate from the specified conditions, a resistance correction has to be applied.

The correction, $R_{AS}$, in newtons, is given by

[33] in Table 1: $R_{AS} = R_{T0}(1-\frac{\rho}{\rho_0}) - R_F(1-\frac{C_{F0}}{C_F})$ (D.1)

where

$$R_{T0} = \frac{1}{2}\rho_0 \cdot V_S^2 \cdot S_W \cdot C_{T0} \text{ (in newtons)} \quad \text{(D.2)}$$

$$R_F = \frac{1}{2}\rho \cdot V_S^2 \cdot S_W \cdot C_F \text{ (in newtons)} \quad \text{(D.3)}$$

$R_{T0}$ is the total resistance at contractually specified water temperature and salt content which may be derived from model tests, in newtons;

$C_{T0}$ is the total resistance coefficient for contractually specified water temperature and salt content;

$R_F$ is the frictional resistance at actual water temperature and salt content in trial, in newtons;

$C_F$ is the frictional resistance coefficient for actual water temperature and salt content in trial;

$C_{F0}$ is the frictional resistance coefficient for the contractually specified water and salt content;

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

$\rho_0$ is the water density for the contractually specified water and salt content, in kilograms per cubic metre.

$\rho$ and $\nu$ may be taken from tables or computed by the following formulae which are given as examples:

Density of freshwater (zero salt content), $\rho$, in kilograms per cubic metre, as a function of temperature, $T_W$:

$$\rho(T_W) = g\left(a + bT_W + cT_W^2 + dT_W^3\right) \quad \text{(D.4)}$$

where

$a = 101{,}949\ 2$

$b = 5{,}503\ 076 \times 10^{-3}$

$c = -7{,}684\ 34 \times 10^{-4}$

$d = 3{,}611\ 636 \times 10^{-6}$

Kinematic viscosity of freshwater (zero salt content), $\nu$, in square metres per second, as a function of temperature:

$$\nu(T_W) = a + b \cdot T_W + c \cdot T_W^2 + d \cdot T_W^3 + e \cdot T_W^4 \quad \text{(D.5)}$$

where

$a = 1{,}786\ 170 \times 10^{-6}$

$b = -6{,}071\ 739 \times 10^{-8}$

$c = 1{,}507\ 093 \times 10^{-9}$

$d = -2{,}552\ 462 \times 10^{-11}$

$e = 2{,}087\ 519 \times 10^{-13}$

Density of seawater (salt content 3,5 %), $\rho$, in kilograms per cubic metre, as a function of temperature:

$$\rho(T_W) = g\left(a + bT_W + cT_W^2 + dT_W^3\right) \quad \text{(D.6)}$$

where

$a = 104{,}830\ 04$

$b = -6{,}210\ 858 \times 10^{-3}$

$c = -5{,}976\ 822 \times 10^{-4}$

$d = 2{,}579\ 739\ 7 \times 10^{-6}$

Kinematic viscosity of seawater (salt content 3,5 %), $\nu$, in square metres per second, as a function of temperature:

$$\nu(T_W) = a + bT_W + cT_W^2 + dT_W^3 + eT_W^4 \quad \text{(D.7)}$$

where

$a = 1{,}827\ 788\ 5 \times 10^{-6}$

$b = -6{,}020\ 031\ 2 \times 10^{-8}$

$c = 1{,}528\ 715 \times 10^{-9}$

$d = -2{,}741\ 868 \times 10^{-11}$

$e = 2{,}371\ 871\ 1 \times 10^{-13}$

$T_W$ denominates the temperature in centigrade. Linear interpolation is to be used for intermediate salt content.

# Annex E
(normative)

# Effect of vessel condition

## E.1 Displacement and trim

Displacement and trim are, in general, factors that can be adjusted to stipulated values at the time of trial but there may be substantial reasons for discrepancies.

The difference of the actual displacement during the individual trial from the specified value should not exceed 2 %.

Trim shall be maintained within very narrow limits, i.e. the deviation from the specified trim shall be less than one per cent of the midship draught.

In particular cases where the impact of displacement deviations is larger, a correction, in newtons, shall be applied in the following way:

[34] in Table 1: $$R_{\mathrm{ADIS}} = 0{,}65 R_{\mathrm{T}} \left(\frac{\Delta_0}{\Delta} - 1\right) \quad \text{(E.1)}$$

where

$$R_{\mathrm{T}} = \frac{1}{2} \rho \cdot V_{\mathrm{S}}^2 \cdot S \cdot C_{\mathrm{T}} \ \text{(N)} \quad \text{(E.2)}$$

$R_{\mathrm{T}}$ is the total resistance, in newtons, for trial conditions which may be derived from model test;

$\Delta$ is the displacement during trial;

$\Delta_0$ is the displacement as contractually specified.

No general correction for deviations in trim can be given. However, reference should be made to model tests performed at constant displacement and variations of trim, if such test results are available for the hull under consideration.

In the case where the contract specifies the speed for draught and displacement which are not achievable during trials, the following is acceptable.

Model tests are performed for the draught specified by the contract and for the draught expected during trials. If the trials confirm the predictions based on the corresponding draught, it is assumed that the same correlation holds for the draught specified by the contract. This means that the contract is fulfilled.

## E.2 Hull and propeller surface roughness

If the trial is performed within a reasonable period of time after final hull painting and propeller polishing, changes in surface roughness should be minimal and their effect on ship performance negligible.

For particular cases where the trial takes place after a lapse of a considerable period following final docking, and the effect of surface roughness can no longer be neglected, some methods may be available for correcting such effects. The methods, however, are not scientific, and the resulting performance should not be utilized for any purpose beyond general guidance.

# Annex F
(normative)

## Effect of shallow water

Speed loss due to shallow water, $\Delta V_S / V_S$, in terms of the parameters, $\sqrt{A_M} / h$ and $V_S^2 / (gh)$, is determined by Figure F.1 and/or equation (F.1), which is given by Lackenby ([16] in the bibliography).

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

where

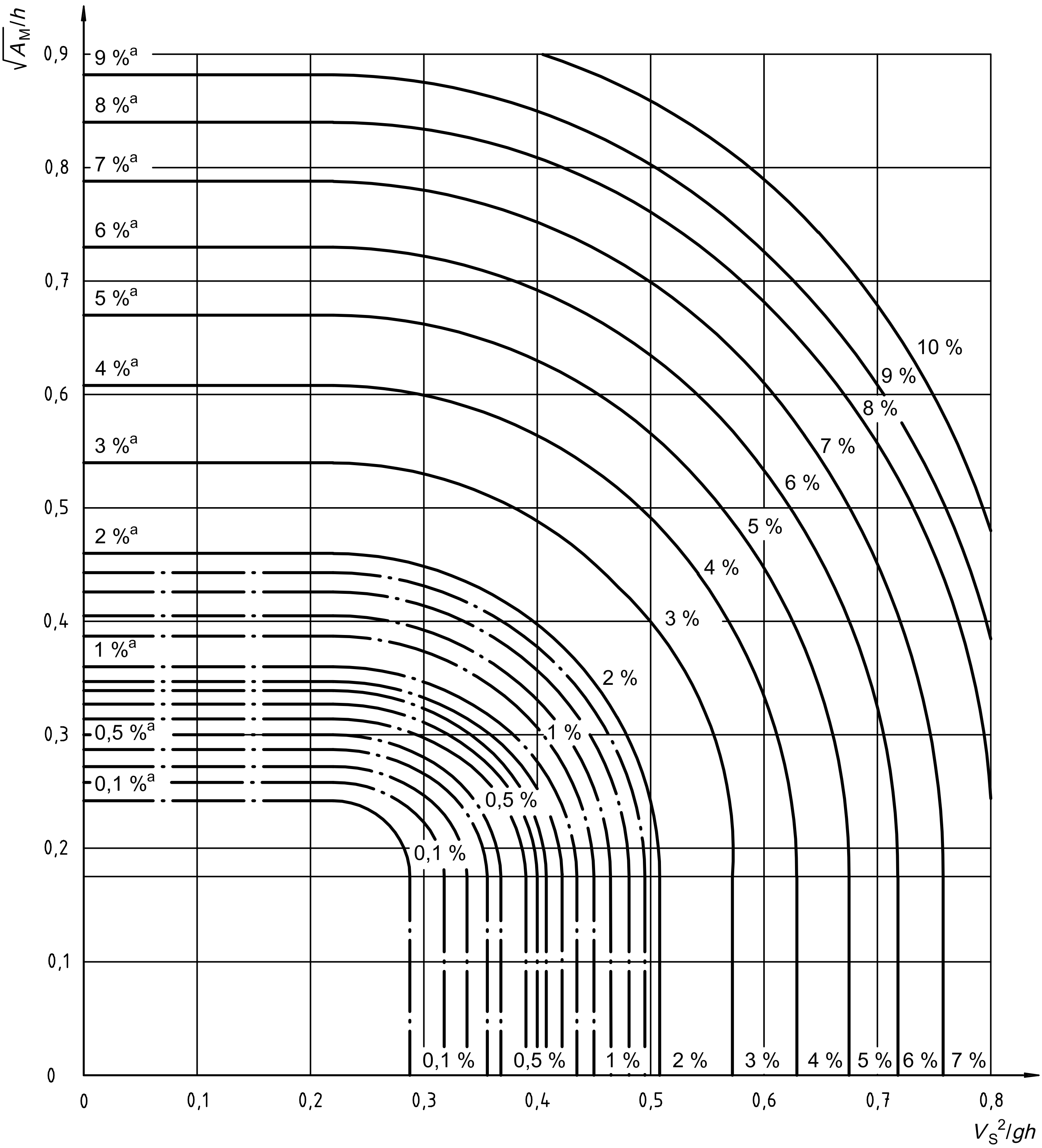
$A_M$ is the midship section area under water, in square metres;

$g$ is the acceleration due to gravity, in metres per second squared;

$h$ is the water depth, in metres;

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

$\Delta V_S$ is the speed loss due to shallow water, in metres per second.




[a] Percentage loss in speed $(\Delta V / V \times 100\ \%)$

**Figure F.1 — Speed loss due to shallow water effect**

# Bibliography


[1] JTTC, *A proposal for a standard method of speed trial analysis*, *Bull. SNAJ*, No. 262, 1944

[2] *Guaranteed speed specifications and the analysis procedure*, Notification No.174 of the Ministry of Transport, Japan, 1955

[3] MARUO, H. *On the increase of the resistance of a ship in rough seas (2nd report)*, *J. SNAJ*, Vol.108, 1960

[4] TANIGUCHI, K. and TAMURA, K. *On a new method of correction for wind resistance relating to the analysis of speed trial results*, 11th ITTC, 1966

[5] JTTC, *A tentative guide for the operation of speed trials with large vessels*, *Bull. SNAJ*, No. 442, 1966

[6] ITTC Performance Committee, *ITTC guide for measured-mile trials*, Report of the ITTC Performance Committee, Appendix I, 12th ITTC, 1969

[7] *Standardization code for trials and testing of new ships*, The Ship Testing and Trial Trip Committee of the Association of Ship Technical Societies in Norway, 2nd Edition, 1971

[8] *A study of ship speed trials*, No. 2 Standardization Panel, SRAJ, Res. Rep. No.12R, 1972

[9] *Code for Sea Trials*, SNAME, 1989

[10] FUJII, H. and TAKAHASHI, T. *Experimental study on the resistance increase of a large full ship in regular oblique waves*, *J. SNAJ*, Vol. 137, 1975

[11] *BSRA standard method of Speed Trial Analysis*, BSRA Report NS 466, 1978

[12] FALTINSEN, O.M., MINSAAS, K.J., LIAPIS, N. and SKJORDAL, S.O. *Prediction of resistance and propulsion of a ship in a seaway*, Proc. 13th Symposium on Naval Hydrodynamics, Tokyo, 1980

[13] JINNAKA, T. *On a method of analysis of ship speed trial results of ships*, *T. WSNAJ*, No. 64, 1982

[14] KWON, Y.J. *The Effect of Weather, Particularly Short Sea Waves, on Ship Speed Performance*, PhD Thesis, University of Newcastle upon Tyne, 1982

[15] TOWNSIN, R.L., KWON, Y.J., BAREE, M.S. and Kim, D.Y. *Estimating the influence of weather on ship performance*, *Tran.*, *RINA*, Vol. 135, 1993

[16] LACKENBY, H. *The Effect of Shallow Water on Ship Speed*, *Shipbuilder*, **70**, No. 672, 1963

[17] ITTC Performance Committee, *Hull Roughness*, Report of the ITTC Performance Committee, 19th ITTC, 1990

[18] VOSSERS, G., SWAAN, W.A. and RIJKEN, H. *Experiments with series 60 Models in Waves*, *Tran., SNAME*, Vol.68, 1960

[19] ITTC Powering Performance Committee, *An Updated Guide For Speed/Powering Trials*, Report of the ITTC Powering Performance Committee, Appendix I, 21st ITTC, 1996

[20] Japan Ship Research Association SR208: *New Speed Trial Analysis Method*, Report of the SR208 Committee, 1993

[21] ISO 7462, *Shipbuilding — Principal ship dimensions — Terminology and definitions for computer applications*

[22] ISO 7463, *Shipbuilding and marine structures — Symbols for computer applications*

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