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AN APPROXIMATE METHOD FOR CALCULATION OF MEAN STATISTICAL VALUE OF SHIP SERVICE SPEED ON A GIVEN SHIPPING LINE , USEFUL IN PRELIMINARY DESIGN STAGE

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ABSTRACT

During ship design, its service speed is one of the crucial parameters which decide on future economic effects. As sufficiently exact calculation methods applicable to preliminary design stage are lacking the so called contract speed which a ship reaches in calm water is usually applied. In the paper [11] a parametric method for calculation of total ship resistance in actual weather conditions (wind, waves, sea current), was presented. This paper presents a parametric model of ship propulsion system (screw propeller - propulsion engine) as well as a calculation method, based on both models, of mean statistical value of ship service speed in seasonal weather conditions occurring on shipping lines. The method makes use of only basic design parameters and may be applied in preliminary design stage.

Keywords: service speed, shipping lines, preliminary design

INTRODUCTION

During ship design one of the crucial parameters which decide on future economic effects is ship service speed in seasonal weather conditions occurring on a given shipping line (or several lines). The service speed for existing ship can be determined during its operation or calculated on the basis of complete design documentation or results of ship model basin tests. The algorithm and results of such calculations were presented in [6] ÷ [8]. The method cannot be used however in preliminary ship design stage where important decisions are made on the basis of only main design parameters (concerning ship hull geometry) which a ship designer has then at his disposal. For this reason a contract speed - to be checked in calm water trials after completing the ship - is introduced into ship building contract. Ship economic effectiveness mainly depends on service speed achieved in actual weather conditions (instantaneous or seasonal). Hence development of a method for calculation of the speed, applicable in preliminary design stage, would make it possible to optimize ship design parameters from the point of view of maximization of ship owner profits to be gained from operation of a ship on a given shipping line.

SHIP PROPULSION

In order to move a ship at a given speed the ship propeller thrust T has to equilibrate the total ship resistance R_C in compliance with the formula:

$$T - \frac{R_C}{1-t} = 0 \qquad (1)$$

and its engine power output N (in terms of torque) has to equilibrate the propeller rotational moment Q:

$$Q - \frac{N \cdot \eta_G \cdot \eta_S \cdot \eta_{RT}}{2\pi \cdot n_S} = 0 \qquad (2)$$

where:

n_S - engine rotational speed (in case of slow speed engine: ns = np – propeller rotational speed),
t - thrust deduction,
η_G - transmission gear efficiency (if applied),
η_S - shaft line efficiency,
η_{RT} - rotational „efficiency".

During voyage if weather conditions change the total resistance R_C also changes, hence propulsion engine load resulting from the moment Q, will be changeable too. Engine working point determined by the power output N and the rotational speed n_s will be changed but must be still located within engine working area. A complete algorithm for searching for the engine working point (N, n_s) in changeable weather conditions was presented in [7]. Calculation results given in the publications [7] and [8] were obtained from the model based on complete data concerning ship hull, screw propeller and propulsion engine. In order to make the model applicable to preliminary design stage , approximate formulae for the thrust T, torque Q, power output N, rotational speed n_s, propulsion engine working area as well as the coefficients t, w_T and η_{RT} should be developed.

APPROXIMATE RELATIONS FOR PROPELLER THRUST AND TORQUE

The mathematical model of ship propulsion system, developed under assumption that complete documentation concerning screw propeller and propulsion engine is available, was presented in [7].

Calculations of exact values of thrust and torque acc. [7] were conducted for many existing ships (163 ships in total) with taking into account their types (bulk carriers, container ships,oil tankers and LNG tankers). Range of examined parameters for bulk carriers is given in Tab. 1.

Tab. 1. Range of examined parameters for bulk carriers

Ship type		L [m]	B [m]	T [m]	C_B [-]	∇ [m³]	V [m/s]	n_p [1/s]
Bulk carriers	max	325	60	18	0,885	288000	9,5	3,33
	min	103	14,5	7	0,734	9770	2	0,44

The approximate model of the propeller thrust T and torque Q was developed on the basis of the obtained results of calculation based on these parameters. Out of many tested methods, the best results were achieved by making use of artificial neural networks.

The first step in developing the model of approximating function was to determine a set of parameters which significantly affect changeability of the thrust T and torque Q of screw propeller, are known already in preliminary design stage and may serve as arguments of the function in question. On the basis of preliminary analyses and personal experience, out of parameters of the examined group of ships, the following quantities were finally selected to be arguments of approximating functions: ship length between perpendiculars L, breadth B, draught T, hull block coefficient C_B, displacement, ∇, ship speed V and propeller rotational speed n_p.

Structure of artificial neural networks as well as activation functions to be used for the thrust T and torque Q, were finally selected on the basis of a compromise between accuracy, simplicity and learning time. In order to simplify solution, the same structure (i.e. 7x11x1), Fig. 1, and network parameters (input data and form of activation functions – sigmoidal and linear) were assumed for thrust and torque.

The general form of the searched for approximating function is as follows:

$$T,Q = f\left(L,B,T,C_B,\nabla,V,n_p\right) \tag{3}$$

The developed approximating function for T and Q has the following form:

$$f(x_1 \cdots x_k) = \sum_{i=1}^{11}\left(c_i \cdot \left(\frac{2}{1+e^{-2\cdot\left(\sum_{k=1}^{7} a_{i,k}x_k + b_i\right)}} - 1\right)\right) + D \tag{4}$$

where : xk =[L, B, T, C_B,∇, V, n_p] are successive arguments of neural network (input data); whereas values of coefficients for each network (thrust T and torque Q) for bulk carriers are contained in Tab. 2 and 3.

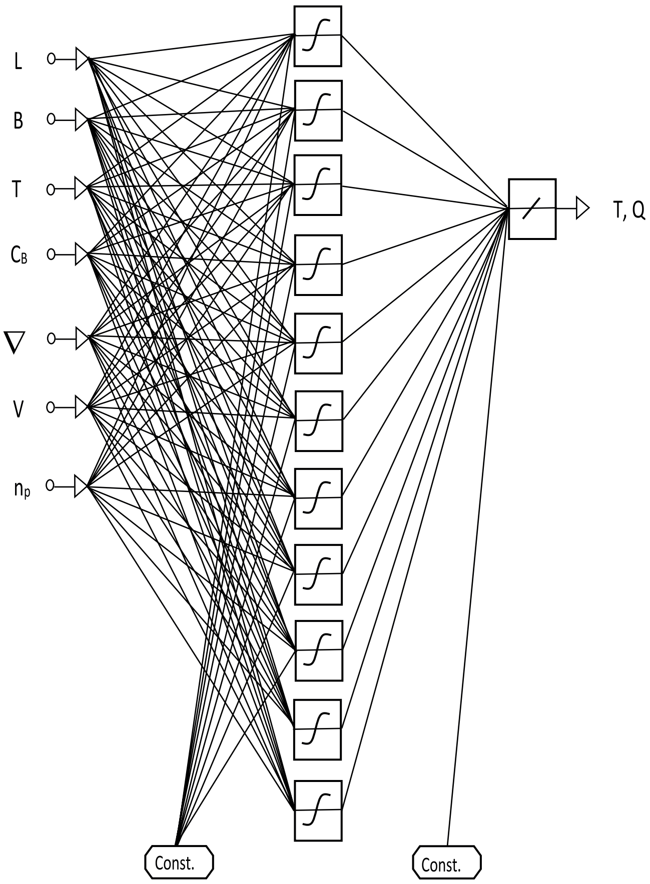


Fig. 1. Structure of the designed neural network

Tab. 2. Values of coefficients for the network, acc. Eq.(4) , which approximates the propeller thrust T for bulk carriers

$a_{i,j}$	1	2	3	4	5	6	7	b_i	c_i
1	-1,323	-0,033	0,461	-0,553	-1,067	-1,092E-3	-1,820	3,128	-584,788
2	1,278	0,126	-0,407	0,570	1,058	1,328E-3	1,949	-2,744	-230,137
3	17,232	-15,595	1,199	-15,519	-0,394	-9,171E-5	0,043	-10,215	-21,977
4	-10,771	3,117	-5,762	-0,661	11,067	1,208E-3	-1,083	9,107	-58,948
5	-5,777	1,788	-8,797	0,059	6,935	-1,279E-3	-0,179	4,642	-1,395
6	11,005	-3,053	5,818	0,733	-11,355	-1,200E-3	1,096	-9,300	-59,993
7	1,284	7,278	7,813	-0,433	-32,028	-4,992E-4	-0,041	-18,075	-4,547
8	-5,441	-10,262	3,827	-3,511	13,081	3,300E-4	0,088	5,268	-3,685
9	-0,849	-0,305	2,100	-0,701	-3,842	-6,562E-5	0,021	-3,540	40,213
10	-0,886	-12,840	-5,727	-1,824	47,000	-5,511E-4	-0,183	29,899	1,789
11	-41,397	-54,010	-4,315	90,146	-55,178	-3,383E-4	-0,381	-20,966	-2,921
D	363,578								

The calculation process of values of the screw propeller thrust T and torque Q with taking into account ship types , and making use of the designed artificial neural network, its structure and values of coefficients (weighing factors) determined from learning process, runs as follows:

1. the scaling (normalizing) of the input data x_k =[L, B, T, C_B,∇, V, np] for x_{max} and x_{min} values (minimum and maximum value of input data) from Tab. 1;
2. the calculation of values from the network, acc. Eq. (4), and parameters in Tab. 2 and 3;
3. the scaling of the values obtained from the network and calculation of final values of the propeller thrust and torque:

$$T, Q = \frac{(f(x_k)+1)(y_{max} - y_{min})}{2} + y_{min} \qquad (5)$$

where :

y_{min}, y_{max} – minimum and maximum values of input quantity – numerical values from the learning set (Tab. 4).

Tab. 3. Values of coefficients for the network, acc. Eq.(4), which approximates the propeller torque Q for bulk carriers

$a_{i,j}$	1	2	3	4	5	6	7	b_i	c_i
1	18,450	17,469	11,030	-10,470	-40,026	-1,402E-6	0,309	-22,720	-9,813
2	89,000	-55,992	-154,217	19,378	65,400	7,236E-6	-0,832	55,516	1034,157
3	10,695	9,503	2,905	2,361	-12,511	-9,180E-5	0,636	-4,301	-0,604
4	0,009	5,800	7,059	-0,133	-29,014	7,762E-5	-0,677	-15,748	-0,599
5	5,764	6,148	6,138	-2,228	-19,374	6,829E-6	-0,753	0,228	1249,010
6	43,162	-22,046	79,506	-23,143	-57,228	-7,233E-6	0,833	-53,624	1034,130
7	-124,473	-141,662	-74,237	25,945	210,380	6,670E-6	-0,279	116,263	9,288
8	32,567	-7,003	-7,839	10,332	-2,262	6,445E-6	0,819	-17,292	114,596
9	-7,283	-2,243	1,324	14,579	-13,893	1,957E-6	-0,435	-3,858	-9,193
10	-12,495	6,130	-3,518	2,406	1,148	-6,805E-6	0,753	-1,169	1246,846
11	1,310	2,542	3,186	-0,244	-5,081	-6,058E-6	0,709	-4,372	6,197
D	107,656								

Tab. 4. Range of examined parameters (thrust and torque) for bulk carriers

Ship type		T [kN]	Q [kNm]
Bulk carriers	max	9988,98	15999,39
	min	0,13	4,16

The correlation coefficient R2, spread diagrams of expected values against observed ones (i.e. those obtained from approximation versus reference ones) as well as mean square error showing learned network quality (Tab. 5), were taken as the basis for statistical verification. Quality assessment of the obtained approximations were performed also by analysing relative and absolute errors.

The subject - matter verification was done for bulk carriers built in Szczecin Shipyard (their main parameters are contained in [11]). Values of the screw propeller thrust T and torque Q, calculated by using the approximation (4), as well as results of the calculations performed in accordance with the algorithm given in [7], are presented in Fig. 2.

Tab. 5. Selected statistical parameters obtained from the used neural networks for bulk carriers

Ship type	Parameter	Correlation coefficient R^2	Mean square error
Bulk carriers	T	0,994	0,0004
	Q	0,999	0,00002

M1 bulk carrier

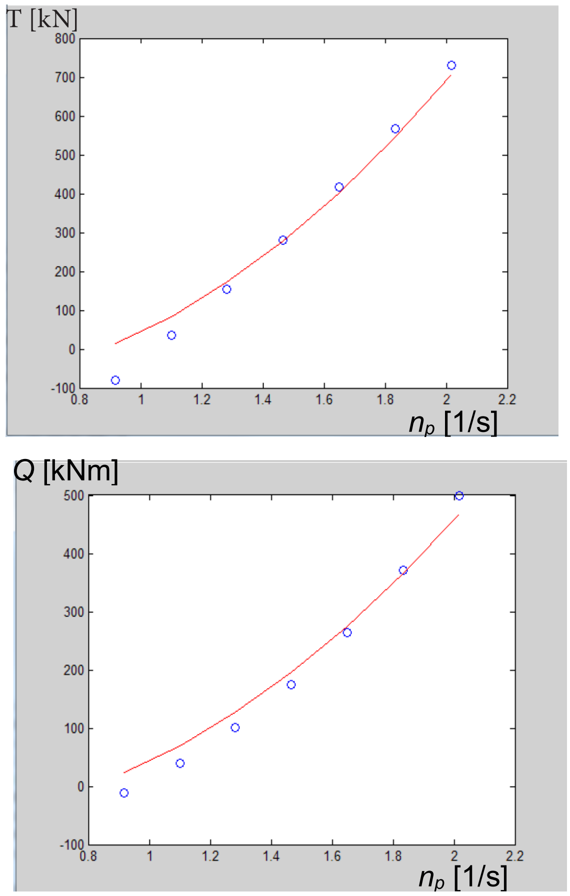


Fig. 2. Propeller thrust and torque values calclated by means of the developed approximations (4) (points marked „°") as well as by using the hydrodynamic characteristics of the screw propellers installed on the existing bulk carriers

APPROXIMATE MODELS FOR POWER OUTPUT, ROTATIONAL SPEED AND WORKING AREA OF PROPULSION ENGINE

Ship propulsion engine working area is defined by its characteristics (see e.g. [7]). In order to calculate ship service speed and determine the engine working point for a designed ship it is necessary to know rated values of power output and rotational speed of propulsion engine. Such values for the task in question were determined by analysing the collected technical and operational data for existing ships.

Approximate models for engine power output

The propulsion engine rated power N_n for bulk carriers was approximated by using linear regression method. The analysis was performed for functional relations of only one parameter or product of some parameters as an argument. In the case of engine power a model of approximating function was also searched for a dependable variable in the form of the rated power/ship speed ratio N_n/V.

The best fit degree (R2 = 0,9464) was reached for the model: $N_n/V = f(F_W)$, Fig. 3.

For further analysis was selected the following engine power approximation (of the auxiliary variable N_n/V) in function of F_W, which reached the best fit degree:

$$N_n = (-2 \cdot 10^{-6} \cdot F_W^2 + 0{,}2 \cdot F_W + 219{,}44) \cdot V \tag{7}$$

The obtained rated power value estimated according to Eq. (7) was compared with the rated power taken from documentation of the existing ships.

Tab. 6 presents exemplary results of the comparisons and calculated accuracy (relative error) of the obtained approximations.

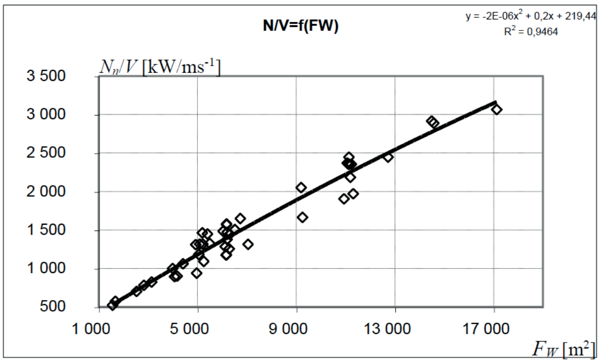


Fig. 3. Approximation of the rated power/ship speed ratio N_n/V in function of F_W ($F_W = L \cdot B \cdot C_{WP}$, where: C_{WP} – water plane coefficient) for bulk carriers

Tab. 6. Accuracy of the calculated value of the propulsion engine rated power N_n for bulk carriers

Ship No.	Power N_n [kW] according to ship's documentation	Power N_n [kW] according to approximation - Eq. (7)	Relative error [%]
M1	5720	5665	1,0
M2	7500	7467	0,4
M3	11400	10153	10,9
M4	12720	11550	9,2

Approximate models for rotational speed of propulsion engine

The searching for of approximating function for the rated rotational speed of propulsion engine, n_{ns}, was conducted in relation to ship's length L, displacement ∇, draught T as well as the product of $L \cdot B \cdot C_{WP}$. The best results (R2 = 0,685) were reached for the relation of the engine rated rotational speed versus ship's draught, i.e. $n_{ns} = f(T)$ expressed in the following form:

$$n_{ns} = 9{,}7516 \cdot T^{-0{,}6757} \tag{8}$$

Fig. 4 graphically shows accuracy of the obtained approximations.

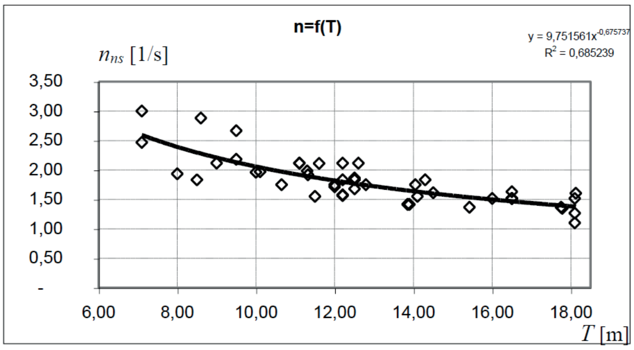


Fig. 4. Approximation of the engine rated rotational speed in function of ship's draught, $n_{ns} = f(T)$, for bulk carriers

The obtained value of the rated rotational speed nns estimated according to Eq. (8) was compared with the rated rotational speed specified in documentation of the existing ships. Tab. 7 presents exemplary results of the comparisons and the calculated accuracy (relative error) of the achieved approximations.

Tab. 7. Accuracy of the calculated value of the rated rotational speed, n_{ns}, of propulsion engine for bulk carriers

Ship No.	Rotational speed n_{ns} [1/s] according to ship's documentation	Rotational speed n_{ns} [1/s] according to approximation – Eq. (8)	Relative error [%]
M1	2,12	2,30	8,5
M2	1,75	1,97	12,7
M3	1,72	1,82	6,0
M4	2,11	1,86	11,8

Approximation of propulsion efficiency coefficients

The relations of Holtrop-Mennen method were applied [2], [3] to calculate values of the thrust deduction coefficient t, the wake coefficient w_T and the rotational "efficiency" η_R, for all the ships, with taking into account ship types. Because in the method ship parameters unknown in preliminary design stage are used, the values calculated on its basis were considered reference ones for searched for approximations.

In searching for appropriate approximating functions the thrust deduction coefficient t, the wake coefficient w_T and the rotational "efficiency" η_R was determined by using the multi-fold regression method, and arguments of the functions were selected on the basis of parameters applied in Holtrop-Mennen method [5].

Tab. 8 shows the approximating functions for the thrust deduction coefficient, wake coefficient and rotational "efficiency" for bulk carriers, obtained during the analyses, as well as the value of the coefficient R2 and standard error of estimation.

Tab. 8. Forms of the functions and model- fit degree for approximation of the thrust deduction coefficient t, wake coefficient w_T and rotational "efficiency" η_R, for bulk carriers

Ship type	Function form	R^2 – model- fit degree	Estimation standard error
Bulk carriers	$t = 0{,}067036 + 0{,}059741 \cdot C_P + 0{,}585806 \cdot \frac{B}{L}$	0,881	0,0044
	$w_T = -1{,}11851 + 0{,}00369 \cdot B + 2{,}0656 \cdot C_P - 0{,}364233 \cdot \frac{T}{B} - 7{,}6 \cdot 10^{-7} \cdot \nabla$	0,947	0,0131
	$\eta_R = 0{,}99660 + 0{,}094350 \cdot C_P - 0{,}000012 \cdot T \cdot B + 0{,}021510 \cdot \frac{B}{L}$	0,876	0,0012

Tab. 9 presents calculation results (with taking into account accuracy) of the values of the thrust deduction coefficient t, wake coefficient w_T and rotational „efficiency" μ_R, obtained from the approximations (Tab. 8) and values calculated according to Holtrop-Mennen method ([2] ÷ [5]) for bulk carriers.

Tab. 9. Accuracy of calculated values of the thrust deduction coefficient t, wake coefficient w_T and rotational „efficiency" μR for reference bulk carriers

Ship No.	t_{wz}* [-]	t_{ap}** [-]	δt*** [%]	w_{Twz}* [-]	w_{Tap}** [-]	δw_T*** [%]	η_{Rwz}* [-]	η_{Rap}** [-]	$\delta\eta_R$*** [%]
M1	0,2105	0,2130	-1,19	0,4544	0,4865	-7,07	1,0137	1,0742	-5,97
M2	0,1882	0,1961	-4,22	0,4070	0,4847	-19,09	1,0175	1,0737	-5,52
M3	0,2231	0,2229	0,09	0,4914	0,4928	-0,28	1,0100	1,0722	-6,16
M4	0,1903	0,1946	-2,27	0,3974	0,5067	-27,51	1,0147	1,0724	-5,68

** reference values calculated by means of Holtrop-Mennen method [2]÷[5]*

*** values obtained from the approximations – Tab. 8*

**** relative error*

MEAN STATISTICAL VALUE OF SHIP SERVICE SPEED ON A SHIPPING LINE

The investigations in question are aimed at development of a method for determining service speed of transport ship in statistical weather conditions occurring on a shipping line where the ship has to operate. As weather conditions occurring on a given shipping line are random quantities, hence the method to be developed should take into account a random character of wind and wave parameters, and this way calculated ship speed will constitute a statistical service speed kept with a determined probability. Level of the probability will result from power output of propulsion engine for ship to be designed.

The above mentioned task was solved in two phases :

- In the 1st phase an instantaneous ship's service speed was determined on the basis of the developed parametric models concerning total ship resistance [11], propeller thrust and propulsion power, for assumed parameters of wind, sea current and waving;
- In the 2nd phase a mean statistical service speed of transport ship was calculated on the basis of distribution of mean statistical, long-term (seasonal) weather parameters occurring on a given shipping line.

Instantaneous ship's service speed

During ship motion in waves, besides still - water resistance, also additional forces resulting from wind, waves and possible sea surface current effects act on the ship. The interactions generate, besides an additional resistance, a lateral force and a moment turning the ship around vertical axis [6]. The lateral force results in ship drift and the turning moment – in change of ship course, hence the rudder must be deflected to keep the ship on a set course over a given sea area under action of the external turning moment. Under assumption that ship course has to be kept, the instantaneous speed is calculated from two sets of equations. The first of the sets consists of the three nonlinear equations :

$$\begin{aligned} R_{xC}(V) &= R_x(V,P_G,P_C) + R_{xA}(V,P_G,P_A) + \\ &+ R_{xW}(V,P_G,P_W) + R_{xR}(V,P_G,P_R) \end{aligned}$$

$$\begin{aligned} R_{yC}(V) &= R_y(V,P_G,P_C,\beta) + R_{yA}(V,P_G,P_A,\beta) + \\ &+ R_{yW}(V,P_G,P_W,\beta) + R_{yR}(V,P_G,P_R,\beta,\delta_R) \end{aligned} \quad (9)$$

$$\begin{aligned} M_{zC}(V) &= M_z(V,P_G,P_C,\beta) + M_{zA}(V,P_G,P_A,\beta) + \\ &+ M_{zW}(V,P_G,P_W,\beta) + M_{zR}(V,P_G,P_R,\beta,\delta_R), \end{aligned}$$

where:

$R_{xC}(V)$, $R_{yC}(V)$, $M_{zC}(V)$ - total ship resistance components and rotating moment around z – axis for a ship sailing with speed V in actual , instantaneous weather conditions,

R_x, R_y, M_z - components of still - water ship resistance and moment , with sea surface current effects taken into account,

R_{xA}, R_{yA}, M_{zA} - components of additional ship resistance and moment due to wind,

R_{xW}, R_{yW}, M_{zW} - components of additional ship resistance and moment due to waves,

R_{xR}, R_{yR}, M_{zR} - components of force and moment acting onto rudder blade,

β	-	ship drift angle,
δ_R	-	rudder deflection angle,
P_G	-	ship geometrical parameters,
P_A	-	wind parameters,
P_C	-	sea surface current parameters,
P_W	-	wave parameters,
P_R	-	rudder blade geometrical parameters.

Particular quantities which appear in the equation set (9) (still-water ship resistance, additional ship resistance due to sea surface current, wind, waves and rudder blade action and corresponding lateral forces and moments) are described by the parametric models presented in [11] for bulk carriers.

From the equation set (9) solved for the preliminarily assumed value of ship speed V and set parameters of wind, waves and possible sea current, the following is yielded: ship drift angle β, rudder deflection angle δR, additional ship resistance due to wind, waves and passive rudder, ΔR, as well as total ship resistance RC.

Next, check is made whether ship propulsion system is capable of keeping the assumed speed V in given weather conditions, and if not - a speed value is searched for at which:

- ship total resistance is balanced by propeller thrust,
- propeller torque is equal to rotational moment of propulsion engine,
- propulsion engine working point lies within a given working area which may be declared during run of calculations.

The searched for instantaneous ship's speed in given weather conditions is calculated in the 2nd phase, by solving the set of two successive nonlinear equations:

$$
\begin{aligned}
T(V, P_G) - \frac{R_C(V)}{1-t} &= 0, \\
Q(V, P_G) - \frac{N(V, P_G)\cdot \eta_G \eta_S \eta_{RT}}{2\pi n_p} &= 0,
\end{aligned}
\qquad (10)
$$

where:

T, Q - approximating functions of propeller thrust and torque, in the form (1),

R_C - total ship resistance described by the approximating function for bulk carriers, presented in [11],

N - propulsion engine power output approximated by the function (7) appropriate for bulk carriers,

t - thrust deduction coefficient approximated by the function appropriate for bulk carriers, given in Tab. 8,

η_{RT} - rotational „efficiency" approximated by the function appropriate for bulk carriers, given in Tab. 8.

As a result of solving the equation set (10) is obtained the instantaneous service speed the ship propelled by a given engine is able to develop in given weather conditions.

Because the propulsion engine working area [7] is confined within appropriate characteristics , hence only in certain cases an assumed speed V can be maintained. If the additional ship resistance due to wind and waves is too large then a ship speed possible to be reached will be searched for on one of the characteristics limiting the engine working area [7]. After calculation of the instantaneous ship's speed in given weather conditions, parameters of ship's sea-going qualities are calculated and, if they are exceeded, the ship speed will be reduced.

Calculation results of service speed for exemplary ships and selected shipping lines

The equation sets (9) and (10) are solved for all weather parameters occurring on sea areas crossed by given shipping lines, and relevant calculations are performed for a set value of ship speed V and set values of course angle ψ. For each set of weather data a definite value of instantaneous ship's service speed is obtained.

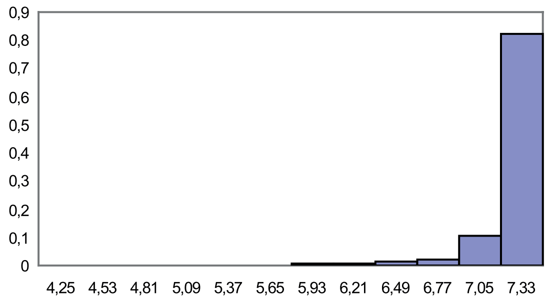
An algorithm for calculating values of instantaneous ship's service speed for all parameters of wind and waves (mean statistical values occurring on a given shipping line) is presented in [8].

Exemplary calculation results for bulk carriers are presented in Fig. 5.

Mean statistical service speed of transport ship (mean statistical yearly weather conditions)

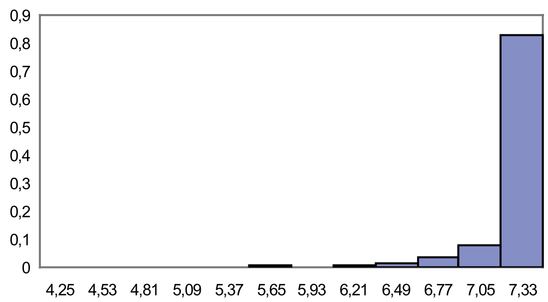
Ship: M1, Route no. 2a

Histogram of service speed



Calculations acc. algorithm: [6] ÷ [8]

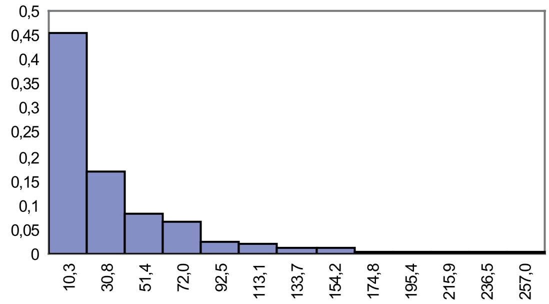
Set service speed [m/s]	V_{ZE}	7,33
Mean speed [m/s]	$\overline{V}_E$	7,22
Occurrence probability of V_{ZE} [%]	P_{VE}	82,4



Calculations based on approximation

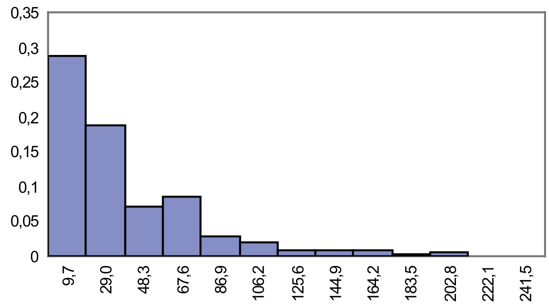
Set service speed [m/s]	V_{ZE}	7,33
Mean speed [m/s]	$\overline{V}_E$	7,24
Occurrence probability of V_{ZE} [%]	P_{VE}	83,0

Histogram of additional resistance



Calculations acc. algorithm: [6] ÷ [8]

Still-water resistance for ship speed V_K [kN]	R	431,8
Mean additional resistance [kN]	$\Delta\overline{R}$	38,95
Resistance increase [%]		9,02



Calculations based on approximation

Still-water resistance for ship speed V_K [kN]	R	405,8
Mean additional resistance [kN]	$\Delta\overline{R}$	39,97
Resistance increase [%]		9,85

Fig. 5. Histograms of ship service speed and additional ship resistance obtained from the "reference" calculations as well as those based on approximation – for M1 ship sailing on route no.2a

Tab. 10 provides the most important results of the calculations, i.e. mean statistical values of the ship service speed $\overline{V}_E$ for bulk carriers, obtained by using two different methods, given together with relative error between results achieved from the developed parametric methods and from calculations according to the algorithms presented in [6] ÷ [8].

Tab. 10. The relative calculation error (δV_E) of mean statistical values of the ship service speed $\overline{V}_E$ obtained from approximating formulae in relation to the "reference" calculation results [6] ÷ [8] for existing bulk carriers and selected shipping routes

Bulk carrier [11]	Shipping route [8]											
	2a			2b			9a			9b		
	$\overline{V}_E$ [m/s]		δV_E[%]	$\overline{V}_E$ [m/s]		δV_E[%]	$\overline{V}_E$ [m/s]		δV_E[%]	$\overline{V}_E$ [m/s]		δV_E[%]
	refer.	appr.		refer.	appr.		refer.	appr.		refer.	appr.	
M1	7,22	7,24	0,3	7,05	7,07	0,3	7,22	7,24	0,3	7,20	7,23	0,4
M2	7,38	7,35	0,3	7,23	7,13	1,4	7,40	7,27	1,8	7,38	7,23	2,0
M3	8,57	8,54	0,4	8,41	8,33	1,0	8,58	8,50	0,9	8,56	8,46	1,2

Route no. 2a - East USA – West Europe
Route no. 2b - West Europe – East USA
Route no. 9a - Persian Gulf – Africa – West Europe
Route no. 9b - West Europe –Africa – Persian Gulf

FINAL CONCLUSIONS

On the basis of analyses of the above presented results the following conclusions may be offered :

- relative calculation error of mean statistical value of ship service speed is in the range from 0,1% to 2,0%, depending on an examined ship and shipping line; accuracy of service speed calculation by using the developed parametric methods is high,

- when calculating the service speed with the use of the developed parametric method the same trend is observed as in the case of using the exact methods (the "reference" calculations acc. [6] ÷ [8]), i.e. if in the reference calculations for a "less difficult" route the service speed was greater than for "more difficult" one, the same was the case when using the parametric models for relevant calculations,

- the presented results of calculations also show that not all the examined ships, especially their propulsion systems , have been properly designed; it can be demonstrated by comparing their contract speeds (in calm water) with their service speeds on a given shipping line in mean statistical weather conditions.

In the monograph [12] can be found results of calculations of mean statistical value of service speed for container ships, oil tankers and LNG tankers.

The developed method may be also applied to optimizing design parameters as early as in preliminary design stage, especially for maximization of ship owner's profits from future operation of a ship to be built [1]. It can be also used for ship's route planning [9], [10].

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