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A verification of the ITTC/ISO speed/power trials analysis

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Abstract Speed and power (S/P) trials are most important to guarantee the ship's propulsive performance. However, it was pointed out that the existing procedures often give a good guideline, but are not specific and can introduce inconsistent results. Recently, ITTC and ISO have improved their S/P trials procedures and harmonized the two procedures. During the harmonization process, we have verified the 'Mean of Means' (MoM) method and the 'Iterative' method which are used as the current correction methods and the 'Direct Power Method' and the 'Extended Power Method' which are applied for the evaluation of the acquired data. The results of verification are presented in this paper. The results show that using the 'MoM' method for each power setting, two double runs should be made to keep the accuracy of S/P trials, and the 'Iterative' method leads to less errors in average of the tested cases when $1 + 2 + 2$ double runs are used in the 'MoM' method, although the methods are equally adequate if the time periods between the runs are short enough. In specific cases, e.g. in case of large speed range and/or humps and hollows within the speed–power curve, the 'MoM' method has advantages over the 'Iterative' method. In case of current time history deviating from the assumed parabolic/sinusoidal trend and the change of the current within the time span of two double runs is very high, neither of the methods are applicable. Summarizing the results, the 'Iterative' method is fully compatible with the simple 'Direct Power Method'.

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1 Introduction

Speed and power (S/P) trials are conducted to establish the ship's performance at design or other stipulated draught and trim under no wind, no wave and no current condition. Although S/P trials are most important to guarantee the ship's propulsive performance, there was no internationally recognized standard prior to ISO15016:2002 [1]. Many shipyards developed their own procedures based on their experience and recommendations given in scientific literature. This literature is published by academic communities. For example, International Towing Tank Conference (ITTC) reported 'ITTC Guide for Measured-Mile Trials' in 1969 [2] and updated it in 1996 [3]. The Society of Naval Architects and Marine Engineers (SNAME) produced 'Code for Sea Trials' in 1978 [4]. This was later superseded in 1989 [5]. The British Ship Research Association (BSRA) issued 'BSRA standard method of Speed Trial Analysis' in 1978 [6].

The sea trial analysis (STA)-JIP [7] pointed out that the existing procedures often give a good guideline, but are not specific and can introduce inconsistent results, and proposed trial procedures based on two practices outlined by the ISO15016:2002 and the recommendations to the 22nd and 23rd ITTC [8, 9]. STA-JIP practice gives a practical overview of the minimum requirements that should be met to obtain reliable and single speed trial results.

On the other hand, in relation to the verification of the Energy Efficiency Design Index (EEDI), Norway proposed IMO to request a revision of ISO15016:2002 at the 62nd Marine Environmental Committee (MEPC) of IMO [10].

The 63rd MEPC [11] had noted that ITTC would develop a standard for the assessment of the speed and power performance by analysis of speed trial data in time. Accordingly, ITTC submitted its new recommended procedure for speed/power trials to the 64th MEPC [12]. This recommended procedure improves the ISO 15016:2002 and takes into account the improvements by the STA-JIP method. The part I of the ITTC procedure (Preparation and Conduct of Speed/Power Trials) was also submitted to the 65th MEPC [13]. At the same time, the MEPC committee requested ISO to revise, as soon as possible, ISO 15016:2002, taking into account the new recommended procedures by ITTC [14].

According to this request, ITTC and ISO started to harmonize the two procedures. During the harmonization process, we have verified the 'Mean of Means' (MoM) method and the 'Iterative' method which are used as the current correction methods and the 'Direct Power Method' and the 'Extended Power Method' which are applied for the evaluation of the acquired data. The aims of this paper are to show the results of the verification and to propose some recommendations on S/P trials procedures.

It is noted that, although the newly developed ISO 15016:2015 [15] mentions other corrections such as the resistance increase due to wind and waves, effects of the water temperature and density, the water depth and so on, only the current correction is in the limelight of this paper, because the current correction is vital in the S/P trials as long as we have no reliable tool for measuring the ship's speed through the water.

2 Current correction method

2.1 Conduct of the trial

It is stated in ISO 15016:2015 [15] that the S/P trial runs are conducted over the same ground area. Each trial run is commenced and completed at the same place. Modified Williamson turns or similar types of maneuvre are executed between each run to return the ship to the reciprocal heading on, or parallel to, the trial baseline. The run duration should be the same for all speed runs with a minimum of 10 min. The speed runs for the same power setting should be evenly distributed in time.

To determine the S/P curve, a certain number of double runs, which are defined as two consecutive speed runs at the same power setting on reciprocal headings, are required. The number of runs is determined to keep the accuracy of current correction. In the case of the 'Iterative' method, a minimum of four double runs at three different power settings is required for the first ship of a ship series. These power settings should be adequately distributed

within the power range of 65 % maximum continuous rating (MCR) and 100 % MCR and comprise at least two double runs around EEDI/Contract power, one double run below EEDI/Contract power and one double run above EEDI/Contract power.

If the MoM method is preferred, a minimum of six double runs at three different power settings is required. These power settings comprise at least two double runs around EEDI/Contract power, two double runs below EEDI/Contract power and two double runs above EEDI/Contract power.

2.2 'Iterative' method

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

$$V_C = V_{C,C} \cos\left(\frac{2\pi}{T_C}t\right) + V_{C,S} \sin\left(\frac{2\pi}{T_C}t\right) + V_{C,T}t + V_{C,0} \tag{2.1}$$

where V_C is the current speed, T_C the period of variation of current speed, t is the time for each run, and unknown factors $V_{C,C}$, $V_{C,S}$, $V_{C,T}$ and $V_{C,0}$.

The most dominant period is the lunar semidiurnal period of 0.517 53 days (12 h, 25 min and 12 s).

The ship's speed through the water V_S is derived from a regression curve (2.2) which represents the relationship between the ship's speed through the water and its power corrected which is defined as

$$P(V_S) = a + bV_S^q \tag{2.2}$$

where $P(V_S)$ is the regression curve and unknown factors a, b and q.

The initial value of V_S is taken as the average of the measured ship's speeds V'_G of a double run. As a first approximation of the regression curve representing the relationship between ship's speed and power, a mean curve is derived by determining the unknown factors, a, b and q of formula (2.2) by fitting the formula (2.2) to combinations of the initial value of V_S and averaged acquired power P'_{id} by the 'least squares' method. The acquired power P'_{id} is explained in Sect. 3.

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

$$V'_C = V_G - V_S \tag{2.3}$$

A current curve is obtained by determining the unknown factors $V_{C,C}$, $V_{C,S}$, $V_{C,T}$ and $V_{C,0}$ of formula (2.1) by fitting the formula (2.1) to the combinations of time and current speed obtained from formula (2.3) by the 'least squares'

method. The current speed on the current curve at the time for each run V_C is calculated from the formula (2.1) with the coefficients obtained as described above, and V_C is used as the updated current speed.

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

$$V'_S = V_G - V_C \qquad (2.4)$$

The updated regression curve representing the relationship between ship's speed and power is obtained by determining new factors of formula (2.2) by fitting the formula (2.2) to the combination of ship's speed obtained from formula (2.4) and corrected power by the 'least squares' method again.

The ship's speed through the water at the corrected power for each run V_S is recalculated as the updated one from the formula (2.2). These processes are then repeated until $\sum \left(P(V'_S)_i - P_{\mathrm{id}i} \right)^2$ is converged.

2.3 'Mean of means' method

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

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

$$V_C = V_{C,2} t^2 - V_{C,1} t + V_{C,0} \qquad (2.6)$$

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

If two double runs, i.e. four runs, are carried out, the MoM method can be used, and the following formula is derived to account for the current effect.

$$V_S = \frac{V_{G1} + 3V_{G2} + 3V_{G3} + V_{G4}}{8} \qquad (2.7)$$

where V_{G1} is the measured ship's speed over the ground on the first of four runs, V_{G2} the measured ship's speed over the ground on the second of four runs, V_{G3} the measured ship's speed over the ground on the third of four runs, and V_{G4} is the measured ship's speed over the ground on the fourth of four runs.

It is noted that an equal time interval between each run is assumed.

3 Evaluation of acquired data

3.1 Direct power method

To derive the S/P performance of the ship from the measured speed over the ground V_G, power P_{ms} and propeller

shaft speed n_{ms}, the 'Direct Power Method' is used. The relationship between delivered power in the trial condition P_{Dms} and measured power is described in the following formula:

$$P_{\mathrm{Dms}} = P_{\mathrm{Sms}} \cdot \eta_S \qquad (3.1)$$

where P_{Sms} is the measured shaft power and η_S is the shaft efficiency.

In this method, the delivered power P_{Dms} is directly corrected with the power increase ΔP due to resistance increase ΔR in the trial condition.

$$P_{\mathrm{Did}} = P_{\mathrm{Dms}} - \Delta P \qquad (3.2)$$

where P_{Did} is the delivered power in the ideal condition and ΔP is the required correction for power.

The required correction for power ΔP is calculated by the following formula:

$$\Delta P = \frac{\Delta R V_S}{\eta_{\mathrm{Did}}} + P_{\mathrm{Dms}} \left(1 - \frac{\eta_{\mathrm{Dms}}}{\eta_{\mathrm{Did}}} \right) \qquad (3.3)$$

where ΔR is the total resistance increase, η_{Dms} the propulsive efficiency coefficient in the trial condition and η_{Did} is the propulsive efficiency coefficient in the ideal condition.

The propulsive efficiency coefficient in the ideal condition η_{Did} is obtained from standard towing tank tests and interpolated for the speed V_S. The effect of resistance increase on the propeller loading and thus on the propulsive efficiency coefficient η_{Dms} is derived considering the load variation effect. It is noted that the ideal condition means no wind, no waves, no current, deep water and standard temperature and density.

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

$$\frac{\eta_{\mathrm{Dms}}}{\eta_{\mathrm{Did}}} = \xi_P \frac{\Delta R}{R_{\mathrm{id}}} + 1 \qquad (3.4)$$

where ξ_P is a coefficient derived from the load variation test and R_{id} is the resistance in the ideal condition.

This leads to P_{Did} as follows under the condition $\left(P_{\mathrm{Dms}} - \frac{\Delta R V_S}{\eta_{\mathrm{Did}}} > 0 \right)$

$$P_{\mathrm{Did}} = \frac{1}{2} \left(P_{\mathrm{Dms}} - \frac{\Delta R V_S}{\eta_{\mathrm{Did}}} + \sqrt{\left(P_{\mathrm{Dms}} - \frac{\Delta R V_S}{\eta_{\mathrm{Did}}} \right)^2 + 4 P_{\mathrm{Dms}} \frac{\Delta R V_S}{\eta_{\mathrm{Did}}} \xi_P} \right) \qquad (3.5)$$

It is noted that the derivation of load variation coefficients is found in ISO15016:2015 [15].

3.2 Extended power method

Since the 'Direct Power Method' shown in Sect. 3.1 does not give any information on the full-scale wake fraction which is essential to know the physics of full-scale ship

propulsion, the following procedure is described in Annex K of ISO15016:2015 [15] to obtain the full-scale wake fraction as well as related intermediate information such as the load factor, propeller efficiency and so on.

The propulsive efficiency coefficient η_D is generally calculated using the propeller open water efficiency η_O (which is assumed to be known here also as in the direct power method) and self-propulsion factors η_R, t and w_S as

$$\eta_D = \eta_O \eta_R \frac{1-t}{1-w_S} \tag{3.6}$$

where η_R is the relative rotative efficiency, t the thrust deduction factor and w_S is the full-scale wake fraction.

Each self-propulsion factor for the trial condition is obtained by adding the deviation of each factor between the trial and the ideal condition. The deviations are described as functions of $\Delta R/R_{id}$ which is obtained from the results of the self-propulsion test with load variation effect.

$$\eta_{Rms} = \eta_{Rid} + \Delta\eta_R(\Delta R/R_{id}), \tag{3.7}$$

$$t_{ms} = t_{id} + \Delta t(\Delta R/R_{id}), \tag{3.8}$$

$$w_{Mms} = w_{Mid} + \Delta w_M(\Delta R/R_{id}) \tag{3.9}$$

where η_{Rms} is the relative rotative efficiency in the trial condition, t_{ms} the thrust deduction factor in the trial condition, w_{Mms} the model wake fraction in the trial condition, η_{Rid} the relative rotative efficiency in the ideal condition, t_{id} the thrust deduction factor in the ideal condition, w_{Mid} the model wake fraction in the ideal condition, $\Delta\eta_R$ the deviation of relative rotative efficiency, Δt the deviation of thrust deduction factor and Δw_M is the deviation of wake fraction.

On the other hand, the thrust coefficient, the torque coefficient and the load factor of a propeller (propeller open characteristics) are described by the following formulae.

$$K_T = a_T J^2 + b_T J + c_T, \tag{3.10}$$

$$K_Q = a_Q J^2 + b_Q J + c_Q, \tag{3.11}$$

$$\tau_P = a_T + b_T/J + c_T/J^2 \tag{3.12}$$

where K_T is the thrust coefficient; K_Q the torque coefficient; τ_P the load factor equal to K_T/J^2; J the propeller advance coefficient; a_T, b_T and c_T the factors for the thrust coefficient curve; and a_Q, b_Q and c_Q are the factors for the torque coefficient curve.

If we know the self-propulsion factors in the trial condition η_{Rms}, t_{ms} and $w_{Mms}\eta_{Rm}$ and the ship's speed through the water V_S, the torque coefficient in the trial condition K_{Qms} is calculated as

$$K_{Qms} = \frac{P_{Dms}}{2\pi\rho_S n_{ms}^3 D^5}\eta_{Rms} \tag{3.13}$$

where ρ_S is the water density, n_{ms} the measured propeller shaft speed and D is the propeller diameter. The propeller advance coefficient J_{ms} is determined by using the torque coefficient K_{Qms}.

$$J_{ms} = \frac{-b_Q - \sqrt{b_Q^2 - 4a_Q(c_Q - K_{Qms})}}{2a_Q}. \tag{3.14}$$

The thrust coefficient in the trial condition K_{Tms} is obtained by the formula (3.10) using the propeller advance coefficient in the trial condition J_{ms}, and the propeller efficiency in the trial condition η_{Oms} is obtained as

$$\eta_{Oms} = \frac{J_{ms}}{2\pi}\frac{K_{Tms}}{K_{Qms}}. \tag{3.15}$$

The load factor in the trial condition τ_{Pms} is obtained as

$$\tau_{Pms} = \frac{K_{Tms}}{J_{ms}^2}. \tag{3.16}$$

The full-scale wake fraction in the trial condition w_{Sms} is obtained as

$$1 - w_{Sms} = \frac{V_A}{V_S} \tag{3.17}$$

where V_S is the ship's speed through the water and the speed of flow into propeller V_A is calculated as

$$V_A = J_{ms}n_{ms}D. \tag{3.18}$$

The total resistance in the trial condition R_{ms} is also estimated using the load factor in the trial condition τ_{Pms}

$$R_{ms} = \tau_{Pms}(1 - t_{ms})(1 - w_{Sms})^2\rho_S V_S^2 D^2. \tag{3.19}$$

The total resistance in the ideal condition R_{id} is obtained by subtracting the resistance increase ΔR from the total resistance in the trial condition R_{ms} as

$$R_{id} = R_{ms} - \Delta R. \tag{3.20}$$

The full-scale wake fraction in the ideal condition w_{Sid} is calculated by the following formula using the model wake fraction in the ideal condition w_{Mid}.

$$1 - w_{Sid} = (1 - w_{Mid})e_i \tag{3.21}$$

where the scale correlation factor of wake fraction e_i is obtained using the full-scale and model wake fractions in the trial conditions as

$$e_i = \frac{1 - w_{Sms}}{1 - w_{Mms}}. \tag{3.22}$$

The load factor in the ideal condition τ_{Pid} is calculated by the following formula.

$$\tau_{Pid} = \frac{R_{id}}{(1 - t_{id})(1 - w_{Sid})^2\rho_S V_S^2 D^2}. \tag{3.23}$$

The propeller advance coefficient in the ideal condition J_{id} is determined using the load factor τ_{Pid} obtained from formula (3.23).

$$J_{id} = \frac{-b_T - \sqrt{b_T^2 - 4(a_T - \tau_{Pid})c_T}}{2(a_T - \tau_{Pid})} \quad (3.24)$$

The thrust coefficient in the ideal condition K_{Tid} and the torque coefficient K_{Qid} are obtained by the formulae (3.10) and (3.11), respectively, using the propeller advance coefficient J_{id}. Thus, the propeller efficiency in the ideal condition η_{Oid} is calculated as

$$\eta_{Oid} = \frac{J_{id}}{2\pi} \frac{K_{Tid}}{K_{Qid}}. \quad (3.25)$$

Finally, the corrected propeller shaft speed in the ideal condition n_{id} is derived from the following equation.

$$n_{id} = \frac{V_S(1 - w_{Sid})}{J_{id}D}. \quad (3.26)$$

It is noted that the value of V_S, and thus the values of η_{Rid}, t_{id} and w_{Mid} are not known before we know the current velocity V_C. Additionally, the value of $\Delta R/R_{id}$, and thus the values of $\Delta\eta_R$, Δt and Δw_M are not known before self-propulsion factors in the trial condition are obtained. Therefore, the analysis described in this section is repeated after the value of V_S is obtained by the current analysis method described in Sect. 2. It is also noted that, for the initial value of the above evaluation, the mean value of V_G for one double run or the 'MoM' value of V_G for two double runs is used and the values of $\Delta\eta_R$, Δt and Δw_M are set to zero.
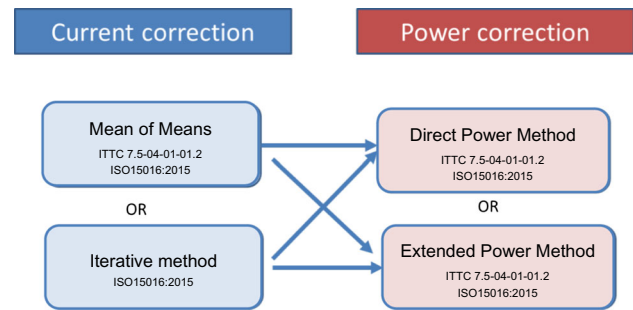
4 Verification

ITTC has been requested by MEPC 66 [66] to investigate and verify the accuracy of the 'Iterative' method, which is one of the choices in ISO 15016:2015 [15] 'Guidelines for the assessment of speed and power performance by analysis of speed trial data'. The alternative is the 'MoM' method proposed by ITTC, where for one power setting two double runs have to be performed. The verification of the 'Iterative' method is performed by members of ITTC's Specialist Committee coming from three independent towing tank institutes, SVA Vienna, HSVA and SSPA.

4.1 Description of the verification

Two current correction methods and two power correction methods have been evaluated, with the assumption that the added resistance is known. The study includes (Fig. 1):

- Iterative method—ISO15016:2015 [15]
- Means of Means method—ITTC 7.5-04-01-01.2 [12]

Fig. 1 Four combinations included in the study

- Direct power method—ITTC 7.5-04-01-01.2 [12]
- Extended power method of Annex K ISO15016:2015 [15]

The verification of the current correction is achieved by fabricated cases using model test performance predictions, which for all considered ship types were available, and for selected areas with known current profiles over the time, to know the 'true answers'.

For a given power setting to the corresponding speed received by the performance prediction the current speed of the respective current profile at the time of the particular run was added/subtracted. The received values were taken as the 'should have been measured' values and as the input for the current correction methods (Fig. 2, speed over the ground, shaft power, shaft speed). The application of the 'MoM' method and the 'Iterative' method gives the result for each method and the difference between the 'true values' and the respective result shows the accuracy of the applied method.

The threshold for an acceptable difference between 'true value' and calculated value of speed through the water is taken as in the ISO 15016:2015 [15] as $\Delta VS \leq 0.10$ knots.

4.2 Ship types

The range of the typical time between the speed runs during the speed trial should cover the time span between half an hour and 2 h for the chosen ship types. Important criteria was also that the required model tests were available. The ship types investigated in this paper are listed in Table 1.

4.3 Number of runs

The number of runs was decided according to the new ISO 15016 standard taking into account the respective correction method for the current. Also, the cases for sister ships were investigated. Below are the number of runs and the power settings for the different cases.

Fig. 2 Image of the fabricated
S/T data
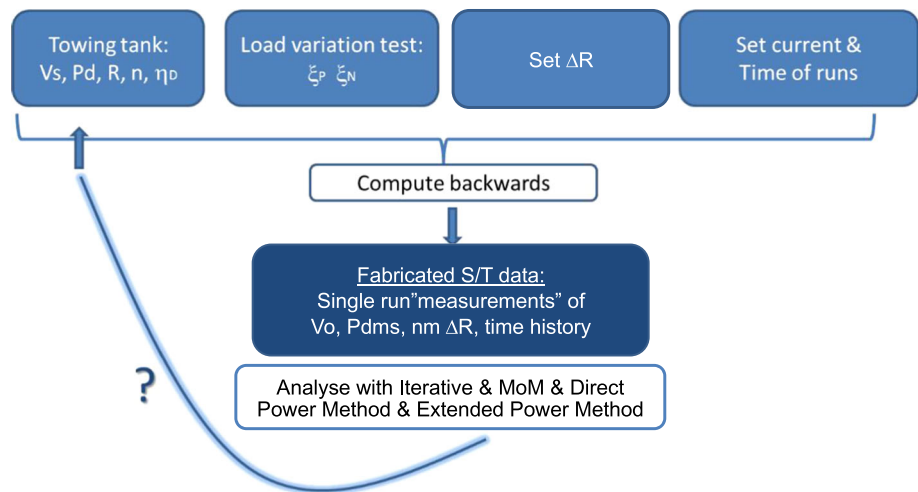
Table 1 Ship types

Ship type	$L_{PP (m)}$	Speed (knots)	Comments
LNG	280	19.5	Large bulb effect
Small tanker	165	14.0	
Large container	340	25.0	14,000 TEU
Small container	195	22.5	2,500 TEU
VLCC	320	15.1	350,000 t
Cruise liner	315.5	20.7	78,000 t

4.3.1 Iterative method

- 1 double run at 50 % MCR
- 1 or two double runs at 75 % MCR (EEDI)
- 1 double run at 85 or 90 % MCR (contract)

4.3.2 Sistership case

- 1 double run at 50 % MCR
- 1 double run at 75 % MCR (EEDI)
- 1 double run at 85 or 90 % MCR

4.3.3 'Mean of means' method

- 1 double run at 50 % MCR
- 2 double runs at 75 % MCR (EEDI)
- 2 double runs at 85 or 90 % MCR (contract)

4.3.4 Sistership case (current speed < 0.2 knots)

- 1 double run at 50 % MCR
- 1 double run at 75 % MCR (EEDI)
- 1 double run at 85 or 90 % MCR

4.4 Current profiles

The criteria for the choice of the current profiles was that they should not be too simple (just sinusoidal or parabolic) but rather realistic with time and maximum current speed. Figure 3 shows the current profiles over the time chosen and applied in this paper.

4.5 Time span and starting time

The starting time of the set of speed runs was varied with relation to the time of the current profiles (time lag). For the time span between the speed runs a typical time for the respective ship type was used. Also, a random variation of maximum 25 % between the time spans has been applied.

5 Results and discussion

The calculation was performed by the spreadsheets which have been developed by the ISO (about 1,000 cases) and by an individually developed code which follows exactly ISO 15016:2015 [15] draft (more than 3,000 cases). It is noted that although the 'Extended Power Method' has some advantages, the verification results by the 'Direct Power Method' are mainly shown here because the 'Extended Power Method' is treated as an informative in ISO15016:2015 [15]

5.1 Examples of the calculations by using the spreadsheets

5.1.1 Containership 14,000 TEU in Current Profile around Japan

Table 2 shows the result of a containership 14,000 TEU in the current profile around Japan. The marked cells in the
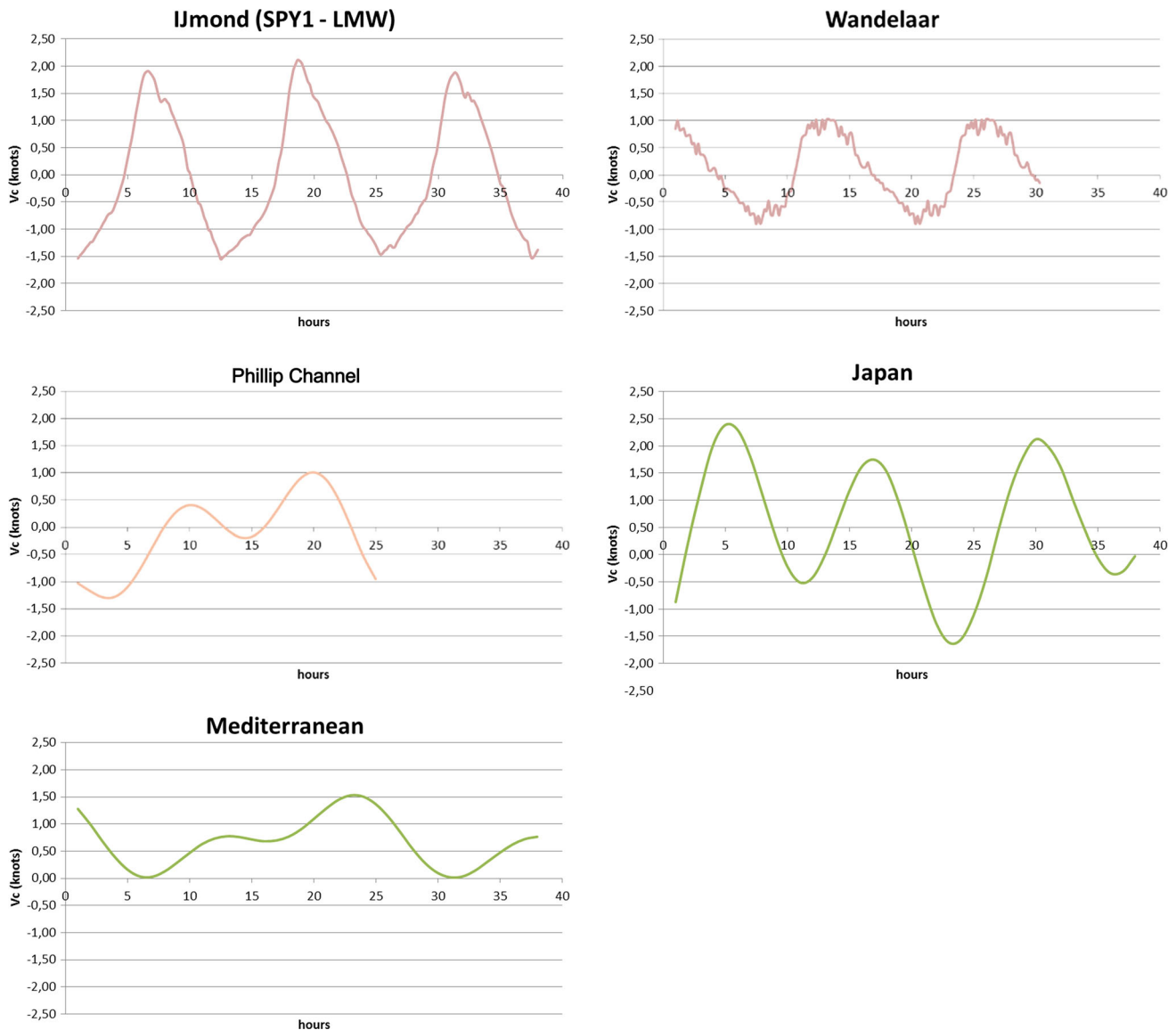
Fig. 3 Current profiles

two last columns at the right hand side of the table show when an error of an individual power setting exceeds the threshold of 0.1 knot. We note that large errors appear for the 'MoM' method for the first power setting in each data set. This is where only 1 double run has been performed. In a real sea trial, a curve will be fitted through the three points, which will smear out the error of the first point, so that the total error is reduced.

5.1.2 VLCC 350,000 t in current profile around Japan

Table 3 shows the result of a VLCC 350,000 t in the current profile around Japan, and Table 4 shows the result of the same ship with random variation of the time step. Comparison of the calculations with and without random

variation of the time steps shows, that the 'MoM' method becomes more accurate if the time steps between the runs of one power setting are as equal as possible.

Figure 4 shows an example how the 'Iterative' method approximates the current speed. The variation of the time steps has no influence on the result. The approximation can only be received after all runs of all power settings have been measured.

5.1.3 Sister ships of VLCC 350,000 t in current profile around Japan

Table 5 shows the results when only three double runs are performed (1 + 1 + 1). This is the case foreseen in ISO 15016 for sister ships.

Table 2 Containership 14,000 TEU in Japanese current profile

	Current	Engine load (%)	Time lag (h)	Time step (min)		Double runs	Speed actual (knots)	Current (knots)		Current variation (knots)	Speed (knots)		Error (knots)	
				Const.	Rand.			Up	Down		MoM	It.M.	MoM	It.M.
													0.00	0.00
14,000 TEU	Japan	65	0	60	–	1	22.72	−0.68	0.34	1.02	22.24	22.74	−0.48	0.02
14,000 TEU	Japan	75	0	50	–	2	23.73	1.28	1.71	0.43	23.73	23.72	0.00	−0.01
14,000 TEL	Japan	90	0	50	–	2	25.03	0.95	−1.61	−2.56	25.00	25.03	−0.03	0.00
14,000TEJ	Japan	65	2	50	–	1	22.72	1.28	1.91	0.63	22.42	22.74	−0.30	0.02
14,000TEJ	Japan	75	2	50	–	2	23.73	2.06	−0.02	−2.08	23.71	23.72	−0.02	−0.01
14,000 TEU	Japan	90	2	60	–	2	25.03	−0.96	−1.53	−0.57	25.02	25.03	−0.01	0.00
14,000 TEU	Japan	65	4	50	–	1	22.72	2.06	1.71	−0.35	22.89	22.74	0.17	0.02
14,000 TEU	Japan	75	4	60	–	2	23.73	0.95	−1.61	−2.56	23.70	23.72	−0.03	−0.01
14,000 TEU	Japan	90	4	60	–	2	25.03	−1.82	0.15	1.97	25.05	25.03	0.02	0.00
14,000TEU	Japan	65	6	50	–	1	22.72	0.95	−0.02	−0.97	23.18	22.74	0.46	0.02
14,000 TEU	Japan	75	6	60	–	2	23.73	−0.96	−1.53	−0.57	23.72	23.72	−0.01	−0.01
14,000 TEU	Japan	90	6	60	–	2	25.03	−0.81	1.83	2.64	25.06	25.03	0.03	0.00
14,000TEU	Japan	65	8	60	–	1	22.72	−0.96	−1.61	−0.65	23.03	22.74	0.31	0.02
14,000TEU	Japan	75	8	60	–	2	23.73	−1.82	0.15	1.97	23.75	23.72	0.02	−0.01
14,000 TEU	Japan	90	8	60	–	2	25.03	1.11	1.91	0.80	25.03	25.03	0.00	0.00
14,000TEU	Japan	65	10	60	–	1	22.72	−1.82	−1.53	0.29	22.58	22.74	−0.14	0.02
14,000TEU	Japan	75	10	60	–	2	23.73	−0.81	1.83	2.64	23.76	23.72	0.03	−0.01
14,000 TEU	Japan	90	10	60	–	2	25.03	2.12	0.34	−1.78	25.01	25.04	−0.02	0.01
													0.00	0.00

Table 3 VLCC 350,000 t in Japanese current profile without variation of the time steps

	Current	Engine load (%)	Time lag (h)	Time step (min)		Double runs	Speed actual (knots)	Current (knots)		Current variation (knots)	Speed (knots)		Error (knots)	
				Const.	Rand.			Up	Down		MoM	It.M.	MoM	It.M.
320, 000 VLCC	Japan	65	0	45		1	13.62	0.81	1.59	0.78	13.41	13.62	−0.21	0.00
320, 000 VLCC	Japan	75	0	45	–	2	14.28	1.05	−1.08	−2.13	14.28	14.26	0.00	−0.02
320, 000 VLCC	Japan	90	0	45	–	2	15.16	1.31	−0.72	−2.03	15.15	15.16	−0.01	0.00
320,000VLCC	Japan	65	3	45	–	1	13.62	1.47	0.48	−0.99	13.77	13.62	0.15	0.00
320,000 VLCC	Japan	75	3	45	–	2	14.28	−1.20	0.54	1.74	14.27	14.28	−0.01	0.00
320,000 VLCC	Japan	90	3	45	–	2	15.16	0.99	−1.26	−2.25	15.16	15.16	0.00	0.00
320,000 VLCC	Japan	65	6	45	–	1	13.62	−0.15	−1.08	−0.93	13.83	13.62	0.21	0.00
320,000 VLCC	Japan	75	6	45	–	2	14.28	−1.02	0.78	1.80	14.28	14.29	0.00	0.01
320,000 VLCC	Japan	90	6	45	–	2	15.16	−1.17	0.11	1.28	15.17	15.15	0.01	−0.01
320,000 VLCC	Japan	65	9	45	–	1	13.62	−1.20	−0.60	0.60	13.57	13.62	−0.05	0.00
320,000 VLCC	Japan	75	9	45	–	2	14.28	0.99	−0.66	−1.65	14.30	14.28	0.02	0.00
320,000 VLCC	Japan	90	9	45	–	2	15.16	−1.26	1.47	2.73	15.20	15.16	0.04	0.00
320,000 VLCC	Japan	65	12	45	–	1	13.62	0.00	0.90	0.90	13.41	13.62	−0.21	0.00
320,000 VLCC	Japan	75	12	45	–	2	14.28	0.78	−1.17	−1.95	14.28	14.28	0.00	0.00
320,000 VLCC	Japan	90	12	45	–	2	15.16	1.05	−0.15	−1.20	15.15	15.16	0.00	0.00
320,000 VLCC	Japan	65	15	45	–	1	13.62	0.99	0.36	−0.63	13.69	13.62	0.07	0.00
320,000 VLCC	Japan	75	15	45	–	2	14.28	−0.56	1.35	2.01	14.04	14.28	−0.24	0.00
320,000 VLCC	Japan	90	15	45	–	2	15.16	1.47	−1.20	−2.67	15.15	15.15	−0.01	−0.01

The 'Iterative' method gives quite accurate results with one double run per power setting whereas the 'MoM' method again would require two double runs for each power setting to be reliable.

5.1.4 VLCC 350,000 t in Ijmond and Wandelaar current profile

Table 6 shows the results for the current distribution at Ijmond, where obviously both methods fail. Figure 5

shows the approximation by the 'Iterative' method for the current distribution at Ijmond. Both the 'MoM' and the 'Iterative' methods failed in many cases for the Wandelaar and Ijmond current distributions. These areas should be avoided for VLCC S/P trials.

Through the verifications, the following conclusions are also obtained. In the case of shorter time periods between the runs (up to 60 min), the methods are equally adequate. In specific cases, the 'MoM' method has advantages over the 'Iterative' method: in cases where the speed-power

Table 4 VLCC 350,000 t in current profile around Japan with random variation of the time steps

	Current	Engine load (%)	Time lag (h)	Time step (min)		Double runs	Speed actual (knots)	Current (knots)		Current variation (knots)	Speed (knots)		Error (knots)	
				Const.	Rand.			Up	Down		MoM	It.M.	MoM	It.M.
320,000 VLCC	Japan	65	0	120	±30	1	13.62	−0.68	1.58	−2.26	12.49	13.58	−1.13	−0.04
320,000 VLCC	Japan	75	0	120	±30	2	14.28	0.94	−1.20	−2.14	14.00	14.28	−0.28	0.00
320,000 VLCC	Japan	90	0	120	±30	2	15.16	0.66	−1.05	−1.71	15.16	15.18	0.00	0.02
320,000 VLCC	Japan	65	3	120	±30	1	13.62	1.91	1.46	0.45	13.85	13.59	0.23	−0.03
320,000 VLCC	Japan	75	3	120	±30	2	14.28	−0.10	0.95	1.05	14.48	14.28	0.20	0.00
320,000 VLCC	Japan	90	3	120	±30	2	15.16	0.68	−0.83	−1.51	15.06	15.20	−0.10	0.04
320,000 VLCC	Japan	65	6	120	±30	1	13.62	0.95	−1.26	2.21	14.73	13.64	1.11	0.02
320,000 VLCC	Japan	75	6	120	±30	2	14.28	−0.95	0.39	1.34	14.58	14.28	0.30	0.00
320,000 VLCC	Japan	90	6	120	±30	2	15.16	−0.79	0.96	1.75	15.13	15.15	−0.03	−0.01
320,000 VLCC	Japan	65	9	120	±30	1	13.62	−1.61	−1.29	0.32	13.46	13.64	−0.16	0.02
320,000 VLCC	Japan	75	9	120	±30	2	14.28	0.63	−1.15	−1.78	14.11	14.28	−0.17	0.00
320,000 VLCC	Japan	90	9	120	±30	2	15.16	−1.10	1.37	2.47	15.31	15.14	0.15	−0.02
320,000 VLCC	Japan	65	12	120	±30	1	13.62	−0.81	1.43	−2.24	12.30	13.37	1.12	−0.05
320,000 VLCC	Japan	75	12	120	±30	2	14.28	0.71	−1.25	−1.96	13.98	14.29	−0.30	0.01
320,000 VLCC	Japan	90	12	120	±30	2	15.16	1.59	−0.51	−2.10	15.17	15.22	0.01	0.06
320,000 VLCC	Japan	65	15	120	±30	1	13.62	1.83	1.71	0.12	13.68	13.56	0.06	−0.06
320,000 VLCC	Japan	75	15	120	±30	2	14.28	−1.22	1.35	2.57	14.42	14.26	0.14	−0.02
320,000 VLCC	Japan	90	15	120	±30	2	15.16	1.46	−1.10	−2.56	15.08	15.18	0.08	0.02

**Fig. 4** An example how the 'Iterative' method approximates the current speed
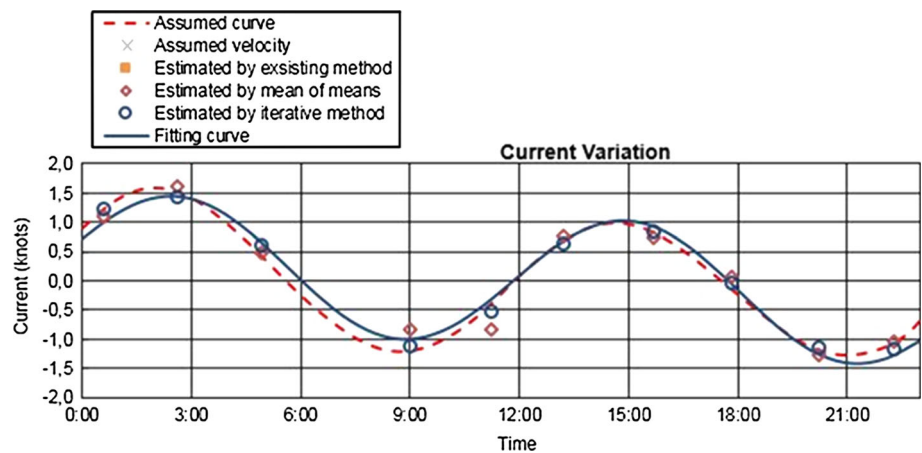
Table 5 Sister ships of VLCC 350,000 t in current profile around Japan

	Current	Engine load (%)	Time lag (h)	Time step (min)		Speed 6run (min)		Error 6run (min)	
				Const.	Rand.	M	It.M.	M	It.M
320,000 VlCC	Japan	65	0	120	±30	12.49	13.61	−1.13	−0.01
320,000 VlCC	Japan	75	0	120	±30	15.13	14.29	0.85	0.01
320,000 VlCC	Japan	90	0	120	±30	15.08	15.16	−0.08	0.00
320,000 VlCC	Japan	65	3	120	±30	13.85	13.61	0.23	−0.01
320,000 VLCC	Japan	75	3	120	±30	14.95	14.29	0.67	0.01
320,000 VLCC	Japan	90	3	120	±30	14.20	15.16	−0.96	0.00
320,000 VlCC	Japan	65	6	120	±30	14.73	13.63	1.11	0.01
320,000 VLCC	Japan	75	6	120	±30	13.47	14.27	−0.81	−0.01
320,000 VLCC	Japan	90	6	120	±30	15.15	15.16	−0.01	0.00
320,000 VLCC	Japan	65	9	120	±30.	13.46	13.63	−0.16	0.01
320,000 VLCC	Japan	75	9	120	±30	13.54	14.27	−0.74	−0.01
320,000 VLCC	Japan	90	9	120	±30	16.10	15.16	0.94	0.00
320,000 VLCC	Japan	65	12	120	±30	12.50	13.61	−1.12	−0.01
320,000 VLCC	Japan	75	12	120	±30	15.02	14.29	0.74	0.01
320,000 VLCC	Japan	90	12	120	±30	15.24	15.16	0.08	0.00
320,000 VLCC	Japan	65	15	120	±30	13.68	13.62	0.06	0.00
320,000 VLCC	Japan	75	15	120	±30	15.08	14.29	0.80	0.01
320,000 VLCC	Japan	90	15	120	±30	14.20	15.14	−0.96	−0.02

Table 6 VLCC 350,000 t in Ijmond current profile

	Current	Engine load (%)	Time lag (h)	Time step (min)		Double runs	Speed actual (knots)	Current (knots)		Current variation (knots)	Speed (knots)		Error (knots)	
				Const.	Rand.			Up	Down		MoM	It.M.	MoM	It.M.
320,000 VLCC	Ijmond	65	0	120	±30	1	13.62	−1.24	−0.29	−0.95	13.15	13.69	−0.47	0.07
320,000 VLCC	Ijmond	75	0	120	±30	2	14.28	1.81	−0.82	−2.63	14.03	14.43	−0.25	0.15
320,000 VLCC	Ijmond	90	0	120	±30	2	15.16	−1.35	1.44	2.79	15.65	15.41	0.49	0.25
320,000 VLCC	Ijmond	65	3	120	±30	1	13.62	0.30	1.69	−1.38	12.93	13.44	−0.69	−0.18
320,000 VLCC	Ijmond	75	3	120	±30	2	14.28	1.43	−1.42	−2.85	14.39	14.39	0.11	0.11
320,000 VLCC	Ijmond	90	3	120	±30	2	15.16	−0.37	2.10	2.47	15.13	15.40	−0.03	0.24
320,000 VLCC	Ijmond	65	6	120	±30	1	13.62	1.39	−0.26	1.65	14.45	13.43	0.83	−0.19
320,000 VLCC	Ijmond	75	6	120	±30	2	14.28	−1.45	0.31	1.76	14.31	14.12	0.03	−0.16
320,000 VLCC	Ijmond	90	6	120	±30	2	15.16	1.69	−1.27	−2.96	15.10	15.07	-0.06	−0.09
320,000 VLCC	Ijmond	65	9	120	±30	1	13.62	0.03	−1.40	1.43	14.34	13.73	0.72	0.11
320,000 VLCC	Ijmond	75	9	120	±30	2	14.28	−1.36	1.85	3.21	14.88	14.47	0.60	0.19
320,000 VLCC	Ijmond	90	9	120	±30	2	15.16	0.05	−1.05	−1.10	15.24	15.30	0.08	0.14
320,000 VLCC	Ijmond	65	12	120	±30	1	13.62	−1.45	−0.93	−0.53	13.36	13.65	−0.26	0.03
320,000 VLCC	Ijmond	75	12	120	±30	2	14.28	2.05	−0.83	−2.88	14.05	14.30	−0.23	0.02
320,000 VLCC	Ijmond	90	12	120	±30	2	15.16	−1.32	1.44	2.76	15.10	15.28	−0.06	0.12
320,000 VLCC	Ijmond	65	15	120	±30	1	13.62	−0.69	1.91	−2.61	12.32	13.29	−1.30	−0.33
320,000 VLCC	Ijmond	75	15	120	±30	2	14.28	1.71	−1.05	−2.76	14.11	14.07	−0.17	−0.21
320,000 VLCC	Ijmond	90	15	120	±30	2	15.16	−0.15	1.79	1.94	14.93	14.91	−0.23	−0.25

Fig. 5 The approximation by
the 'Iterative' method for the
current distribution at Ijmond
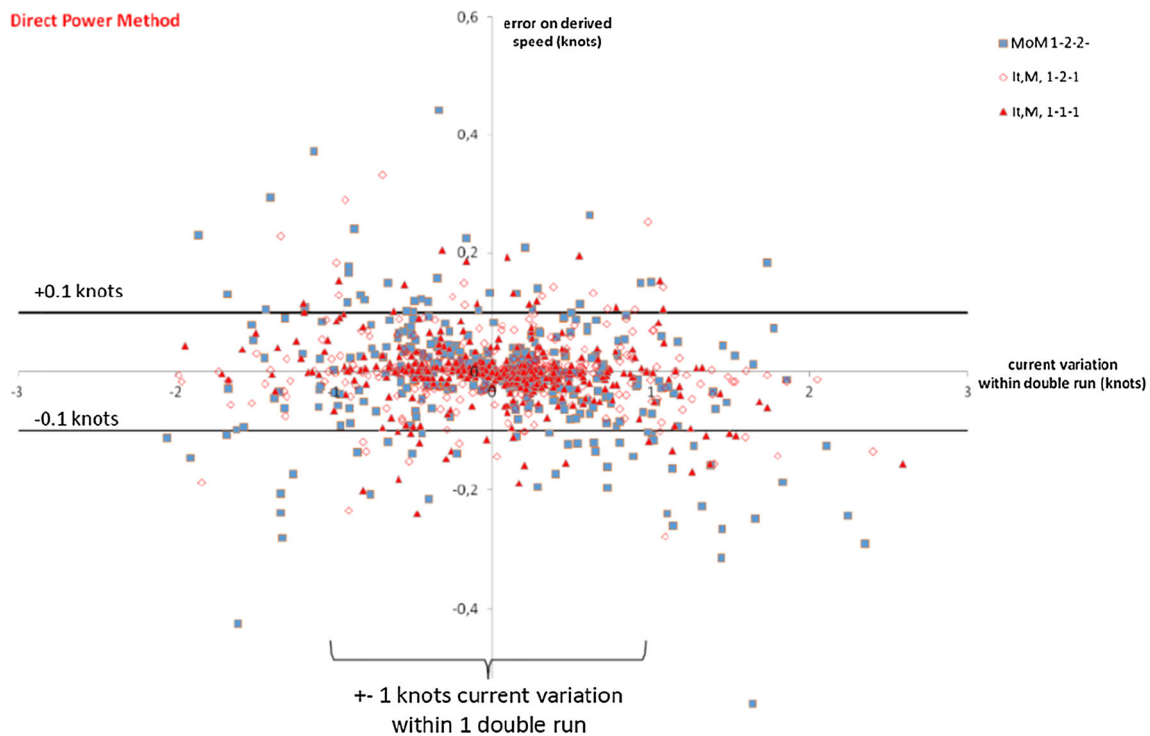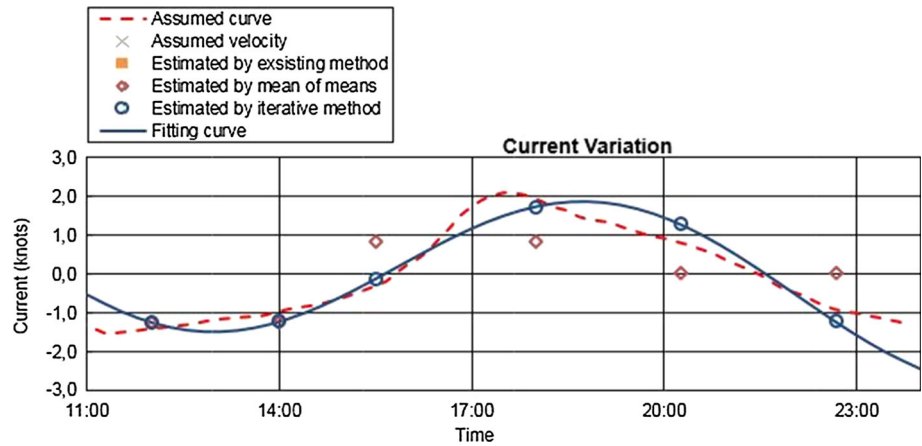
Fig. 6 The spreading of the results of the two methods

curve deviates significantly from the assumed power function $(a + bV_{p})$, e.g. in case of large speed range and/or humps and hollows within the curve.

5.2 Statistical approach

An independently developed verification code was used in conjunction to the spreadsheets provided by the ISO group. In this approach the error was extracted from the faired speed–power curve, as in a real sea trial, and not taken for each individual power setting, as in the mentioned spreadsheets. A large number of test cases made a statistical evaluation of the error possible. Figure 6 shows the spreading of the results of the two methods, where all red points represent the 'Iterative' and the blue points the 'MoM' method. From the mean and the variance of this, a normal distribution can be derived as shown in Fig. 7. Figure 7 shows that both methods are adequate if for the 'MoM' method at each power setting two double runs are performed (dotted blue line represents the 'MoM' method with $1 + 2 + 2$ double runs).
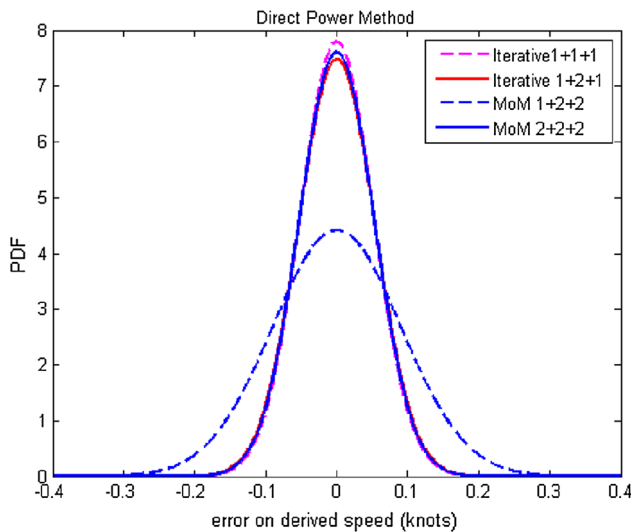
Fig. 7 Probability distribution of the error on derived speed

6 Conclusions

The following concluding remarks have been obtained through the present verification study.

1. Using the 'MoM' method for each power setting, two double runs (2 + 2 + 2 double runs) should be made to keep the accuracy of S/P trials.
2. In general the 'Iterative' method leads to less errors in average of the tested cases when 1 + 2 + 2 double runs are used in the 'MoM' method.
3. In the case of shorter time periods between the runs (up to 60 min) the methods are equally adequate.
4. In specific cases, the 'MoM' method has advantages over the 'Iterative' method: in cases where the speed–power curve deviates significantly from the assumed power function ($a + bV_{\mathrm{p}}$), e.g. in case of large speed range and/or humps and hollows within the curve.
5. In case of current time history deviating from the assumed parabolic/sinusoidal trend and the change of the current within the time span of two double runs is very high, neither of the methods are applicable. These areas, when known, should be avoided.
6. The 'Iterative' method is fully compatible with the 'Simple Direct Power Method' which is shown in ITTC Recommended Procedure 7.5-04-01-01.2 [12].

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