Table of Contents

Updated / Edited by	Approved
Specialist Committee on Performance of Ships in Service 27th ITTC	27th ITTC 2014
Date 2014	

Analysis of Speed/Power Trial Data

1. PURPOSE

These Guidelines concern the method of analysis of the results obtained from the speed/power trials as conducted according Part 1 of these Guidelines; ITTC 7.5-04-01-01.1.

The descriptions for the calculation methods of the resistance increase due to wind and waves, as well as guidelines for analysis and speed corrections are based on relevant research results and modified from ITTC 7.5-04-01-01.2/2005 to meet the IMO EEDI requirements.

The primary purpose of speed trials is to determine the ship's performance in terms of speed, power and propeller frequency of revolutions under prescribed ship conditions, and thereby to verify the satisfactory attainment of the contractually stipulated ship speed.

The purpose of these Guidelines is to define the evaluation and correction of speed/power trials covering all influences which may be relevant for the individual trial runs with assurance of the highest accuracy of speed and power determination in contractual and stipulated conditions.

The applicability of these Guidelines is limited to commercial ships of the displacement type.

2. TERMS AND DEFINITIONS

For the purposes of these Guidelines, the following terms and definitions apply:

- **Brake Power:** power delivered by the output coupling of the propulsion machinery.
- **Contract Power:** Shaft Power that is stipulated in the newbuilding or conversion contract between Shipbuilder and Owner.
- **Docking Report:** report that documents the condition of the ship hull and propulsors (available from the most recent dry-docking).
- **Double Run:** two consecutive Speed Runs at the same power setting on reciprocal heading.
- **EEDI:** Energy Efficiency Design Index as formulated by IMO.
- **EEDI Power:** Shaft Power that is stipulated by the EEDI regulations.
- **Ideal Conditions:** ideal weather and sea condition; deep water, no wind, no waves and no current.
- **Owner:** party that signed the newbuilding or conversion contract with the Shipbuilder.
- **Propeller Pitch:** the design pitch, also for controllable pitch propellers.
- **Running Pitch:** the operating pitch of a CPP.
- **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.
- **Shipbuilder:** ship yard that signed the newbuilding or conversion contract with the Owner.
- **Ship Speed:** speed that is realised under the stipulated conditions. "Contract Speed" refers to the contractual conditions agreed. "EEDI Speed" refers to the conditions specified by IMO. The ship's speed during a Speed Run is derived from the headway distance between start and end position and the elapsed time of the Speed Run.

- **Sister Ships:** ships with identical main dimensions, body lines and propulsor system built in a series by the same Shipbuilder.
- **S/P Trials:** speed-power trials to establish the Speed-Power relation of the vessel.
- **Speed Run:** ship track with specified heading, distance and duration over which Ship Speed and Shaft Power are measured.
- **S/P Trial Agenda:** document outlining the scope of a particular S/P Trial. This document contains the guidelines on how to conduct the trial and table(s) portraying the runs to be conducted.
- **Trial Log:** for each Speed Run, the log contains the run number, the times when the Speed Run starts and stops, and the data as described in Section 9.4 and Appendix C of Part I of these Guidelines.
- The **Trial Leader** is the duly authorised (Shipbuilder's representative) person responsible for the execution of all phases of the S/P Trials including the pre-trial preparation.
- The **Trial Team** consists of the Trial Leader, the Owner's representative, the appointed persons responsible for the S/P Trial measurements and the Verifier.
- **Verifier:** third party responsible for verification of the EEDI.

For further definitions, system of co-ordinates and sign conventions, reference is made to Part I of these Guidelines.

3. RESPONSIBILITIES

The Trial Team is responsible for carrying out the trials and for correcting the data received. Preferably before the sea trials start, but at the latest when the trial area is reached and the environmental conditions can be studied, agreement between the trial team, shipyard and ship-owner shall be obtained concerning the limits of wind forces, wave heights and water depths up to which the trials shall be performed. Agreement shall be obtained concerning the methods used to correct the trial data. The measured data, analysis process and the results shall be transparent and open to the Trial Team.

4. ANALYSIS PROCEDURE

4.1 General Remarks

This document describes different methods to analyse the results of speed/power tests as conducted according to Part 1 of these Guidelines. The method to be used depending on situation and available data is given in the matrix of Table 1.

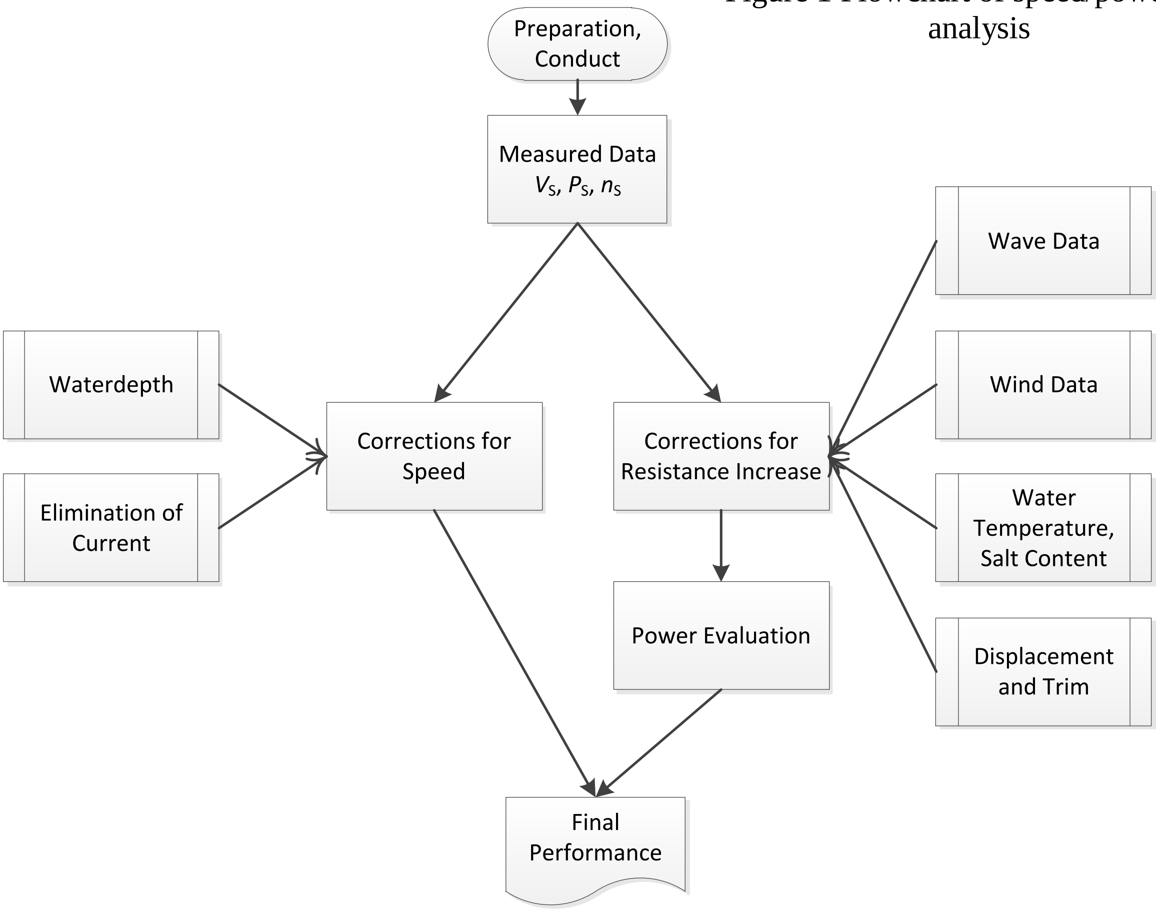
The procedure for the analysis of speed trials is the Direct Power Method and requires displacement, power, rate of revolutions, speed-over-ground, wind speed and direction, wave condition, η_D and η_S as input values.

4.2 Description of the Analysis Procedure

The analysis of speed/power trials shall consist of

- evaluation of the acquired data
- correction of ship performance for resistance increase due to wind, waves, water temperature and salt content
- elimination of current
- correction of ship speed at each run for the effect of shallow water
- correction of ship performance for displacement
- presentation of the trial results

Figure 1 Flowchart of speed/power trial analysis



In the following chapters details of the methods are given. For wave and wind corrections the methods depend on the level of information which is available to the conducting party of the speed/power sea trials. The analysis and correction method to be followed is prescribed below and summarized in Table 1.

Evaluation

For the evaluation the Direct Power Method in combination with the propulsive efficiency correction based on load variation tests (Section 4.2.3, Appendix A) shall be used.

Wind Correction

In calculating resistance increase due to wind, three methods can be used, depending on whether there are wind tunnel measurements available or not:

If **wind tunnel measurements are available**:

Same method as with dataset on the wind resistance coefficient (Appendix C.1)

If **wind tunnel measurements are not available**:

Data set on the wind resistance coefficient (Appendix C.2)

or regression formula by Fujiwara et al. (Appendix C.3).

Table 1 Evaluation method to be followed. The numbers identify the method by the chapters in which the methods are described, e.g.: 4.2.3: Evaluation based on Direct Power Method, D.1: Wave correction STAwave-1.

Condition				Evaluation / Correction Method							
				Evaluation	Waves	Wind	Current	Air Resistance	Temp. & Density	Water Depth	Displ. & Trim
Data set of STA resistance coefficients available	no					C.2					
						C.3					
Load Variation Test available	yes			4.2.3							
	no			4.2.3							
Ship Lines available to all parties		heave and pitch			D.1		Included in method		4.3.3	4.3.4	4.3.5
					D.2						
	yes				D.1 or D.2,D.3		Included in method		4.3.3	4.3.4	4.3.5
	Full Seakeeping Model Tests available				D.4		Included in method		4.3.3	4.3.4	4.3.5
Dataset of Wind	Wind Tunnel Tests available					C.1		Included in method	4.3.3	4.3.4	4.3.5

Wave correction

In calculating resistance increase due to waves, the following procedure shall be used:

If ship **geometry can't be made available** to all involved parties and under the condition that heaving and pitching are small, the direct correction wave method based on wave reflection prescribed in D.1 shall be used.

In case significant heave and pitch is observed during the trials, the empirical formulation of the response function prescribed in D.2, shall be used for the analysis. This empirical transfer function covers both the mean resistance increase due to wave reflection and the motion induced added resistance.

Provided that the **ship geometry is available** to all parties involved and the wave spectrum encountered during the speed/power trials is measured, the theoretical method as prescribed in Appendix D.3 in combination with simplified seakeeping model test may be used. In this case the derived transfer functions for added resistance should be used in combination with the measured wave spectrum.

In the case transfer functions of added resistance in waves derived from seakeeping tank tests are available for the specific vessel at the relevant draught, trim, speed range and relative wave direction, are available, these shall be used in combination with the wave encountered wave spectrum measured during the trials (Appendix D.4).

Shallow water

To correct for shallow water effect the method proposed by Lackenby[12]. shall be applied to the ship speed measured during each run.

Prescribed Method

Table 1 shows which method shall be used, depending on the information available.

4.2.1 Resistance data derived from the acquired data

The resistance values of each run shall be corrected for environmental influences by estimating the resistance increase ΔR as,

$$\Delta R = R_{AA} + R_{AW} + R_{AS} \tag{1}$$

with

R_{AA} : resistance increase due to relative wind,

R_{AS} : resistance increase due to deviation of water temperature and water density,

R_{AW} : resistance increase due to waves.

The added resistance due to wind, waves, temperature and water density is estimated according section 4.3

4.2.2 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 each 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 shallow water effect and for displacement and trim are applicable to resistance values.

4.2.3 Evaluation based on Direct Power Method

To derive the speed/power performance of the vessel from the measured speed over ground, shaft torque and rpm, the Direct Power Method is to be used. In this method the measured power is directly corrected with the power increase due to added resistance in the trial conditions. The measured delivered power is:

$$P_{\mathrm{DM}} = P_{\mathrm{SM}}\eta_{\mathrm{s}} \tag{2}$$

with

P_{SM}: Shaft power measured for each run

η_S: Shaft efficiency (0.99 for conventional shaft)

The corrected delivered power is found from the measured shaft power by taking into account the propeller efficiency according to Appendix A:

$$P_{\mathrm{DC}} = P_{\mathrm{DM}} - \frac{\Delta R V_{\mathrm{SM}}}{\eta_{\mathrm{D0}}}\left(1 - \frac{P_{\mathrm{DM}}}{P_{\mathrm{DC}}}\xi_p\right) \tag{3}$$

with

V_{SM}: ship speed measured, means of means from double run

η_{D0}: propulsion efficiency coefficient in ideal condition, from model test.

ξ_p: derived from load variation model test.

ΔR: Resistance increase due to wind, waves and temperature deviations (eq. 1).

P_{DC} is the power in no wind and no other disturbance. For shallow water a speed correction is applied according to 4.3.4. Deviations in displacement are corrected for according to 4.3.5.

In the Direct Power Method the current is eliminated by averaging the results of double runs. Per set of measurements for one engine setting, after power correction, the average is determined by calculating the “mean of means” (ref. Principles of Naval Architecture[20]) of the corrected speed and power points.

From the corrected trial points the differences in speed with the fitted curve at the same power are derived. Plotting these speed differences on the basis of time for each trial run, a tidal curve can be fitted through these points. The purpose of creating this tidal curve is to have a quality control on the measured data.

The correction of the propeller frequency of revolution is also based on the results of the load variation tank tests (Appendix A). The corrected shaft rate n_C is

$$n_{\mathrm{C}} = \frac{n_{\mathrm{M}}}{\xi_n \dfrac{P_{\mathrm{DM}} - P_{\mathrm{DC}}}{P_{\mathrm{DC}}} + \xi_v \dfrac{\Delta V}{V_{\mathrm{SM}}} + 1} \tag{4}$$

with

n_{M}: measured propeller frequency of revolution,

V_{SM}: measured ship speed, means of means from double run

ξ_n, ξ_v: overload factors derived from load variation model test (Appendix A)

ΔV: speed correction due to shallow water, determined by according to 4.3.4.

If load variation tests are not available, the overload factors ξ_p, ξ_n *and* ξ_v may be obtained from statistical values from sufficient load variation tests for this specific ship type, size and propulsor. If these can not be provided, the overload factors may be derived by ITTC 7.5-02-03-01.4 (2011).

4.2.4 Prediction of power curve from ballast condition to full load or stipulated condition

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

The tank test results shall be provided by the Shipbuilder. These tank test results shall be obtained in full compliance with the requirements given in Section 7.5 of Part 1 of these Guidelines.

The conversion method to be followed to convert the trial results for ballast condition to results for full load or stipulated condition is given in Appendix E.

4.2.5 Presentation of the trial results

The corrected shaft and/or delivered power values, together with the associated, corrected speed values of runs at almost identical power level, but in opposite directions (double run), shall be combined and the mean values of speed, power and propeller rate of revolutions shall be used to derive the final results.

4.3 Calculation methods for resistance increase and other corrections

4.3.1 Resistance increase due to the effects of wind

The resistance increase due to relative wind is calculated by

$$R_{\mathrm{AA}} = \frac{1}{2} \rho_{\mathrm{A}} V_{\mathrm{WR}}{}^2 C_{\mathrm{X}}(\psi_{\mathrm{WR}}) A_{XV} \tag{5}$$

with

A_{XV}: area of maximum transverse section exposed to the wind,

C_{X}: wind resistance coefficient

Note: $CX_{=} - C_{\mathrm{A}}$ for method C.3

V_{WR}: relative wind speed,

ρ_{A}: mass density of air,

ψ_{WR}: relative wind direction; 0 means heading wind. See System of Co-ordinates in Part 1.

By nature wind speed and direction vary in time and therefore these are defined by their average values over a selected period.

For speed/power trials it is assumed that the wind condition is stationary i.e. that the speed and direction are reasonably constant over the duration of each double run. The average speed and direction during the double run are then determined for the duration of each measurement run.

The wind speed and direction are usually measured by the on-board anemometer, positioned mostly in the radar mast on top of the bridge. Both wind speed and direction at this location may be affected by the geometry of the vessel in particular the shape of the superstructure and the wheel house.

The true wind vector for each speed-run is found from the speed and heading of the vessel and the measured wind speed 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 averaged true wind vector is then used to recalculate the relative wind vector for each speed-run of the set. This procedure is explained in detail in Appendix B-1.

The wind speed as measured by the anemometer shall be corrected for the wind speed profile taking into account the height of the anemometer and the reference height for the wind resistance coefficients (normally 10 m) according to Appendix B-2.

The wind resistance coefficient shall be 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 can be used instead of carrying out model tests. Besides, a statistical regression formula concerning wind resistance coefficients of various ship types has been developed. The methods are mentioned in Appendix C.

4.3.2 Resistance increase due to the effects of waves

The most reliable way to determine the decrease of ship speed in waves is to carry out sea keeping tests in regular waves of constant wave height, and different wave lengths and directions at various speeds according to ITTC 7.5-02-07-02.2.

Irregular waves can be 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 mean resistance increase in regular waves R_{wave}.

$$R_{\mathrm{AW}} = 2\int_0^{2\pi}\int_0^{\infty}\frac{R_{\mathrm{wave}}(\omega,\alpha;V_{\mathrm{S}})}{\zeta_{\mathrm{A}}^{2}}E(\omega,\alpha)d\omega d\alpha \tag{6}$$

with

R_{AW}: mean resistance increase in short crested irregular waves,

R_{wave}: mean resistance increase in regular waves,

ζ_{A}: wave amplitude,

ω: circular frequency of regular waves,

α: angle between ship heading and incident regular waves; 0 means heading waves,

V_{S}: ship speed through the water,

E: directional spectrum; if the directional spectrum is measured at sea trials by a sensors and the accuracy is confirmed, the directional spectrum is available. If the directional spectrum is not measured it is calculated by the following relation:

$$E = S_{\mathrm{f}}(\omega)G(\alpha) \tag{7}$$

with

G: angular distribution function.

S_{f}: frequency spectrum, for ocean waves modified Pierson-Moskowitz type.

The standard form of the frequency spectrum and the angular distribution function are assumed for the calculation. The modified Pierson-Moskowitz frequency spectrum of ITTC 1978 shown in formula (8).

$$S_{\mathrm{f}}(\omega) = \frac{A_{\mathrm{f}}}{\omega^{-5}}\exp\left(-\frac{B_{\mathrm{f}}}{\omega^{4}}\right) \tag{8}$$

with

$$A_f = 173 \frac{H_{W1/3}^{\;2}}{T_1^4} \tag{9}$$

$$B_f = \frac{691}{T_1^4} \tag{10}$$

$$T_1 = 2\pi \frac{m_0}{m_1} \tag{11}$$

where
$H_{W1/3}$: significant wave height,
m_n: n^{th} moment of frequency spectrum.

For the angular distribution function the cosine-power type shown in formula (12) is generally applied; e.g. s=1 for seas and s=75 for swells are used in practice.

$$G(\alpha) = \frac{2^{2s}}{2\pi}\frac{\Gamma^2(s+1)}{\Gamma(2s+1)}\cos^{2s}\left(\frac{\theta-\alpha}{2}\right) \tag{12}$$

where
s: directional spreading parameter,
Γ: Gamma function,
θ: primary wave direction; 0 means heading waves.

For seas and swells R_{AW} is calculated for each run with different wave height, period and direction.

The resistance increase due to waves shall be determined by tank tests or formulae shown in Appendix D.

4.3.3 Resistance increase due to water temperature and salt content

Both, water temperature and salt content, affect the density of the sea water and thus the ship resistance; usually the prediction calculations of speed trials are based on a temperature of the sea water of 15°C and a density of 1025 kg/m³. The effects of water temperature and salt content are calculated as follows:

$$R_{AS} = R_{T0}\left(\frac{\rho}{\rho_0}-1\right) - R_F\left(\frac{C_{F0}}{C_F}-1\right) \tag{13}$$

with

$$R_F = \frac{1}{2}\rho S\, V_S^{\;2} C_F \tag{14}$$

$$R_{F0} = \frac{1}{2}\rho S V_S^{\;2} C_{F0} \tag{15}$$

$$R_{T0} = \frac{1}{2}\rho_0 S\, V_S^{\;2} C_{T0} \tag{16}$$

where
C_F: frictional resistance coefficient for actual water temperature and salinity,
C_{F0}: frictional resistance coefficient for reference water temperature and salinity,
C_{T0}: total resistance coefficient for reference water temperature and salinity,
R_{AS}: resistance increase due to deviation of water temperature and water density,
R_F: frictional resistance for actual water temperature and salt content,
R_{F0}: frictional resistance for reference water temperature and salt content,
R_{T0}: total resistance for reference water temperature and salt content,
S: wetted surface area,
V_S: ship's speed through the water,
ρ: water density for actual water temperature and salt content,
ρ_0: water density for reference water temperature and salt content.

4.3.4 Correction of the ship performance due to the effects of shallow water.

The formula (17) by Lackenby[(12)]. for the correction of shallow water effects results in a correction to the ship's speed.

$$\frac{\Delta V}{V} = 0.1242\left(\frac{A_M}{H^2} - 0.05\right) + 1 - \left(\tanh\frac{gH}{V^2}\right)^{1/2}$$

for $\frac{A_M}{H^2} \geq 0.05$ (17)

where
A_M: midship section area under water,
g: acceleration due to gravity,
H: water depth,
V: ship speed,
ΔV: decrease of ship speed due to shallow water.

4.3.5 Correction of the ship performance due to the effects of displacement and trim

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

Trim shall be maintained within very narrow limits. For the even keel condition the trim shall be less than 1.0% of the mid-ships draught. For the trimmed trial condition, the immergence of the bulbous bow on the ship shall be within 0.1 m compared to the model test condition, whereas the displacement shall be within 2% of the displacement of the model tested condition.

Ship resistance is known to be sensitive for trim in particular for cases where the bulbous bow or the transom is close to or protrudes the waterline. For such effects no reliable correction methods exist and therefore trim deviations shall be avoided during speed/power trials.

A practical formula which can be applied either to resistance- or power values is the Admiral-formula. This formula (37) has to be used in case the displacement of the vessel at the speed/power trial differs from the displacement at the relevant model test within the above mentioned limits.

$$\frac{P_1}{V_1^3 \Delta_1^{2/3}} = \frac{P_2}{V_2^3 \Delta_2^{2/3}} \quad (18)$$

where
P_1: power corresp. to displacement Δ_1,
P_2: power corresp. to displacement Δ_2,
V_1: speed corresponding to displacement Δ_1,
V_2: speed corresponding to displacement Δ_2.

5. PROCESSING OF THE RESULTS

After completion of the S/P Trials the measured data shall be processed in the following sequence (see also Part 1):

1. Derive the average values of each measured parameter for each Speed Run. The average speed is found from the DGPS recorded start and end positions of each Speed Run and the elapsed time;
2. The true wind speed and direction for each Double Run is derived by the method described in Appendix B;
3. Correction of power due to resistance increase due to wind described in Appendix C;
4. Correction of power due to resistance increase due to waves (Appendix D);
5. Correction of power due to resistance increase due to effect of water temperature and salinity (4.3.3);
6. Correction of power for the difference of displacement from the stipulated contractual and EEDI conditions (4.3.5);

7. Correction of the rpm and propulsive efficiency from the load variation model test results (4.2.3, Appendix A);
8. Average the speed, rpm and power over the two runs of each Double Run and over the Double Runs for the same power setting according to the “mean of means” method to eliminate the effect of current;
9. Check the current speed for each individual speed run by comparing the “Mean of Means” result at one power setting (step 8) with the results of the individual run;
10. Correction of speed due to the effect of shallow water(4.2.4);
11. Use the speed/power curve from the model tests for the specific ship design at the trial draught. Shift this curve along the power axis to find the best fit with all averaged corrected speed/power points (from step 8) according to the least squares method;
12. Intersect the curve at the specified power to derive the ship’s speed at trial draught in Ideal Conditions;
13. Apply the conversion to other stipulated load conditions according to 4.2.4;
14. Apply corrections for the contractual weather conditions if these deviate from Ideal Conditions.

6. REFERENCES AND BIBLIOGRAPHY

(1) ISO 15016, Ships and marine technology – Guidelines for the assessment of speed and power performance by analysis of speed trial data, 2002.

(2) JTTC, "A proposal for a standard method of speed trial analysis", Bull. SNAJ, No.262, 1944.

(3) "Guaranteed speed specifications and the analysis procedure", Notification No. 174 of the Ministry of Transport, Japan, 1955.

(4) Maruo H., "On the increase of the resistance of a ship in rough seas (2nd report)", J. SNAJ, Vol. 108, 1960.

(5) Taniguchi, K. & Tamura, K., "On a new method of correction for wind resistance relating to the analysis of speed trial results", 11th ITTC, 1966.

(6) JTTC, "A tentative guide for the operation of speed trials with large vessels", Bull. SNAJ, No. 442, 1966.

(7) ITTC Performance Committee, "ITTC guide for measured-mile trials", Report of the ITTC Performance Committee, Appendix I, 12th ITTC, 1969.

(8) "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.

(9) "A Study of ship speed trials", No. 2 Standardization Panel, SRAJ, Res. Rep. No. 12R, 1972.

(10) "Code for Sea Trials", SNAME, 1989.

(11) "BSRA standard method of Speed Trial Analysis", BSRA Report NS 466, 1978.

(12) Lackenby, H., "The Effect of Shallow Water on Ship Speed", Shipbuilder, 70, No. 672, 1963.

(13) ITTC Performance Committee, "Hull Roughness", Report of the ITTC Performance Committee, 19th ITTC, 1990.

(14) ITTC Powering Performance Committee, "An Updated Guide For Speed/Powering Trials", Report of the ITTC Powering Performance Committee, Appendix I, 21st ITTC, 1996.

(15) Japan Ship Research Association, "SR208: New Speed Trial Analysis Method", Report of the SR208 Committee, 1993.

(16) Fujiwara, T., Ueno, M. and Ikeda, Y.: "A New Estimation Method of Wind Forces and Moments acting on Ships on the basis of Physical Component Models", J. JASNAOE, Vol.2, 2005.

(17) Sea Trial Analysis Joint Industry Project: Recommended Analysis of Speed Trials, MARIN, 2006.

(18) Tsujimoto, M., Shibata, K., Kuroda, M. and Takagi K.: "A Practical Correction Method for Added Resistance in Waves", J. JASNAOE, Vol.8, 2008.

(19) Boom, H.van den, Huisman, H. and Mennen, F.:”New Guidelines for Speed/Power Trials” SWZ/Maritime, Jan./Feb.2013;

Hansa Int. Maritime Journal 150th year, No. 4, April 2013; Hansa-online.de/STA-JIP.pdf.

(20) “Principles of Naval Architecture”, Volume II, Section II, Ship Standardization Trials, SNAME 1988.

APPENDIX A. PROPULSIVE EFFICIENCY CORRECTION BASED ON LOAD VARIATION TESTS

A.1 propulsion efficiency correction

At the sea trial the following quantities are obtained on board:

- P_{SM} shaft power measured on board for each single run
- V_{SM} ship speed, means of means from double run
- ΔR_M resistance increase from wind, waves etc for each run. The value is computed according to section 4.3 in these Guidelines.

The measured delivered power is

$$P_{DM} = P_{SM}\eta_S \qquad \text{(A-1)}$$

with

η_S Shaft efficiency

(normally 0.99 for conventional shaft)

The delivered power corrected to ideal condition is derived by

$$P_{DC} = P_{DM} + \Delta P_{corr} \qquad \text{(A-2)}$$

with

ΔP_{corr} correction of delivered power due

- to the increased resistance and the
- changed propulsive efficiency

ΔP_{corr} can be written as

$$\Delta P_{corr} = -\frac{\Delta R_M V_{SM}}{\eta_{D0}} - P_{DM}\left(1-\frac{\eta_{DM}}{\eta_{D0}}\right) \qquad \text{(A-3)}$$

with

η_{D0} propulsion efficiency coefficient

- in ideal condition

η_{DM} propulsion efficiency coefficient

- during sea trial

The propulsion efficiency coefficient in ideal condition, η_{D0}, is obtained from standard towing tank test and interpolated to the speed V_{SM}.

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

$$\frac{\eta_{DM}}{\eta_{D0}} = \xi_p \frac{\Delta R_M}{R_0} + 1 \qquad \text{(A-4)}$$

where

- ξ_P is overload factor derived from load variation model test as described in section A.3.
- R_0 resistance in ideal condition

This leads to the expression for the corrected delivered power:

$$P_{DC} = P_{DM} - \frac{\Delta R_M V_{SM}}{\eta_{D0}}\left(1-\frac{P_{DM}}{P_{DC}}\xi_p\right) \qquad \text{(A-5)}$$

This is solved as:

$$P_{DC} = \frac{1}{2}\left\{ P_{DM} - \frac{\Delta R_M V_{SM}}{\eta_{D0}} + \sqrt{\left(P_{DM} - \frac{\Delta R_M V_{SM}}{\eta_{D0}} \right)^2 + 4 P_{DM} \frac{\Delta R_M V_{SM}}{\eta_{D0}} \xi_p } \right\} \quad \text{(A-6)}$$

Note that V_{SM} is the mean of double runs to eliminate the effect of current, or mean of means in case of quadruple runs.

A.2 Correction on shaft rotation rate – effect of added resistance and of shallow water

With the P_{DC} found as described above the correction on shaft rate is

$$\frac{\Delta n}{n_C} = \xi_n \frac{P_{DM} - P_{DC}}{P_{DC}} + \xi_v \frac{\Delta V}{V_{SM}} \quad \text{(A-7)}$$

where

$$\Delta n = n_M - n_C \quad \text{(A-8)}$$

with

n_M measured rpm

n_C corrected rpm

$\xi n, \xi v$ overload factors derived from load variation model test as described in section A.3.

ΔV speed correction due to shallow water, determined by equation (17) in Guidelines

From this follows that the corrected shaft rate n_C is

$$n_C = \frac{n_M}{\xi_n \frac{P_{DM} - P_{DC}}{P_{DC}} + \xi_v \frac{\Delta V}{V_{SM}} + 1} \quad \text{(A-9)}$$

A.3 Load variation test

It is assumed that propeller open water test, resistance and self-propulsion tests are carried out at trial draught and evaluated according to the tanks normal procedures. In addition, a load variation test is carried out at the trial draught and at 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 load variation test includes at least 4 self-propulsion test runs, each one at a different rate of revolution while keeping the speed constant. The rate of revolutions are to be selected such that

$$\frac{\Delta R}{R_0} \approx [-0.1 \quad 0 \quad +0.1 \quad +0.2] \text{-} \quad \text{(A-10)}$$

where-

$$\Delta R = \left(F_D - F_X \right) \lambda^3 \frac{\rho_S}{\rho_M} \text{-} \quad \text{(A-11)}$$

R_0 full scale resistance R_{TS} at the actual speed, from resistance test
F_X external tow force, measured during load variation test
F_D skin friction correction force, same as in the normal self-propulsion tests
λ scale factor
ρ_S,ρ_M-water density in full scale and model test

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_D, the measured data is processed according to the mentioned procedure with one modification: from section 2.4.3 and onwards.

C_{TS} is replaced by C_{TSAdd}

with

$$C_{TSAdd} = C_{TS} + \frac{\Delta R}{\frac{1}{2}\rho_s (V_s)^2 S_s} \qquad \text{(A-12)}$$

where

V_S full scale ship speed

S_S full scale wetted surface, same values as used in 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_s, P_{DS}, η_{OS}, and η_D.

Dependency of propulsion efficiency with resistance increase

The fraction between the propulsion efficiency η_{DM} from the load variation test and that from the normal self-propulsion test η_D is plotted against the added resistance fraction $\Delta R/R_0$ (with ideal condition R_0 in the nominator). Figure A.1 shows an example. The variable ξ_p is the slope of the linear curve going through {0,1} and fitted to the data points with least square method.

Dependency of shaft rate with power increase

Similarly, the effect on shaft rate $\Delta n/n$ is plotted against $\Delta P/P_{D0}$ (with ideal condition n and P_D in the nominators). The variable ξ_n is the slope of the linear curve going through {0,0} and fitted to the data points with least square method. Figure A.2 gives an example.

Dependency of shaft rate with speed change

The shaft rate n from the load variation test is plotted against the resistance $R_0 + \Delta R$. The corresponding curves for other speeds are assumed to be parallel to this line (red lines in Figure 3) and go through the point { R_0 , n} from the calm water self-propulsion test (red *). The intersection of these lines with a constant resistance gives the rpm dependency of speed (green squares □). The slope of the $\Delta n/n$ - $\Delta V/V$ curve fitted with least square method is ξ_v (Figure A.3).

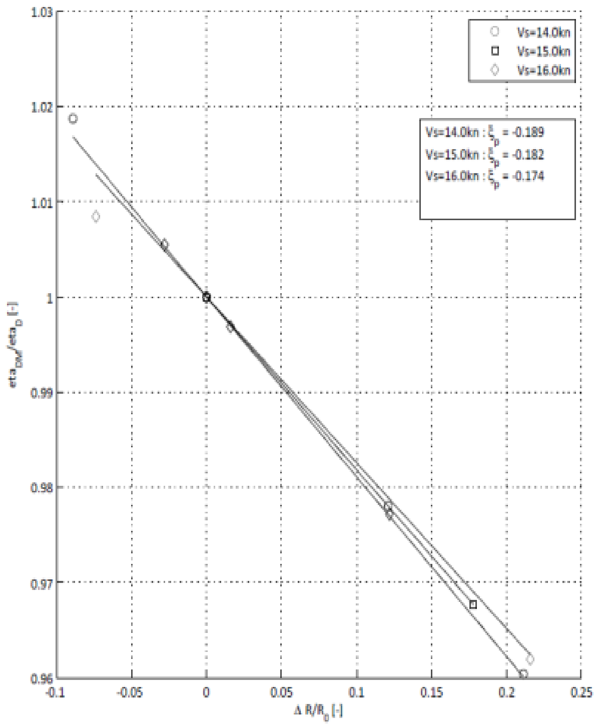


Figure A.1 Relation between propeller efficiency and resistance increase

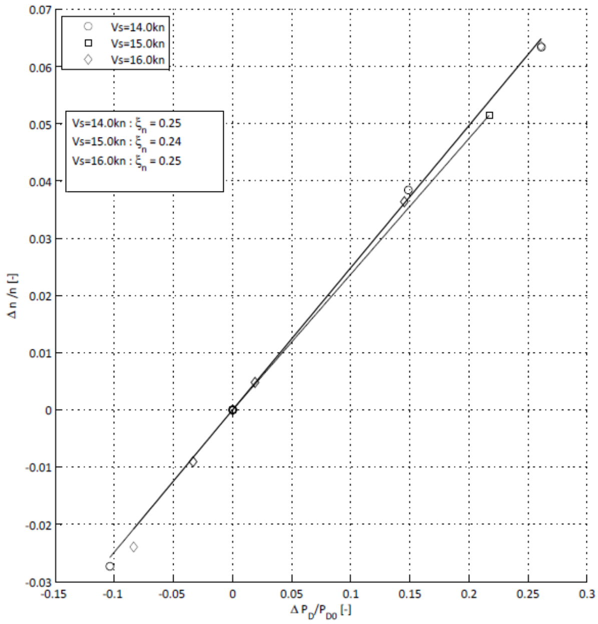


Figure A.2 Relation between propeller rate and power increase

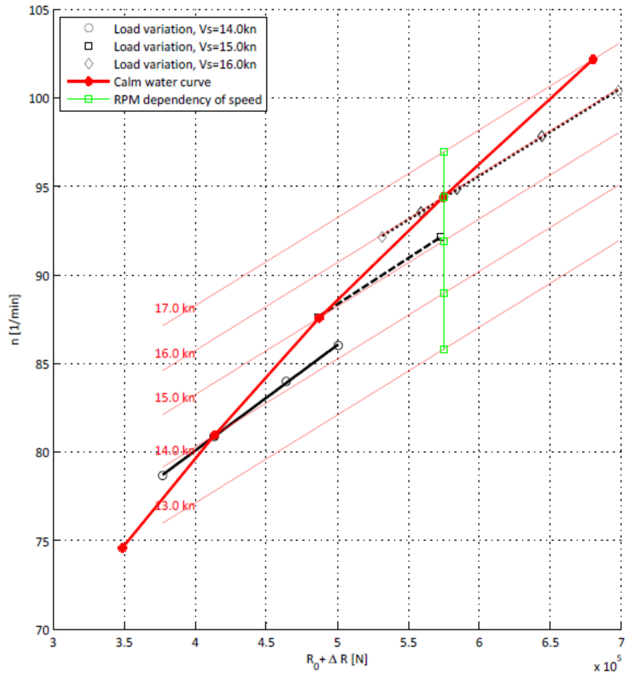


Figure A.3 Relation between propeller rate and speed change

APPENDIX B. EVALUATION OF WIND DATA

B.1 Averaging process for the true wind vectors

The true wind vectors in each run are found from the speed and heading of the vessel and the measured wind speed and direction. By averaging the true wind vectors over both runs of the double run, the true wind vector for the run-set is found. This averaged true wind vector is then used to recalculate the relative wind vector for each run of the set.

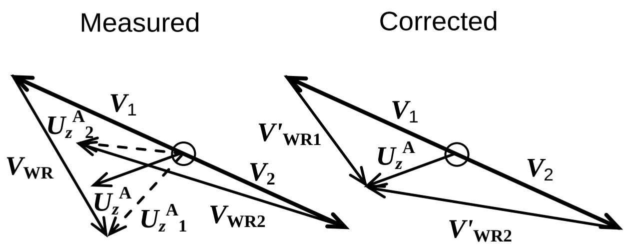


Figure B-1 True wind vectors and relative wind vectors.

The averaging procedure of the wind vectors is explained by Figure B-1 where:

U_z^A: averaged true wind vector,

$U_z^A{}_1$: true wind vector at a run 1,

$U_z^A{}_2$: true wind vector at a run 2,

V_1: ship movement vector at a run 1,

V_2: ship movement vector at a run 2,

V_{WR1}: measured relative wind vector at run 1,

V_{WR2}: measured relative wind vector at run 2,

B.2 Correction for the height of the anemometer

The difference between the height of the anemometer and the reference height is to be corrected by means of the wind speed profile given by formula (B-1).

$$U_z^A(z_{ref}) = U_z^A(z)\left(\frac{z_{ref}}{z}\right)^{1/7} \tag{B-1}$$

where

$U_z^A(z)$: wind speed at height z,

z_{ref}: reference height.

The reference height is selected as the corresponding height for the specific wind resistance coefficient from wind tunnel tests (normally 10 m).

APPENDIX C. CORRECTION METHODS FOR RESISTANCE INCREASE DUE TO WIND

For calculating the resistance increase due to wind the following methods are to be used:

C.1 Wind resistance coefficients by wind tunnel test

If wind resistance tests for the specific vessel have been performed in a qualified wind tunnel, the wind resistance coefficients derived by these measurements shall be used to compute the wind resistance of the vessel in the trial condition.

C.2 Data sets of wind resistance coefficients

Data sets of the wind resistance coefficients have been collected by STA-JIP(19).

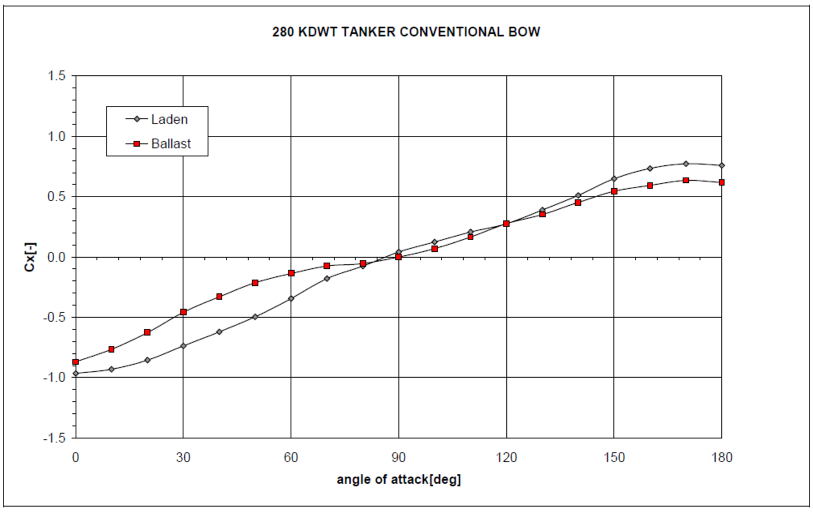
Data sets are available for tankers/bulkers, LNG carriers, container ships, car carriers, ferries/cruise ships and general cargo ships as shown in Table C-1. The wind resistance coefficients for each ship type are shown in Fig. C-1.

For the use of these coefficients the vessel type, shape and outfitting shall be carefully evaluated and compared with the geometry of the vessel from the data set. The data provided are limited to the present-day common ship types. For special vessels such as tugs, supply ships, fishery vessels and fast crafts, the geometry of the vessel is too specific to make use of the available database wind tunnel results for the specific shiptype are required.

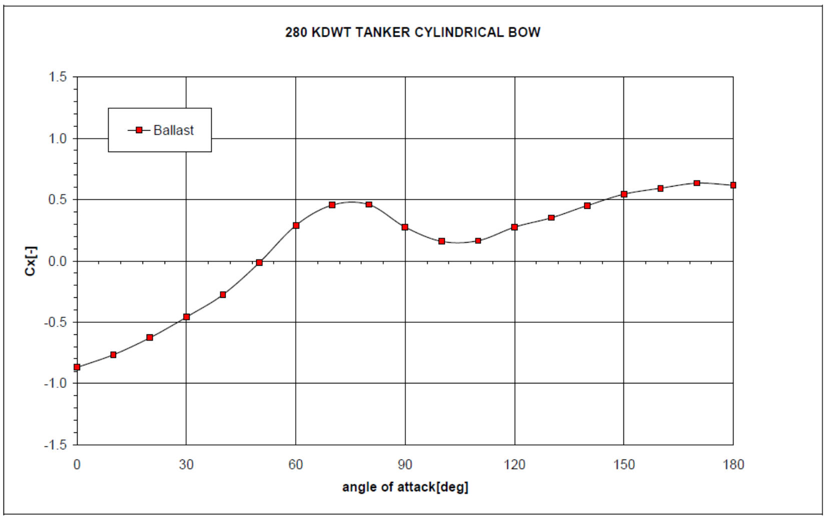
Table C-1 Ship type for the wind resistance data set

Ship type	LC	Superstructure	Test vessel
Tanker/bulker conventional bow	L	normal	280kDWT
Tanker/bulker conventional bow	B	normal	280kDWT
Tanker/bulker cylindrical bow	B	normal	280kDWT
LNG carrier	A	prismatic integrated	125k-m^3
LNG carrier	A	prismatic extended deck	138k-m^3
LNG carrier	A	spherical	125k-m^3
Container ship	L	with containers	6800TEU
Container ship	L	without containers, with lashing bridges	6800TEU
Container ship	B	with lashing bridges	6800TEU
Container ship	B	without lashing bridges	6800 TEU
Car Carrier	A	normal	Autosky
Ferry/Cruise ship	A	normal	
General Cargo ship	A	normal	

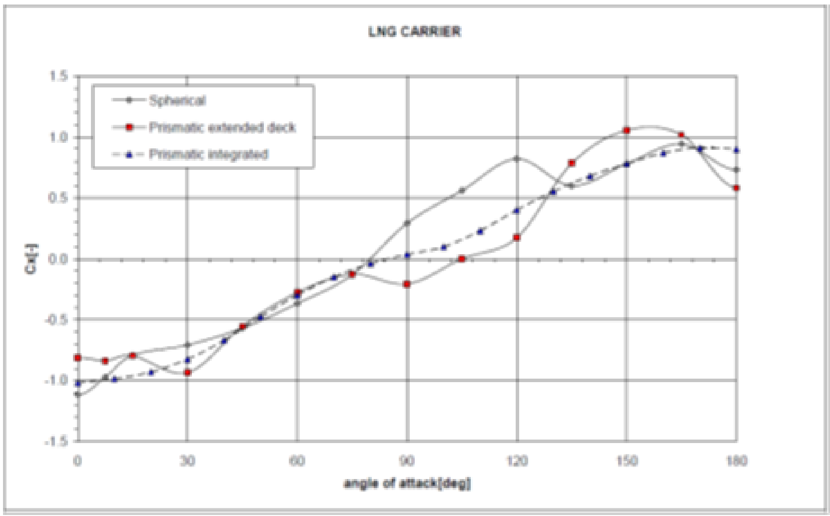
LC = Loading Condition
L = Laden
B = Ballast
A = Average



280 KDWT TANKER CONVENTIONAL BOW
Laden
Ballast
Cx[-]
angle of attack[deg]

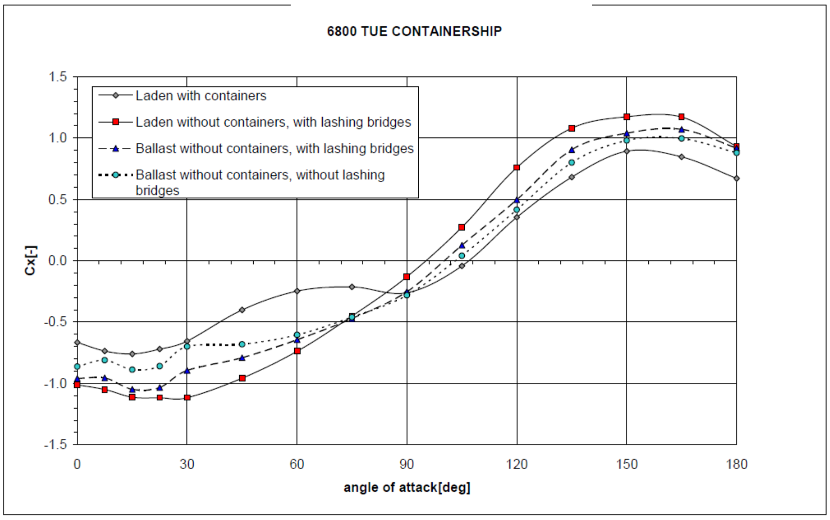


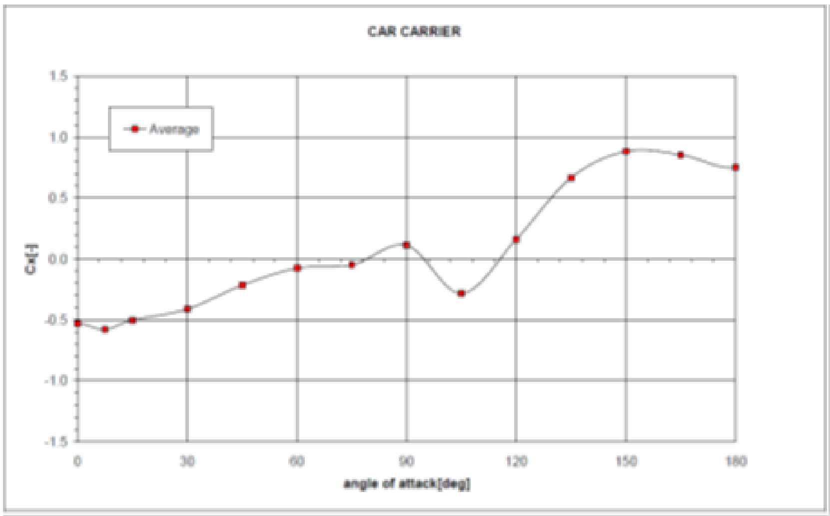
280 KDWT TANKER CYLINDRICAL BOW
Ballast
Cx[-]
angle of attack[deg]

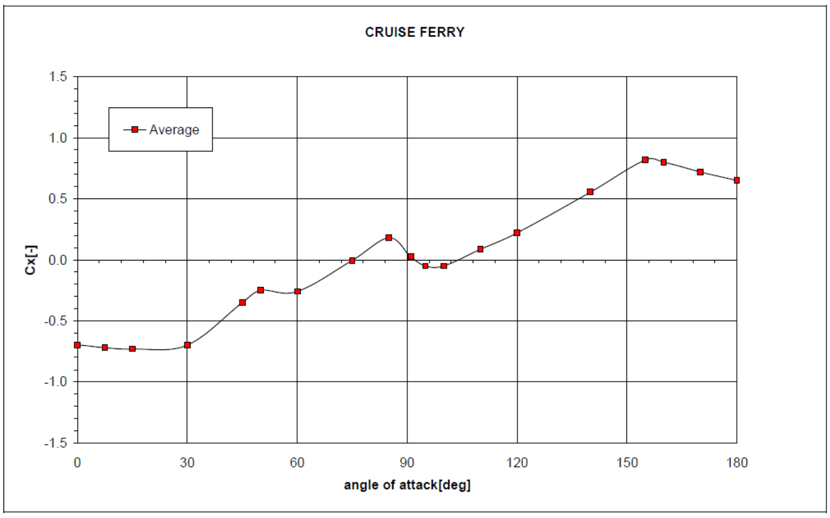


LNG CARRIER
Spherical
Prismatic extended deck
Prismatic integrated
angle of attack[deg]

6800 TEU CONTAINERSHIP







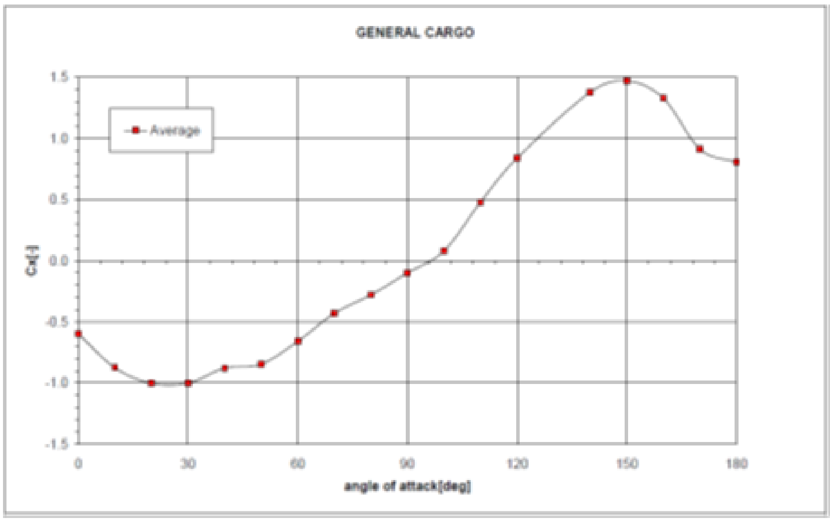


Fig.C-1 Wind resistance coefficients for various ship types[19].

C.3 Regression formula by Fujiwara et al.

A general regression formula based on model tests in wind tunnels for various ships has been developed by Fujiwara et al.[16].

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

with

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

$$C_{LF} = \beta_{10} + \beta_{11}\frac{A_{YV}}{L_{OA}B} + \beta_{12}\frac{C_{MC}}{L_{OA}} \quad \text{(C-2)}$$

$$C_{XLI} = \delta_{10} + \delta_{11}\frac{A_{YV}}{L_{OA}h_{BR}} + \delta_{12}\frac{A_{XV}}{Bh_{BR}} \quad \text{(C-3)}$$

$$C_{ALF} = \varepsilon_{10} + \varepsilon_{11}\frac{A_{OD}}{A_{YV}} + \varepsilon_{12}\frac{B}{L_{OA}} \quad \text{(C-4)}$$

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

$$C_{XLI} = \delta_{20} + \delta_{21}\frac{A_{YV}}{L_{OA}h_{BR}} + \delta_{22}\frac{A_{XV}}{A_{YV}} + \delta_{23}\frac{B}{L_{OA}} + \delta_{24}\frac{A_{XV}}{Bh_{BR}} \quad \text{(C-5)}$$

$$C_{LF} = \beta_{20} + \beta_{21}\frac{B}{L_{OA}} + \beta_{22}\frac{h_C}{L_{OA}} + \beta_{23}\frac{A_{OD}}{L_{OA}^2} + \beta_{24}\frac{A_{XV}}{B^2} \quad \text{(C-6)}$$

$$C_{ALF} = \varepsilon_{20} + \varepsilon_{21}\frac{A_{OD}}{A_{YV}} \quad \text{(C-7)}$$

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

$$C_{AA}\big|_{\psi_{WR}=90(\text{deg.})} = \frac{1}{2}\left(C_{AA}\big|_{\psi_{WR}=90(\text{deg.})-\mu} + C_{AA}\big|_{\psi_{WR}=90(\text{deg.})+\mu}\right)$$

where

A_{OD}: lateral projected area of superstructures etc. on deck,

A_{XV}: area of maximum transverse section exposed to the winds,
A_{YV} projected lateral area above the waterline,
B: ship breadth,
C_{AA}: wind resistance coefficient,
C_{MC}: horizontal distance from midship section to centre of lateral projected area A_{YV},
h_{BR}: height of top of superstructure (bridge etc.),
h_C: height from waterline to centre of lateral projected area A_{YV},
L_{OA}: length overall,
μ: smoothing range; normally 10(deg.),
ψ_{WR}: relative wind direction; 0 means heading winds.

The non-dimensional parameters β_{ij}, δ_{ij} and ε_{ij} used in the formulae are shown in Table C-2.

	j				
	0	1	2	3	4
β_{ij}	0.922	-0.507	-1.162	-	-
	-0.018	5.091	-10.367	3.011	0.341
δ_{ij}	-0.458	-3.245	2.313	-	-
	1.901	-12.727	-24.407	40.310	5.481
ε_{ij}	0.585	0.906	-3.239	-	-
	0.314	1.117	-	-	-

Table C-2 Non-dimensional parameters

The system of co-ordinates and the sign conventions and explanation of the input parameters are shown in Fig C.2

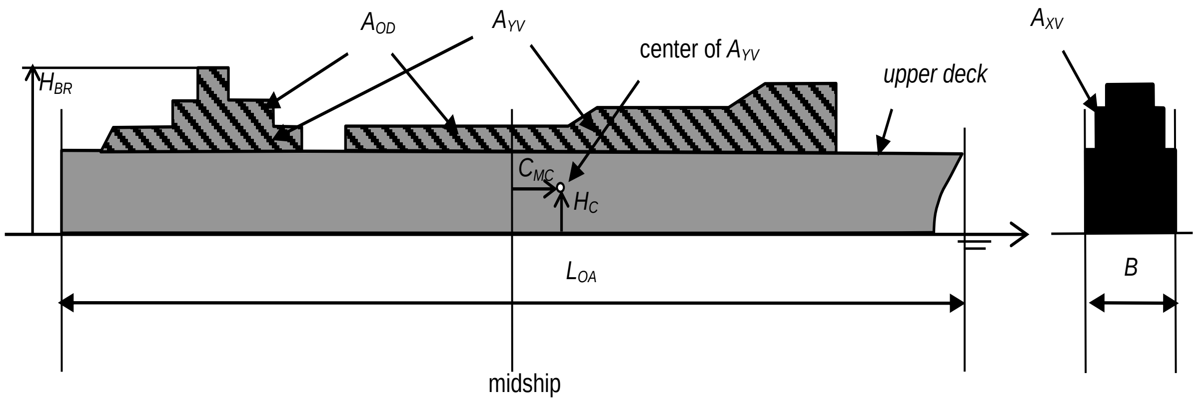


Figure C.2 Input parameters for regression formula by Fujiwara

APPENDIX D. CORRECTION METHODS FOR RESISTANCE INCREASE DUE TO WAVES

D.1 Direct correction method STAwave-1

Specifically for speed trial conditions with present day ships a dedicated and practical method has been developed by STA-JIP [19] to estimate the added resistance in waves with limited input data.

Speed trials are conducted in low to mild sea states with restricted wave heights. In short 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 (Fig D.1).

Formula (D-1) estimates the resistance increase in head waves provided that heave and pitching are small. The application is restricted to waves in the bow sector (within +/- 45 deg. off bow). For wave directions outside this sector no wave correction is applied.

$$R_{\mathrm{AWL}} = \frac{1}{16}\rho g H_{\mathrm{W1/3}}^{2} B \sqrt{\frac{B}{L_{\mathrm{BWL}}}} \qquad \text{(D-1)}$$

where

B: beam of the ship

$H_{\mathrm{W1/3}}$: significant wave height,

L_{BWL}: Length of the bow on the water line to 95% of maximum beam as shown in Fig.D-1,

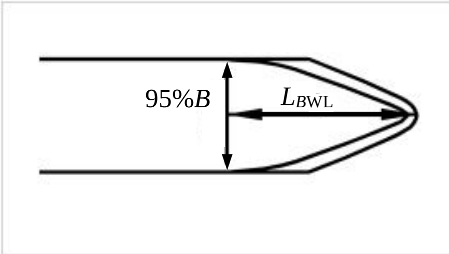


Fig.D-1 Definition of L_{BWL}

STAwave-1 has been extensively validated for the following conditions:

1. Significant wave height; $H \leq 2.25\sqrt{L_{pp}/100}$
2. Heave and pitch during speed/power trial are small; (vertical acceleration at bow < 0.05g)
3. Head waves;

The wave corrections are thus restricted to wave directions in the bow sector to ±45 (deg.) off bow. Wave within this sector are corrected as head waves. Waves outside the ±45 (deg.) sector are not corrected for.

D.2 Empirical transfer function STAwave-2

The empirical method STAwave-2[19] has been developed by STA-JIP to approximate the transfer function of the mean resistance increase in heading regular waves by using the main parameters such as ship dimensions and speed, see Fig.D-2. For this purpose an extensive seakeeping model test results for large population of ships has been used to derive parametric transformation functions.

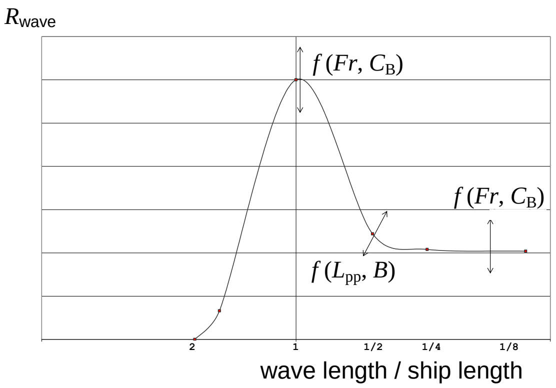


Fig.D-2 Parametric transfer function of meanresistance increase in regular waves.

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

$$R_{\text{AWM}} = 4\rho g {\zeta_A}^2 B^2 / L_{pp} \overline{raw}(\omega) \quad \text{(D-2)}$$

With

$$\overline{raw}(\omega) = \bar{\omega}^{b_1} \exp\left\{\frac{b_1}{d_1}\left(1-\bar{\omega}^{d_1}\right)\right\} a_1 Fr^{1.50} \exp\left(-3.50 Fr\right) \quad \text{(D-3)}$$

$$\bar{\omega} = \frac{\sqrt{\dfrac{L_{PP}}{g}} \sqrt[3]{k_{yy}}}{1.17 Fr^{-0.143}} \omega \quad \text{(D-4)}$$

$$a_1 = 60.3 {C_B}^{1.34} \quad \text{(D-5)}$$

$$b_1 = \begin{cases} 11.0 & \text{for } \bar{\omega} < 1 \\ -8.50 & \text{elsewhere} \end{cases} \quad \text{(D-6)}$$

$$d_1 = \begin{cases} 14.0 & \text{for } \bar{\omega} < 1 \\ -566\left(\dfrac{L_{PP}}{B}\right)^{-2.66} & \text{elsewhere} \end{cases} \quad \text{(D-7)}$$

and

$$R_{\text{AWR}} = \frac{1}{2}\rho g {\zeta_A}^2 B \alpha_1(\omega) \quad \text{(D-8)}$$

$$\alpha_1(\omega) = \frac{\pi^2 {I_1}^2 (1.5kT_M)}{\pi^2 I_1^2 (1.5kT_M) + K_1^2 (1.5kT_M)} f_1 \quad \text{(D-9)}$$

$$f_1 = 0.692\left(\frac{V_S}{\sqrt{T_M g}}\right)^{0.769} + 1.81 {C_B}^{6.95} \quad \text{(D-10)}$$

where:

C_B: block coefficient,

k_{yy}: non dimensional radius of gyration in lateral direction,

L_{pp}: ship length between perpendiculars,

T_M: draught at midship,

I_1: modified Bessel function of the first kind of order 1,

K_1: modified Bessel function of the second kind of order 1,

With the following restrictions:

1. $75(\text{m}) < L_{pp} < 350(\text{m})$,
2. $4.0 < \dfrac{L_{pp}}{B} < 9.0$,
3. $2.2 < \dfrac{B}{T} < 5.5$,
4. $0.10 < Fr < 0.30$,

5. $0.50 < C_B < 0.90$ and
6. wave direction within 0 to ±45 deg. from bow.

The method is applicable to the mean resistance increase in long crested irregular head waves R_{AWL}, formula (D-11). The wave corrections are thus restricted to wave directions in the bow sector to ±45 (deg.) off bow. Waves within this sector are corrected as head waves. Waves outside the ±45 (deg.) sector are not corrected for.

$$R_{\mathrm{AWL}} = 2\int_0^\infty \frac{R_{\mathrm{wave}}(\omega;V_S)}{\zeta_{\mathrm{A}}^2} S_{\mathrm{f}}(\omega) d\omega \tag{D-11}$$

D.3 THEORETICAL METHOD WITH SIMPLIFIED TANK TESTS

Applying the theoretical formula, the mean resistance increase in regular waves R_{wave} is calculated from the components of the mean resistance increase based on Maruo's theory R_{AWM} and its correction term which primarily is valid for short waves R_{AWR}.

$$R_{\mathrm{wave}} = R_{\mathrm{AWM}} + R_{\mathrm{AWR}} \tag{D-12}$$

with

R_{AWM}: mean resistance increase in regular waves based on Maruo's theory(4), which is mainly induced by ship motion.

R_{AWR}: mean resistance increase due to wave reflection for correcting R_{AWM}. R_{AWR} should be calculated with accuracy because the mean resistance increase in short waves is predominant one.

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

$$R_{\mathrm{AWM}} = 4\pi\rho\left(-\int_{-\infty}^{m_3} + \int_{m_4}^{\infty}\right)\left|H_1(m)\right|^2 \frac{(m+K_0\Omega_{\mathrm{E}})^2(m+K\cos\alpha)}{\sqrt{(m+K_0\Omega_{\mathrm{E}})^4 - m^2K_0^{\ 2}}}\, dm \quad \text{for } \Omega_{\mathrm{E}} \geq \frac{1}{4} \tag{D-13}$$

$$R_{\mathrm{AWM}} = 4\pi\rho\left(-\int_{-\infty}^{m_3} + \int_{m_4}^{m_2} + \int_{m_1}^{\infty}\right)\left|H_1(m)\right|^2 \frac{(m+K_0\Omega_{\mathrm{E}})^2(m+K\cos\alpha)}{\sqrt{(m+K_0\Omega_{\mathrm{E}})^4 - m^2K_0^{\ 2}}}\, dm \quad \text{for } \Omega_{\mathrm{E}} < \frac{1}{4} \tag{D-14}$$

with

$$\Omega_{\mathrm{E}} = \frac{\omega_{\mathrm{E}} V_{\mathrm{S}}}{g} \tag{D-15}$$

$$K = \frac{\omega^2}{g} \tag{D-16}$$

$$K_0 = \frac{g}{V_{\mathrm{S}}^{\ 2}} \tag{D-17}$$

$$\omega_{\mathrm{E}} = \omega + K V_{\mathrm{S}} \cos\alpha \tag{D-18}$$

$$m_1 = \frac{K_0\left(1 - 2\Omega_{\mathrm{E}} + \sqrt{1-4\Omega_{\mathrm{E}}}\right)}{2} \tag{D-19}$$

$$m_2 = \frac{K_0\left(1 - 2\Omega_{\mathrm{E}} - \sqrt{1-4\Omega_{\mathrm{E}}}\right)}{2} \tag{D-20}$$

$$m_3 = -\frac{K_0\left(1 + 2\Omega_{\mathrm{E}} + \sqrt{1+4\Omega_{\mathrm{E}}}\right)}{2} \tag{D-21}$$

$$m_4 = -\frac{K_0\left(1 + 2\Omega_{\mathrm{E}} - \sqrt{1+4\Omega_{\mathrm{E}}}\right)}{2} \tag{D-22}$$

$$H_1(m) = \int_L \sigma(x)\, \mathrm{e}^{imx}\, dx \tag{D-23}$$

where

- g: gravitational acceleration,
- $H_1(m)$: function to be determined by the distribution of singularities which represents periodical disturbance by the ship,
- V_S: ship speed through the water,
- α: encounter angle of incident waves (0 deg. means head waves),
- ρ: density of fluid,
- ω: circular wave frequency,
- ω_E: circular wave frequency of encounter.

The expression of R_{AWR} is given by Tsujimoto et al.(18) 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.

$$R_{AWR} = \frac{1}{2}\rho g \zeta_A{}^2 B B_f \alpha_T (1 + C_U Fr) \qquad \text{(D-24)}$$

where

- B: ship breadth,
- B_f: bluntness coefficient,
- C_U: coefficient of advance speed,
- Fr: Froude number,
- α_T: effect of draught and encounter frequency,
- ζ_A: wave amplitude.

with

$$\alpha_T = \frac{\pi^2 I_1{}^2(k_e T)}{\pi^2 I_1^2(k_e T) + K_1^2(k_e T)} \qquad \text{(D-25)}$$

$$k_e = k\left(1 + \Omega\cos\alpha\right)^2 \qquad \text{(D-26)}$$

$$\Omega = \frac{\omega V_S}{g} \qquad \text{(D-27)}$$

$$B_f = \frac{1}{B}\left\{\int_I \sin^2(\alpha + \beta_w)\sin\beta_w dl + \int_{II} \sin^2(\alpha - \beta_w)\sin\beta_w dl\right\} \qquad \text{(D-28)}$$

where

- I_1: modified Bessel function of the first kind of order 1,
- K_1: modified Bessel function of the second kind of order 1,
- k: wave number,
- T: draught; for a trim condition T is the deepest draught,
- β_w: slope of the line element dl along the water line and domains of the integration (I & II) are shown in Fig.D-3.

When B_f <0, then R_{wave}= 0 is assumed.

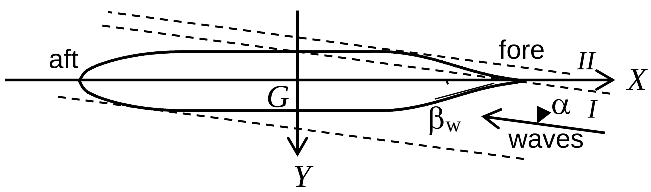


Fig.D-3 Coordinate system wave reflection.

The coefficient of the advance speed in oblique waves $C_U(\alpha)$ is calculated on the basis of the empirical relation line shown in Fig. D-4[1], which has been obtained by tank tests of various ship types following to the procedures in the

$$C_U = \frac{1}{Fr}\left\{\frac{R_{wave}^{EXP}(Fr) - R_{AWM}(Fr)}{\frac{1}{2}\rho g \zeta_A{}^2 B B_f \alpha_T} - 1\right\} \qquad \text{(D-29)}$$

[1] The empirical relation line in Fig.D-4 was obtained as follows. C_U is derived from the result of tank tests and R_{AWM}, as formula (D-29).

next paragraph. When $C_U(\alpha=0)$ is obtained by tank tests the relation used in oblique waves is shifted parallel to the empirical relation line. This is illustrated in Fig.D-5 for both fine and blunt ships.

The aforementioned coefficient $C_U(\alpha=0)$ is determined by tank tests which should be carried out in short waves since R_{AWR} is mainly effected by short waves. The length of short waves should be $0.5L_{PP}$ or less. The coefficient of advance speed C_U is determined by the least square method through the origin against Fr; see Fig.D-6.

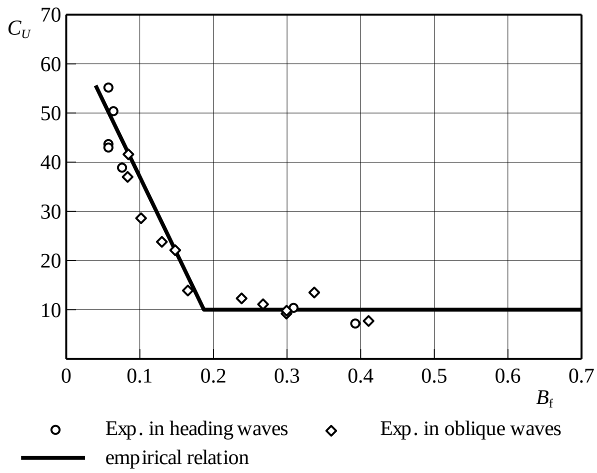


Fig.D-4 Relation between the coefficient of advance speed on added resistance due to wave reflection and the bluntness coefficient for conventional hull form above water.

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

When tank tests are not carried out, the coefficient of advance speed in head waves C_U ($\alpha = 0$) is calculated by the following empirical relations, formulae (D-31) and (D-32), shown in Fig.D-4. The formulae are suitable for all ships.

$$C_U(\alpha=0) = -310B_f + 68 \quad \text{for} \quad B_f < 58/310 \tag{D-31}$$

$$C_U(\alpha=0) = 10 \quad \text{for} \quad B_f \geq 58/310 \tag{D-32}$$

with

R_{wave}^{EXP}: mean resistance increase in regular waves measured in the tank tests.

In calculating R_{AWM} the strength of the singularity σ is calculated by the formulation of slender body theory as formula (D-30) and the singularity is concentrated at depth of $C_{VP}T_M$.

$$\sigma = -\frac{1}{4\pi}\left(\frac{\partial}{\partial t} - V_S\frac{\partial}{\partial x}\right)\{Z_r(x)B(x)\} \tag{D-30}$$

with

$B(x)$: sectional breadth,
C_{VP}: vertical prismatic coefficient,
t: time,
T_M: draught at midship,
x: longitudinal coordinate,
Z_r: vertical displacement relative to waves in steady motion.

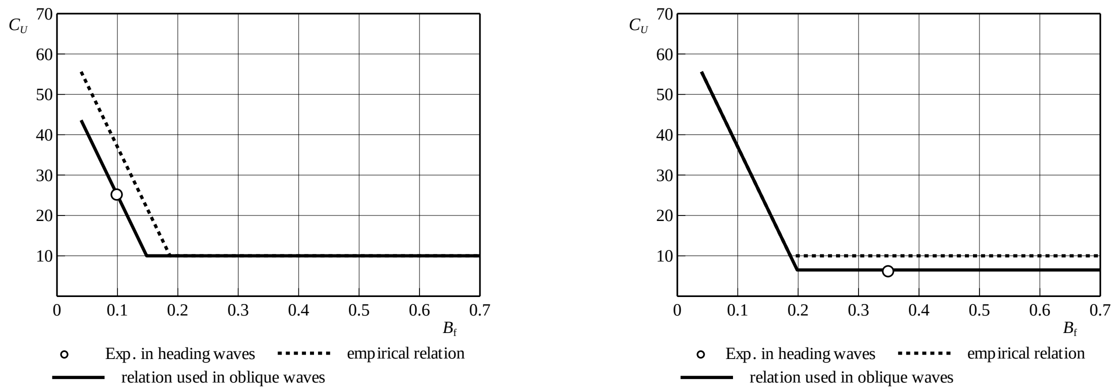


Fig.D-5 Shift of the empirical relation in oblique waves (upper; for fine ship $B_f < 58/310$, lower; for blunt ship $B_f \geq 58/310$).

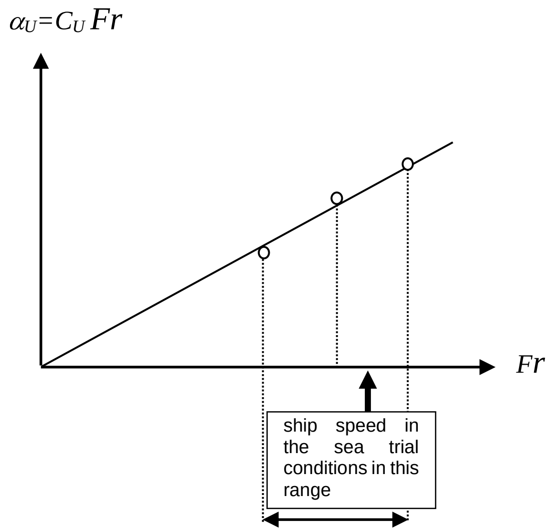


Fig.D-6 Relation between effect of advance speed (α_U=C_UFr) and Froude number Fr.

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 vessel geometry at the trial draughts and trim; and at contractual draughts if required. A minimum of two different ship speeds 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 should 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°-90°) but may be larger for beam to following seas (90°-180°).

These tests shall be performed for a combination of circular frequency of regular waves (ω), angle between ship heading and incident regular waves (α) and ship speed through the water (V_S) based on the following: A minimum of 5 wave lengths in the range of $0.5L_{PP}$ or less to $2.0L_{PP}$. The test set-up and procedure shall follow ITTC 7.5-02 07-02.2.

APPENDIX E. CONVERSION FROM BALLAST SPEED/POWER TEST RESULTS TO OTHER STIPULATED LOAD CONDITIONS

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

The power curve at full load/stipulated condition is obtained from the results of the speed trials at ballast condition using the power curves predicted by model tank tests. The tank tests should be carried out at both draughts: ballast condition corresponding to that of the speed trials and full load/stipulated condition.

Using the power curve obtained by the speed trials at ballast condition, the conversion on ship speed from ballast condition to full load condition to be carried out by the power ratio α_P defined in formula (E-1). The adjusted power at full load condition ($P_{\mathrm{Full,S}}$) is calculated by formula (E-2).

$$\alpha_{\mathrm{P}} = \frac{P_{\mathrm{Ballast,P}}}{P_{\mathrm{Ballast,S}}} \quad \text{(E-1)}$$

$$P_{\mathrm{Full,S}} = \frac{P_{\mathrm{Full,P}}}{\alpha_{\mathrm{P}}} \quad \text{(E-2)}$$

where

$P_{\mathrm{Ballast,P}}$: predicted power at ballast condition by tank tests,
$P_{\mathrm{Ballast,S}}$: power at ballast condition obtained by the speed trials,
$P_{\mathrm{Full,P}}$: predicted power at full load condition by tank tests,
$P_{\mathrm{Full,S}}$: power at full load condition,
α_{P}: power ratio.

Fig.E-1 shows an example of the conversion to derive the resulting ship speed at full load condition ($V_{\mathrm{Full,S}}$) at 75%MCR.

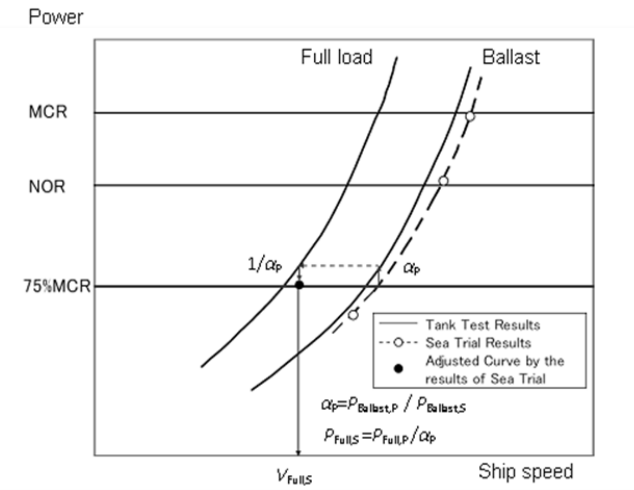


Fig.E-1 An example of ship speed adjustment using power ratio.

APPENDIX F. NOMENCLATURE

A_E/A_O	blade area ratio [-]
A_X	transverse area above water [m²]
A_M:	midship section area under water [m²]
A_R	rudder area
A_T	submerged area transom [m²]
A_{XV}	area of maximum transverse section exposed to the winds [m²]
B	ship breadth [m]
B_f	bluntness coefficient [-]
b_R:	rudder span [m]
C	coefficient for starboard and port rudder [-]
C_{AAjj}	measured wind resistance coefficient at wind tunnel [-]
$\hat{C}_{AAij}$	estimated wind resistance coefficient [-]
$C_{AA}(\psi_{WR})$:	wind resistance coefficient
C_B	block coefficient
C_F	frictional resistance coefficient for actual water temperature and salt content [-]
C_{F0}	frictional resistance coefficient for reference water temperature and salt content. [-]
C_M	midship area coefficient [-]
$C_{n\mathrm{margin}}$	rpm margin in percent rpm at NCR [%]
C_{PA}	prismatic coefficient of aft part (from midship to A.P.) [-]
C_{SEAMAR}	sea margin in percentage NCR [%]
C_{T0}	total resistance coefficient for reference water temperature and salt content, [-]
C_U	coefficient of advance speed [-]
C_{WA}	water plane area coefficient of aft part (from midship to A.P.) [-]
C_{WL}	prismatic waterline coefficient [-]
D	diameter of the actual full scale propeller [m]
D	depth, moulded, of a ship hull [m]
E:	directional sea spectrum
Fr	Froude number [-]
G	angular distribution function [-]
g	gravitational acceleration [m/s²]
h	waterdepth [m]
h_{ANEMO}	height anemometer above water [m]
h_R	rudder height [m]
$H_{S1/3}$	sum of significant wave height of swell and wind driven seas [m]
$H_{W1/3}$	significant wave height [m]
I_1	modified Bessel function of the first kind of order 1 [-]
J	propeller advance ratio [-]
K_Q	propeller torque coefficient [-]
K_T	propeller thrust coefficient [-]
K_1	modified Bessel function of the second kind of order 1[-]
k	wave number [-]
k_{YY}	non dimensional longitudinal radius of gyration [% of L_{PP}]
L_{CB}	longitudinal centre of buoyancy forward of midship [% of L_{PP}]
L_{BWL}	distance of the bow to 95% of maximum breadth on the waterline [m]
L_{PP}	length between perpendiculars [m]
L_{WL}	length at waterline [m]
MCR	maximum continuous rating [kW]
NCR	nominal continuous rating [kW]
n_{MCR}	rpm at MCR [rpm]
n_{NCR}	rpm at NCR [rpm]
N_P	number of propellers [-]
N_S	number of ships [-]
N_ψ	number of wind directions [-]

n:	measured rate of revolution of propeller at each run
n_C	corrected rpm (RPMC) [rpm]
$n_{(i)}$	propeller frequency of revolutions at $(i)^{th}$ run [rpm]
$n_{(i+1)}$	propeller frequency of revolutions at $(i+1)^{th}$ run [rpm]
P	propeller pitch at 0.7 R [m]
P_B	break horse power [kW]
P_D	delivered power at propeller [kW]
P/D	pitch/diameter ratio at 0.7R [-]
P_S	ship shaft power [kW]
P_{SC}	Corrected ship power (PSC) [kW]
R_{AA}	resistance increase due to relative winds [N]
R_{AS}	resistance increase due to deviation of water temperature and water density [N]
R_{AW}	mean resistance increase in short crested irregular waves [N]
R_{AWM}	mean resistance increase in regular waves based on Maruo's theory(4),
R_{AWR}	mean resistance increase due to wave reflection for correcting R_{AWM}.
R_T	total resistance in still water [N]
R_{T0}	resistance for reference water temperature and salt content [N]
R_{wave}	mean resistance increase in regular waves [N]
$R_{\beta\beta}$	resistance increase due to drift [N]
$R_{\delta\delta}$	resistance increase due to steering [N]
S	wetted surface hull [m^2]
S	frequency spectrum, for ocean waves modified Pierson-Moskowitz type [-]
S_{APP}	wetted surface appendages [m^2]
$\overline{SE}_{EST}$	averaged standard errors of wind resistance coefficient [-]
T_A	draught at aft perpendicular [m]
T_F	draught at forward perpendicular [m]
T_M	draught at midships [m]
t	thrust deduction fraction [-]
t_{Aref}	reference air temperature [°C]
t_{Sref}	reference sea water temperature [°C]
V_{FM}	mean current velocity [m/s]
$V_{G'(i+1)}$:	ship speed over the ground at $(i+1)^{th}$ run [kn]
V_{KN}	ship speed over ground [kn]
V_S	ship speed (VS) [kn]
$V_{SC.}$	corrected ship speed (VSC) [kn]
V_{WR}	apparent wind speed, relative wind velocity [m/s]
w	wake fraction [-]
w_m	mean wake fraction
Z	number of propeller blades [-]
α:	wave direction relative to bow, angle between ship heading [deg] and incident regular waves; 0 means head waves.
α_T:	effect of draught and encounter frequency [-]
β	drift angle [deg]
β_w	slope of the line element dl along the water line [deg]
β_{WR}	apparent wind direction relative to bow [deg]
∇	displaced volume [m^3]
Δ	displacement [t]
ΔR	resistance increase [N]
Δ_{ref}	reference displacement[m^3]
ΔV_S	decrease of ship speed due to shallow water [kn]
$\Delta\tau$	load factor increase due to resistance increase [-]
δ	rudder angle [deg]
δ_n	correction factor for RPM (DRPM) [-]
δP_A	power correction factor for wind (DPWIN) [kW]

δP_t	pwer correction factor for temperature (DPTEM) [kW]
$\delta P\rho$	power correction factor for density (DPDEN) [kW]
$\delta P\Delta$	power correction factor for displacement (DPDIS) [kW]
δV_H	speed correction factor for depth (DVDEP) [kn]
ζ_a	wave amplitude [m]
η_D	propulsive efficiency or quasi propulsive coefficient [-]
η_R	relative rotative efficiency by use of the thrust identity [-]
η_S	mechanical efficinecy in shafting(s) and gear box(es) [-]
Λ_R	aspect ratio of rudder [-]
λ	model scale 1: λ [-]
ρ	density of the sea water,for actual temperature & salt content [kg/m^3]
ρ_A	mass density of air [kg/m^3]
ρ_{WSref}	sea water density according to contract [kg/m^3]
ρ_{WS}	sea water density [kg/m^3]
ρ_0	water density for reference water temperature and salt content [kg/m^3]
ψ	heading of ship; compass course [deg]
ψ_{WR}:	relative wind direction [deg]
ω	circular frequency of incident regular waves [rad/s]