Development of Empirical Formulae for Estimating Ship Performance

by

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Abstract

A ship performance simulator called Vessel Performance Evaluation Tool in Actual Seas (VESTA) has been developed, which requires the input of detailed ship data or results of tank tests. Except for the ship designer or ship builder, it is difficult to input such data. To support input into VESTA assuming it is used at shipping companies, a program called United Tool for Assessment of a Ship has been developed. However for information service providers, it is necessary to additionally estimate data such as the displacement, longitudinal centre of buoyancy, draught and trim of a ship in operation, parameters relating to the estimation of wind forces, propeller characteristics and rudder forces, and specific fuel consumption for initial estimation. Therefore, empirical formulae using recent ship data and geometric relationships have been developed.

These empirical formulae are not only useful for information service providers but also for the initial estimating ship performance.

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Contents

1. Introduction

When a ship navigates on the sea, speed decreases and fuel consumption increases due to winds and waves. A ship performance simulator called Vessel Performance Evaluation Tool in Actual Seas (VESTA) has been developed to simulate ship operation in such a situation[1), 2)]. However, VESTA requires the input of detailed ship design data. As shipping companies wishing to simulate ship performance during operation cannot obtain the detailed data without cooperation of the shipyard, it is necessary to estimate the ship design data. To solve this problem, a program called United Tool for Assessment of a Ship (UNITAS) to estimate the hull form and ship performance has been developed[3), 4)]. UNITAS uses some of the empirical formulae of a program called Hull Optimization Program for Economy (HOPE) Light[5)].

For information service providers, such as a weather routing service, it is necessary to additionally estimate displacement, longitudinal centre of buoyancy, draught and trim of a ship during operation, parameters relating to the estimation of wind forces, propeller characteristics and rudder forces, and specific fuel consumption. Therefore, empirical formulae using recent ship data and geometric relationships have been developed.

2. Development of empirical formulae

2.1 Block coefficients

Since ship performance changes depending on the displacement, it is necessary to estimate when the displacement value during a voyage is unknown.

The block coefficient at the design load condition (C_{Bdes}) is expressed using Eq. (1).

$$C_{Bdes} = \frac{\nabla_{des}}{L_{pp} B_{max} d_{mid}} \tag{1}$$

where ∇_{des} is the displacement volume at the design load condition, L_{pp} is the ship length between perpendiculars, B_{max} is the maximum ship breadth, and d_{mid} is the midship draught at the design load condition.

When C_{Bdes} is unknown, it is estimated using the regression formula (Eq. (2)), which was translated to match recent ships based on the Heckscher formula[6] (Eq. (3)).

$$C_{Bdes} = \begin{cases} \mathrm{Min}(C_{BH} + 0.08, 0.875) & \text{for Bulker, Tanker and General cargo ship} \\ \mathrm{Min}(C_{BH}, 0.875) & \text{for Container ship} \\ \mathrm{Min}(C_{BH} - 0.08, 0.875) & \text{for RoRo ship} \end{cases} \tag{2}$$

$$C_{BH} = 1.04 - 1.67 Fr \tag{3}$$

$$Fr = \frac{V}{\sqrt{L_{pp} g}} \tag{4}$$

where Fr is the Froude number, V is the design speed, and g is the gravitational acceleration. Fig. 1 shows the relation between C_{Bdes} and Fr using data that can be opened for public.

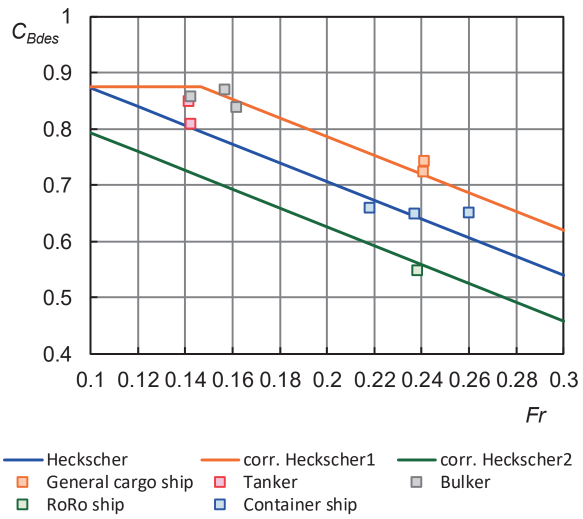


Fig. 1 Estimation of block coefficient at design load condition.

Assuming that the waterline shape is constant, i.e., the waterline area (A_w) is constant, against draught change, actual displacement is expressed using Eq. (5), where d_v is the midship draught during a voyage. From Eq. (5), the block coefficient during a voyage (C_{Bv}) can be expressed using Eq. (6). Here, C_w is the water plane area coefficient and its estimation will be discussed in Section 2.2.

$$\nabla_v = \nabla_{des} - A_w(d_{mid} - d_v) \tag{5}$$

$$C_{Bv} = C_{Bdes}\frac{d_{mid}}{d_v} - C_w\left(\frac{d_{mid}}{d_v} - 1\right) \tag{6}$$

$$C_w = \frac{A_w}{L_{pp} B_{max}} \tag{7}$$

2.2 Water plane area coefficient

Estimation of C_w is necessary for estimating C_{Bv} and is described below.

Based on the data of a chart of the Shipbuilding Design Handbook[6], C_w can be estimated using the regression formulas on the prismatic coefficient (C_P). The chart plotting recent ship data is shown in Fig. 2. The empirical formula is derived as Eq. (8). If C_P is unknown, it can be estimated using the regression formula for the midship section coefficient (C_M) (Eq. (10))[5],. The relations between C_P - C_B and C_M- C_B are also shown in Fig. 2.

$$C_w = \begin{cases} 0.845C_P + 0.211 & \text{for Bulker, Tanker and General cargo ship} \\ 0.845C_P + 0.287 & \text{for Container ship and RoRo ship} \end{cases} \quad (8)$$

$$C_P = \frac{C_B}{C_M} \quad (9)$$

$$C_M = \begin{cases} -6.6698C_B^4 + 22.631C_B^3 - 28.838C_B^2 + 16.368C_B - 2.4978 \\ \qquad \text{for } 32.2\text{m} \le B_{max} \le 32.26\text{m and } 0.4 \le C_B \le 0.9 \\ -7.0219C_B^4 + 23.589C_B^3 - 29.771C_B^2 + 16.755C_B - 2.5556 \\ \qquad \text{for } B < 32.2\text{m},\ 32.26\text{m} < B_{max} \text{ and } 0.4 \le C_B \le 0.9 \end{cases} \quad (10)$$

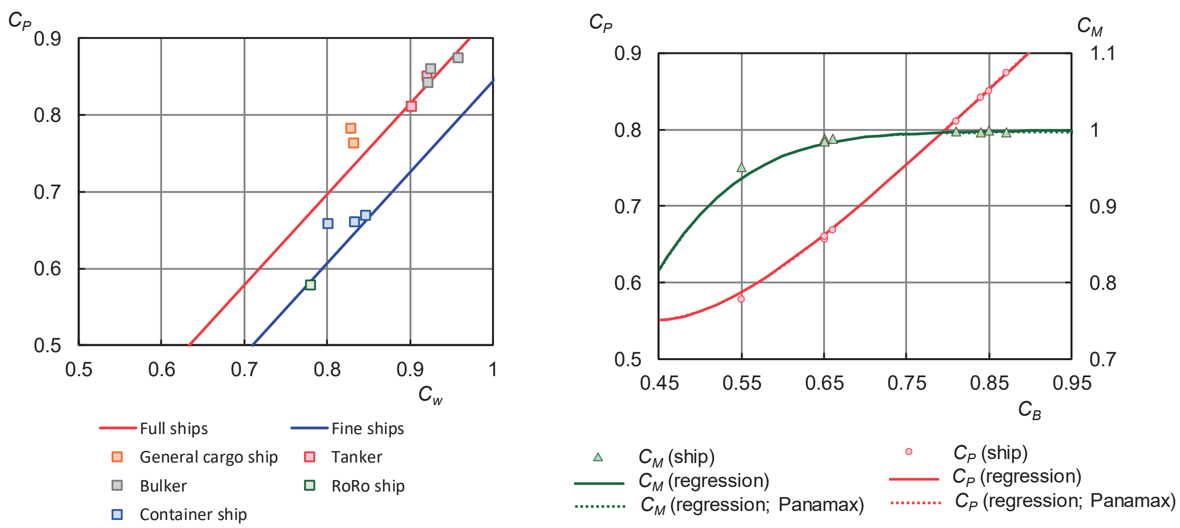


Fig. 2 Empirical relations (left; C_P - C_w, and right; C_P - C_B and C_M - C_B).

2.3 Longitudinal centre of buoyancy

The longitudinal centre of buoyancy is important for performance estimation. If this value is obtained at the voyage load condition, it is better to use that value. However, if it is not obtained, an estimation formula is needed.

The distance from the midship to the longitudinal centre of buoyancy (X_{CB}) is converted to l_{CB} (%L_{pp}, which is the ratio of L_{pp}). The relation is shown in Eq. (11). A positive X_{CB} is defined as from the midship to the bow, which is shown in Fig .3, whereas a positive l_{CB} is defined here as from the midship to the stern.

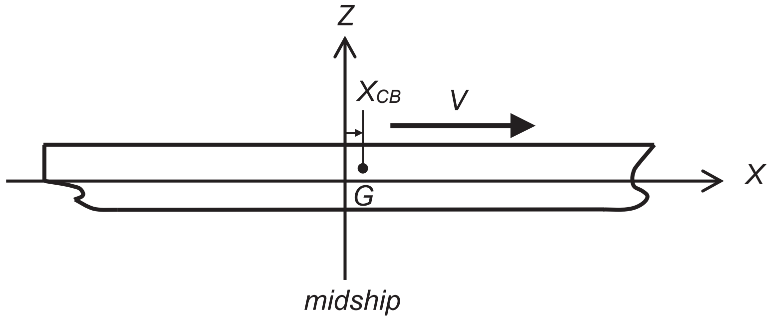


Fig. 3 Coordinate system.

$$X_{CB} = -l_{CB}\frac{L_{pp}}{100} \tag{11}$$

1) Estimating the longitudinal centre of buoyancy at the design load condition (l_{CB}).

The l_{CB} at the design load condition is estimated using Eq. (12) [5].

$$l_{CB} = -23.0161911C_{Bdes} + 15.0527428 + 44.5\ dFr \tag{12}$$
$$dFr = Fr - Fr_{STD} \tag{13}$$
$$Fr_{STD} = -0.4233695C_{Bdes} + 0.4933884 \tag{14}$$

2) Estimating the longitudinal centre of buoyancy at the voyage load condition (l_{CBv})

The l_{CB} at the voyage load condition (l_{CBv}) is estimated using Eq. (15), which matches the value from Eq. (11) at the design load condition.

$$l_{CBv} = -23.0161911C_{Bdes} + 15.0527428 + 44.5\ dFr_v \tag{15}$$
$$dFr_v = Fr - Fr_{STDv} \tag{16}$$
$$Fr_{STDv} = -0.4233695C_{Bv} + 0.4933884 \tag{17}$$

3) Validation

To validate Eq. (15), X_{CB} for various voyage conditions is compared with the ship data. For this, Eq. (18) is used instead of Eq. (12) for a different draught.

$$l_{CBv} = -23.0161911C_{Bv} + 15.0527428 + 44.5\ dFr_v \tag{18}$$

The validation is carried out for a bulk carrier and a roll-on/roll-off (RoRo) vehicle carrier. The principal dimensions of each ship are shown in Table 1, and the results are shown in Fig. 4, where dN is the ratio of the design to voyage draughts.

From Fig. 4, X_{CB} from Eq. (18) shows the opposite tendency to that derived from ship data, but X_{CB} from Eq. (15) shows the right tendency.

Table 1 Principal dimensions.

Dimensions	Bulk carrier	RoRo vehicle carrier
Ship length between perpendiculars (L_{pp})	217.487 m	190.0 m
Maximum ship breadth (B_{max})	32.26 m	32.26 m
Midship draught (d_{mid})	14.0 m	9.0 m
Block coefficient at the design load condition (C_{Bdes})	0.851	0.55
Design speed (V)	14.5 knots	20.0 knots

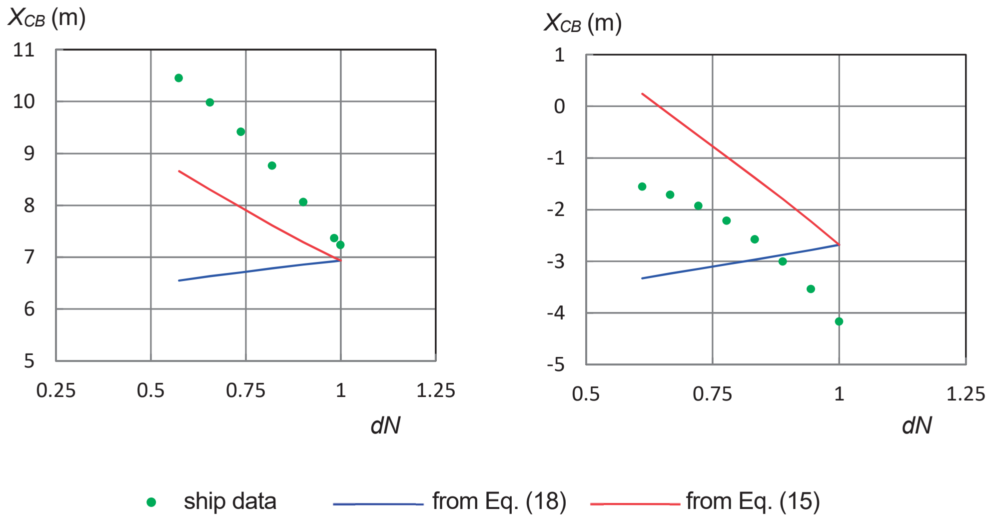


Fig. 4 Validation of X_{CB} (left; Bulk carrier, right; RoRo vehicle carrier).

2.4 Draught and trim at ballast load condition

When simulating the ship performance at the ballast load condition, information on the draught and the trim is required as well as C_B and X_{cb} value. However, if it is not obtained, it must be estimated. If the draught and trim are known in addition to the principal dimensions, it is possible to estimate the hull form at the ballast load condition by using UNITAS[3), 4)].

Using tankers, bulk carriers, and general cargo ships of the recent ship data, the midship draught at the ballast load condition (d_{mb}) and the trim (*trim*) are varied, as shown in Fig. 5, where d_m is the midship draught at the design load condition, and D_P is the propeller diameter. Eqs. (19) and (20) show the banded empirical relations.

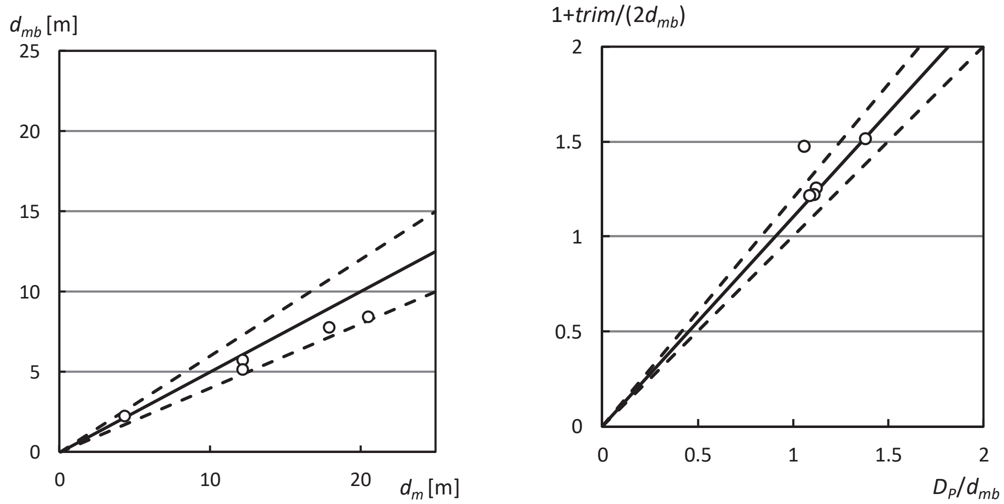


Fig. 5 Empirical relations for draught and trim at ballast load condition.

$$d_{mb} = \begin{cases} 0.4d_m & \text{lower line} \\ 0.5d_m & \text{average line} \\ 0.6d_m & \text{higher line} \end{cases} \tag{19}$$

$$1 + \frac{trim}{2d_{mb}} = \begin{cases} D_P / d_{mb} & \text{small trim} \\ 1.1D_P / d_{mb} & \text{average trim} \\ 1.2D_P / d_{mb} & \text{large trim} \end{cases} \tag{20}$$

From Eq. (20), *trim* is expressed as Eq. (21).

$$trim = \begin{cases} 2(D_P - d_{mb}) & \text{small trim} \\ 2(1.1D_P - d_{mb}) & \text{average trim} \\ 2(1.2D_P - d_{mb}) & \text{large trim} \end{cases} \tag{21}$$

When estimating the draught and trim at the ballast condition, the average lines in Eqs. (19) and (21) can be used, however, in order not to expose the propeller, $trim \geq 0$ is required for Eq. (21).

2.5 Draught and trim correction for area exposed to wind

Regression formulae have been developed to estimate wind forces[7], and empirical formulae have also been developed for the input parameters of these formulae[8] and are implemented in VESTA[4] and UNITAS[3), 4]. However, considering the ship condition during operation, it is necessary to estimate or correct the values at ballast load condition.

These input parameters are illustrated in Fig. 6, where A_T is the transverse projected area above the waterline including superstructures, A_L is the lateral projected area above the waterline including superstructures, A_{OD} is the lateral projected area of superstructures above the upper deck, C_{dis} is horizontal distance from midship section to centre of A_L, H_{BR} is the height of top of superstructure (e.g., bridge), and H_C is the height from the waterline to centre of A_L. The subscript 0 means the value at even keel. The correction of the parameters for draught and trim change is carried out using the geometrical relations.

The draught variation (Δd) is expressed using Eqs. (22) and (23), where the subscript a means aft, f means fore, and 0 means the draught at even keel.

$$\Delta d_a = d_a - d_{a0} \tag{22}$$

$$\Delta d_f = d_f - d_{f0} \tag{23}$$

Fig. 6 shows various ship conditions. The red line shows the waterline at even keel.

From the geometric relations, A_T is expressed using Eq. (24).

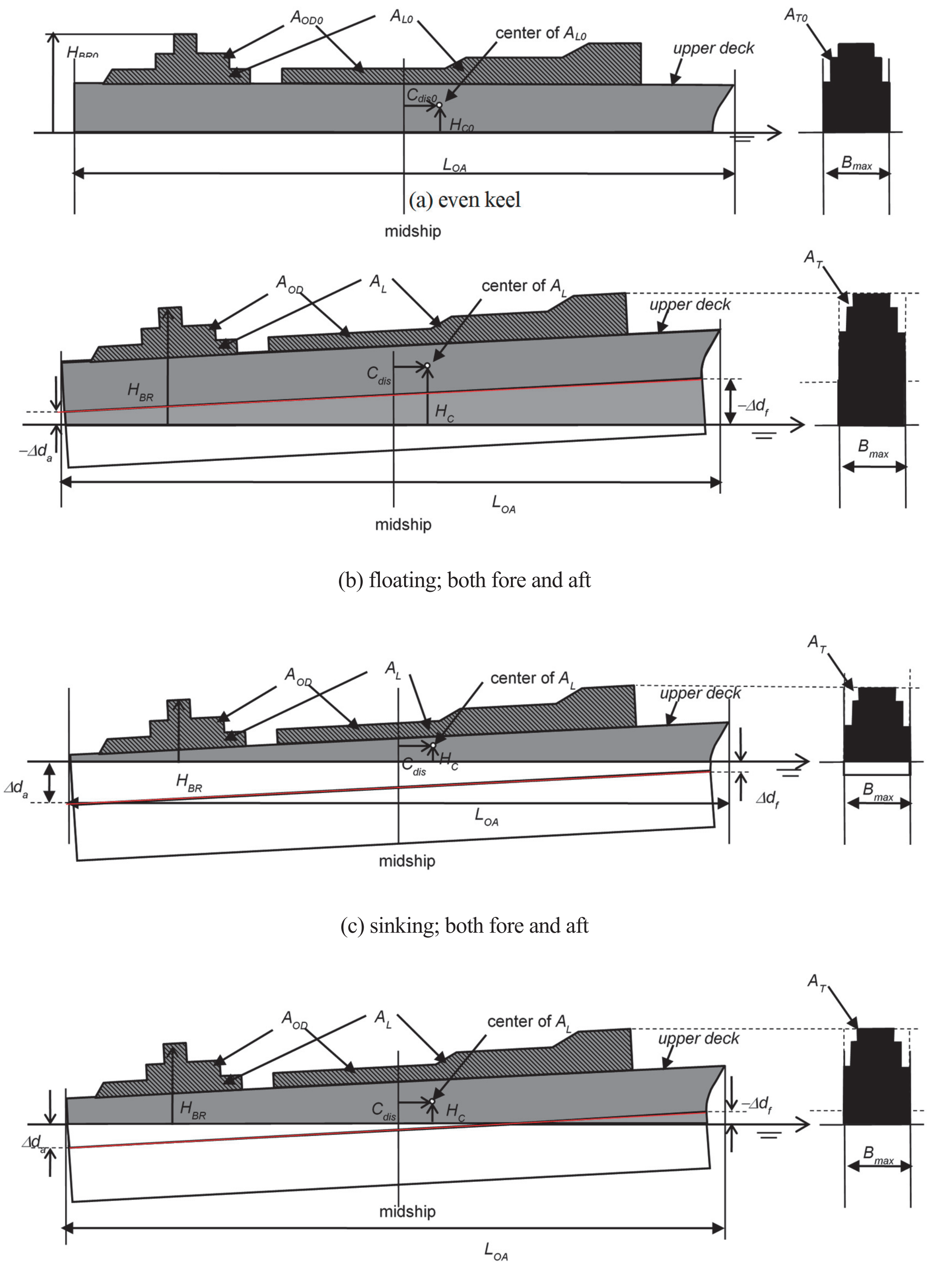
$$A_T = A_{T0} + \max(-\Delta d_a, -\Delta d_f) \cdot B_{max} \tag{24}$$

The increased A_L from even keel is approximated as a trapezoidal shape, A_L is approximated using Eq. (25). It is not necessary to estimate A_{OD} since it does not change along with the draught and trim change.

$$A_L = A_{L0} + \frac{1}{2} L_{pp} (-\Delta d_a - \Delta d_f) \tag{25}$$

From the geometric relations, H_{BR} is expressed using Eq. (26).

$$H_{BR} = H_{BR0} + \max(-\Delta d_a, -\Delta d_f) \tag{26}$$



(b) floating; both fore and aft

(c) sinking; both fore and aft

(d) floating at fore but sinking at aft

Fig. 6 Ship conditions.

The increased A_L from even keel (A_{inc}) is approximated as a trapezoid, the area A_{inc} is estimated using Eq. (27).

$$A_{inc} = \frac{1}{2} L_{pp} (-\Delta d_a - \Delta d_f) \tag{27}$$

The horizontal distance (C_{inc}) from the midship to the centre of the increased trapezoid is expressed using Eq. (28), and the height (H_{Cinc}) from the waterline for the increased trapezoid is expressed using Eq. (29).

$$C_{inc} = \begin{cases} \dfrac{\Delta d_f - \Delta d_a}{6(\Delta d_a + \Delta d_f)} L_{pp} & (\Delta d_a + \Delta d_f \neq 0) \\ 0 & (\Delta d_a + \Delta d_f = 0) \end{cases} \tag{28}$$

$$H_{Cinc} = \begin{cases} \dfrac{\Delta d_f{}^2 + \Delta d_a \Delta d_f + \Delta d_a{}^2}{-3(\Delta d_a + \Delta d_f)} & (\Delta d_a + \Delta d_f \neq 0) \\ 0 & (\Delta d_a + \Delta d_f = 0) \end{cases} \tag{29}$$

From the area ratio, C_{dis} and H_C can be expressed using Eqs. (30) and (31), respectively.

$$C_{dis} = \frac{A_{L0} C_{dis0} + A_{inc} C_{inc}}{A_{L0} + A_{inc}} \tag{30}$$

$$H_C = \frac{A_{L0} \left\{ H_{C0} + \dfrac{-\Delta d_f + \Delta d_a}{L_{pp}} \left(\dfrac{L_{pp}}{2} + C_{dis0} \right) \right\} + A_{inc} H_{Cinc}}{A_{L0} + A_{inc}} \tag{31}$$

2.6 Length overall

Since the length overall (L_{OA}) is related to the estimated wind forces, it is necessary to determine if this value is known or not known. If L_{OA} is known, it might be restricted due to a regulation or law and can be used. Otherwise, a regression formula derived from ship data is needed. Fig. 7 shows the relation between L_{OA} and L_{pp} from recent ship data. Equation (32) is the regression formula. For a RoRo vehicle carrier of 190 m ≤ L_{pp} ≤ 192 m, it is better to use L_{OA}=200 m.

$$L_{OA} = 1.04 L_{pp} \tag{32}$$

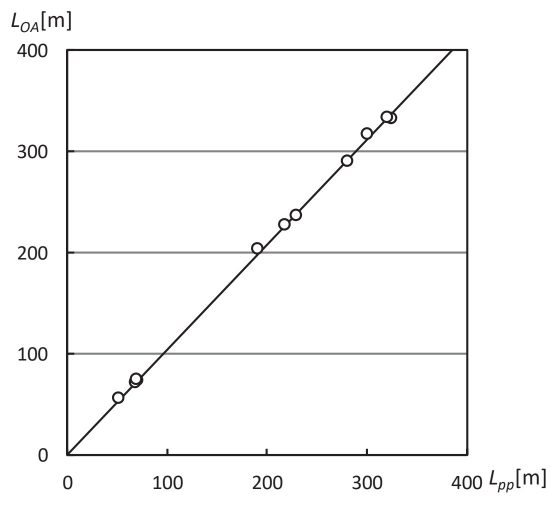


Fig. 7 Relation between L_{OA} and L_{pp}.

2.7 Propeller diameter

To make an estimation of required power of a ship, it is necessary to input the D_P and propeller characteristics in open water. These characteristics can be estimated using UNITAS[3), 4)]. If D_P is not known, it is necessary to estimate it.

The D_P can be estimated using Eq. (33)[5)].

$$D_P = (C_1 d_a + C_2) d_a \tag{33}$$

where d_a is the draught at aft, C_1 and C_2 are the coefficients for propeller diameter, the values of which are shown in Table 2. The relation between D_P and d_a is shown in Fig. 8.

Table 2 Coefficients for propeller diameter.

Ship type	C_1	C_2
Container ship	0.0	0.650
RoRo ship	-0.0020	0.710
Bulker	-0.0080	0.600
Tanker	-0.0044	0.575

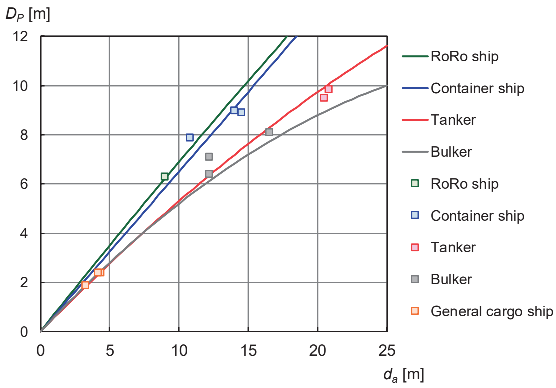


Fig. 8 Relation between D_P and d_a.

2.8 Expanded blade area ratio of a propeller

When estimating propeller characteristics in open water, chart-based estimation can be done, and it is implemented in UNITAS[3), 4)]. To use the chart, it is necessary to input the expanded blade area ratio (a_E).

An estimation method for a_E was proposed by Ito[9)]. The method derives the relation between $K=PS/(V_s D_P^2 a_E)$ and $N_P D_P$, where PS is the power of the main engines at NOR in PS, V_s is the ship speed at NOR of 0% sea margin in knots, and N_p is the rate of the propeller revolution in rpm. For three-blade propellers, a_E should be increases by 5% to apply it. Based on the method, similar charts are published[10), 11)]. The combined chart is shown in Fig. 9, in which the unit of the parameters are changed, i.e., PS' is the power of the main engines at NOR in kW, V_s' is the ship speed at NOR of 0% sea margin in m/s, and n_p' is the rate of the propeller revolution at NOR in rps.

Since the evaluation conditions are difficult for practical use, the definition of ship speed and power is changed. The parameters are redefined as $K_p = MCR / (V_{des} D_p^2 a_E)$ and $n_p D_p$, as shown in Fig. 10, where MCR is the maximum continuous rate of the main engines in kW, V_{des} is the designed speed in m/s, and n_p is the rate of the propeller revolution at MCR in rps.

Although comparison between Fig. 9 and Fig. 10 is difficult because of changing parameters, the recent ship data are divided into the two groups; full ships (tankers, bulkers, and general cargo ships) and fine ships (RoRo and container ships). Therefore, the empirical formula is expressed as Eq. (34). The parameters are listed in Table 3.

The evaluation data are 4 to 6 blade propellers and a_E ranging from 0.4 to 0.65 for full ships and from 0.65 to 0.8 for fine ships.

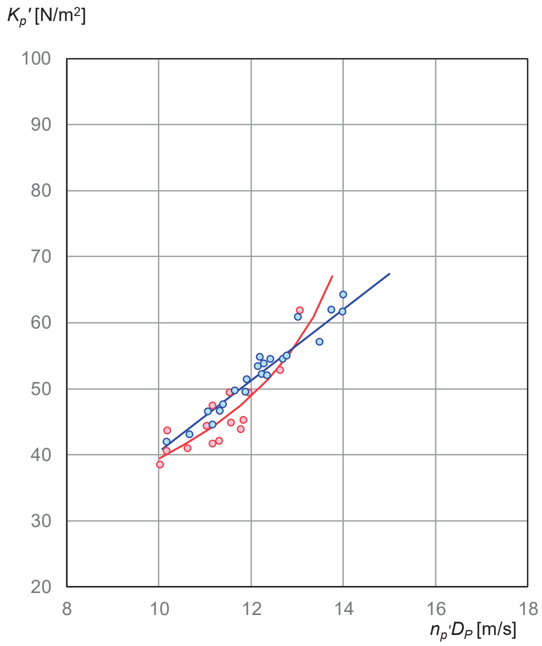


Fig. 9 Rearranged chart of estimating a_E (Blue; reference 10), Red; reference 11)).

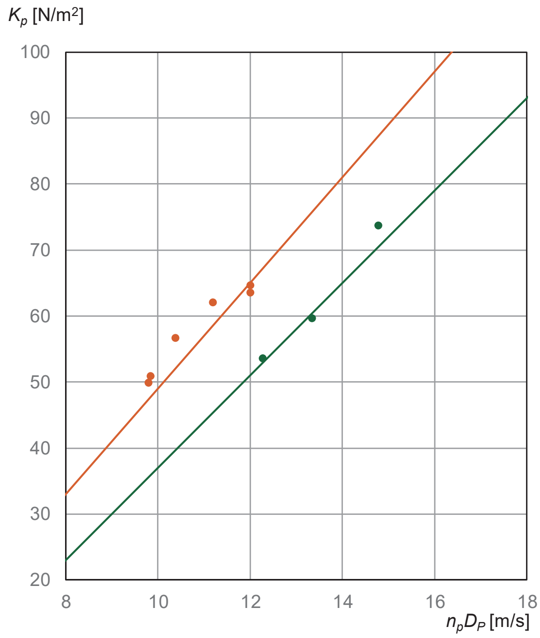


Fig. 10 Distribution of a_E. (Orange; full ships, Green; fine ships).

$$a_E = \frac{1}{K_p} \frac{MCR}{V_{des} {D_p}^2} \tag{34}$$

$$K_p = K_{p1}(n_p D_P) + K_{p0} \tag{35}$$

Table 3 Coefficients for a_E.

	K_{p1} [Ns/m^3]	K_{p0} [N/m^2]
Full ships	8.0	-31.0
Fine ships	7.0	-33.0

To make validation of the formula, estimation error (Err) for a_E is evaluated at first. Difference between a_{Eest}, which is estimated from Eq. (34), and the actual a_E is determined using Eq. (36).

$$Err = \frac{a_{Eest} - a_E}{a_E} \tag{36}$$

From the comparison, it was found that *Err* ranged from -2 to 9% (average 4%) for full ships and from -1 to 5% (average 2%) for fine ships.

Next, the effect of a_E on propeller efficiency in open water (η_O) is evaluated. The propeller was a four-blade propeller for a bulk carrier with a pitch ratio of 0.844 and a_E of 0.425. The propeller characteristics in open water are shown in Fig. 11. Estimated a_E was obtained using UNITAS, where a_E was derived from Eq. (34) (a_{Eest}), and POT was obtained from tank tests. The difference in η_O was about 0.72% at the propeller advance ratio J = 0.6, while a_{Eest} was 0.464 (9% larger than the true value). Therefore, Eq. (34) is suitable to estimate the propeller characteristics in open water.

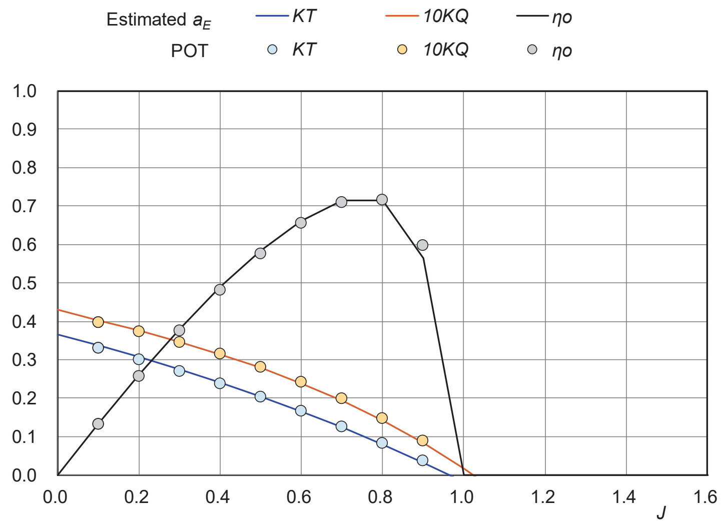


Fig. 11 Effect of a_E on propeller characteristics in open water.

2.9 Rudder area

1) Estimation at design load condition

Rudder dimensions are required for estimating rudder forces. If the dimensions are not known, they should be estimated. The rudder dimensions to be estimated are illustrated in Fig. 12.

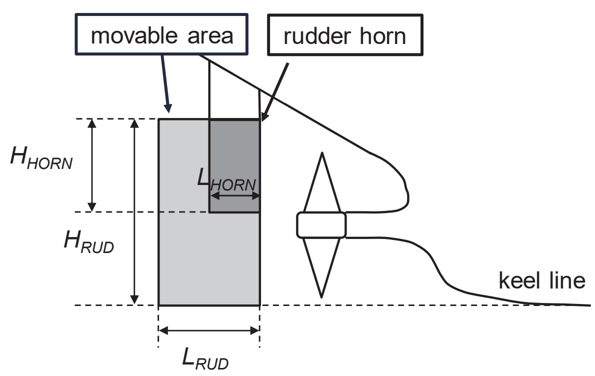


Fig. 12 Rudder dimensions at design load condition.

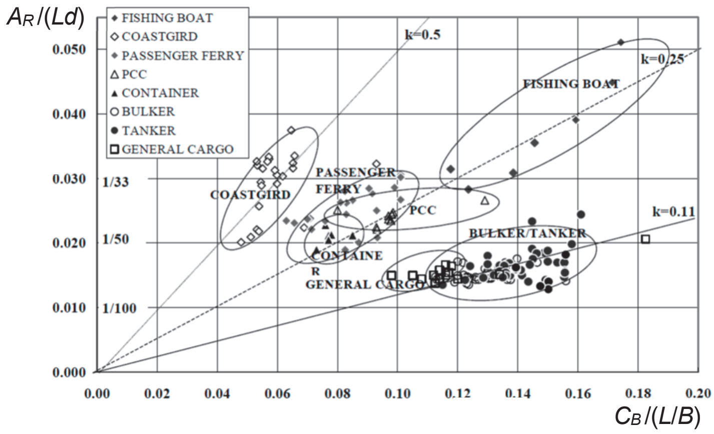


Fig. 13 Rudder movable area[12].

From the chart[12] shown in Fig. 13, the rudder movable area (A_R) can be estimated by d_m, C_B, and B_{max}. The A_R can be obtained from Eq. (37) by using the correction factor (R_k) for each ship type. The R_k is expressed using Eq. (38)

$$A_R = R_k C_B B_{max} d_m \tag{37}$$

$$R_k = \begin{cases} 0.11 & \text{Bulker and Tanker} \\ 0.25 & \text{Container ship and RoRo ship} \end{cases} \tag{38}$$

The total rudder area (A_{RT}) including the rudder horn can be estimated using Eq. (39) using the correction factor for the total rudder area (R_{kt}). The R_{kt} is derived from the recent ship data and expressed using Eq. (40).

$$A_{RT} = R_{kt} A_R \tag{39}$$

$$R_{kt} = \begin{cases} 1.20 & \text{Bulker, Tanker and Container ship} \\ 1.15 & \text{RoRo ship} \end{cases} \tag{40}$$

The rudder height (H_{RUD}) can be estimated using Eq. (41) where k_{dr} is the empirical coefficient derived from the recent ship data and expressed using Eq. (42). The aspect ratio of the rudder (Λ_R) is calculated using Eq. (43) and the height of the rudder horn (H_{HORN}) can be set to half H_{RUD} by using Eq. (44).

$$H_{RUD} = k_{dr} d_m \tag{41}$$

$$k_{dr} = \begin{cases} 0.75 & \text{Bulker and Tanker} \\ 0.85 & \text{Container ship} \\ 0.90 & \text{RoRo ship} \end{cases} \tag{42}$$

$$\Lambda_R = \frac{{H_{RUD}}^2}{A_{RT}} \tag{43}$$

$$H_{HORN} = 0.5 H_{RUD} \tag{44}$$

The cord length of the rudder (L_{RUD}) and length of the rudder horn (L_{HORN}) can be estimated using Eqs. (45) and (46), respectively.

$$L_{RUD} = \frac{A_{RT}}{H_{RUD}} \tag{45}$$

$$L_{HORN} = \frac{(R_{kt} - 1)A_R}{H_{HORN}} \tag{46}$$

2) Estimation at voyage load condition

During the voyage, the effective rudder area differs from the rudder area due to the draught and trim change. When d_a is larger than H_{RUD}, the rudder area is used at the design load condition. However, when d_a is smaller than H_{RUD}, the rudder area should be estimated. The rudder dimensions at voyage load condition are shown in Fig. 14.

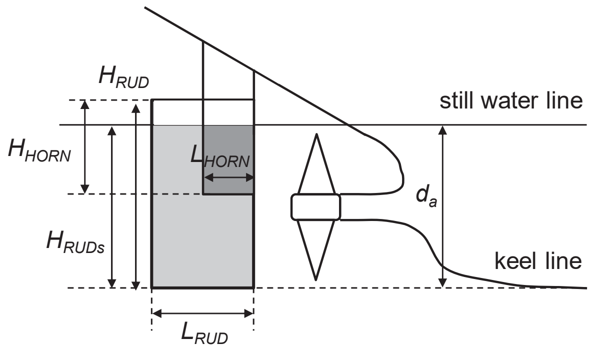


Fig. 14 Rudder dimensions at voyage load condition.

Assuming the H_{RUD} during the voyage (H_{RUDs}) is equal to d_a, the rudder movable area (A_{Rs}), total rudder area (A_{RTs}) and aspect ratio of the rudder (Λ_{Rs}) during the voyage are estimated from the geometric relations expressed using Eqs. (48), (49), and (50), respectively.

$$H_{RUDs} = d_a \tag{47}$$

$$A_{Rs} = 0.5H_{RUD}L_{RUD} + (d_a - 0.5H_{RUD})(L_{RUD} - L_{HORN}) \tag{48}$$

$$A_{RTs} = H_{RUDs}L_{RUD} \tag{49}$$

$$\Lambda_{Rs} = \frac{H_{RUDs}{}^2}{A_{RTs}} \tag{50}$$

2.10 Specific fuel consumption

To estimate fuel consumption, it is necessary to input the specific fuel consumption (*SFC*). This value depends on the power and revolution rate of the engines. Normally, it is evaluated by the change in the engine output since information of the two parameters cannot be obtained. The change in *SFC* with respect to the engine output shifts depending on the fuel used, so it is better to estimate from the operation data. However, if this is not available, estimation is necessary.

The relationship between the output of the main engines (*BHP*) and *SFC* can be expressed using a quadratic expression (Eq. (51)) with the minimum *SFC* at 75%*MCR*. The relationship is shown in Fig. 15.

$$SFC = a(BHP - 0.75MCR)^2 + b \tag{51}$$

where *a* and *b* are the coefficients determined in Table 4. If the actual *SFC* at 75%*MCR* is known, it should be used as *b* in Eq. (51).

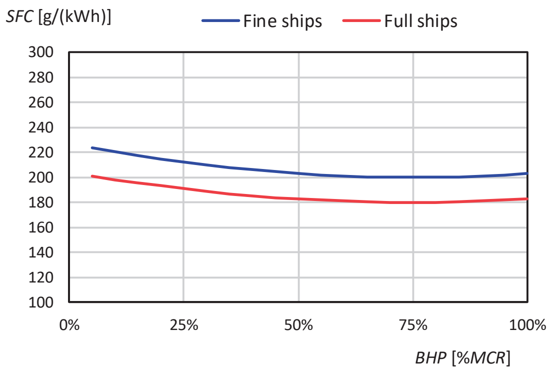


Fig. 15 Estimation of *SFC*.

1) Full ships; tanker and bulker

b=170.0 g/(kWh) and *SFC* at 50%*MCR* and *MCR* set 1.5% larger than *SFC* at 75%*MCR*.

2) Fine ships; container and RoRo ships

b=200.0 g/(kWh) and *SFC* at 50%*MCR* and *MCR* set 1.5% larger than *SFC* at 75%*MCR*.

Table 4 Coefficients for estimating *SFC*.

Ship type	a [g/(kW^{3}h)]	b [g/(kWh)]
Full ships	$0.24b/MCR^2$	170.0
Fine ships	$0.24b/MCR^2$	200.0

3. Comprehensive evaluation

Using these empirical formulae, a comprehensive evaluation was carried out[13] for the purpose of developing an advanced weather routing system. The evaluation was carried out using a 200-m-long RoRo vehicle carrier. The dimensions and performance of the ship were estimated using the formulae shown in this paper since the weather routing service often cannot obtain the data. Five voyage simulations for ship speed, engine output, and fuel consumption were conducted and compared with the ship monitoring data obtained onboard. The estimated total fuel consumption for the five voyages varied from -2.6 to 1.7% of the measured value and its average was 0.5% of that.

It is found that the formulae shown in this paper are sufficient to simulate ship performance.

4. Conclusions

We developed empirical formulae for estimating ship performance that use recent ship data and geometric relationships.

Though improving the accuracy for estimating longitudinal centre of buoyancy is for future work, these empirical formulae are sufficiently accurate for estimating ship performance.

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