Scientific Journals
Maritime University of Szczecin

Zeszyty Naukowe
Akademia Morska w Szczecinie

2014, 38(110) pp. 89–95
ISSN 1733-8670

2014, 38(110) s. 89–95

Forecasting operating speed of the ship in the selected weather conditions

Tadeusz Szelangiewicz[*], Bernard Wiśniewski[*], Katarzyna Żelazny[**]

[*] Maritime University of Szczecin
70-500 Szczecin, ul. Wały Chrobrego 1–2, e-mail: tadeusz.szelangiewicz@zut.edu.pl, bw@am.szczecin.pl
[**] West Pomeranian University of Technology in Szczecin, Faculty of Technology and Maritime Transport
71-065 Szczecin, al. Piastów 41, e-mail: katarzyna.zelazny@zut.edu.pl

Key words: the influence of the marine environment in the ship, instantaneous service speed, mathematical model

Abstract

To forecast the optimum route passage of a vessel in the real weather conditions using the so-called velocity characteristics of the ship. These are developed in the way, as to have a very simple form, which can not guarantee high precision in calculating the speed of the vessel. The paper presents a mathematical model of the external forces operating in the vessel and the algorithm to solve this model for calculating the instantaneous speed of the vessel in the selected weather conditions. Made of a computer program, after appropriate research and testing, can be used to optimize the transport route of the ship.

Introduction

During the study optimization of route passage of a vessel or of the vessel carrying traffic simulation at selected weather conditions, is necessary to develop a mathematical model and a computer program which allows the calculation of the instantaneous speed the vessel in selected, instantaneous weather conditions [1, 2]. This a computer program should contain all models interaction on the marine environment of vessel (wind, waves, surface the sea currents), and impacts of driving and control devices (eg, rudder fin, bolt for ships, including the drive motor). The paper presented a general mathematical model and a computer program, whose aim is to calculate speed of the vessel for:

- vessel
  - with known characteristics of aero- and hydrodynamic;
  - with known characteristics of frequency swings and wave drift forces on the wave of a regular;
  - with known hydrodynamic characteristics of the propeller;
  - with known characteristics of the drive motor;
- known:
  - weather parameters (wind, waves, surface currents);
  - the course of the vessel.

The algorithm for calculating the vessel speed in selected weather conditions

During the movement of the ship after the rippling water, in addition to resistance in calm water, the ship operate additional forces of wind, waves, and possibly from the currents. These effects, in addition to additional resistance, give rise to lateral forces and torque rotating vessel around a vertical axis. Lateral force causes the drift of the ship, and torque causes a change in the exchange rate- to course of the vessel was constants on the water area, when the rotating action of external torque, must be inclined fin rudder passive. Assuming that change the speed of the vessel due to e.g. of swings on the wave, are negligible, this ship reaches the instantaneous average operating speed, when the total resistance R_C is balanced by the pressure of the screw T_S:

$$R_C(P_P, P_G) = T_S(P_{GS}, P_P, P_{SN}) \cdot (1 - t) \tag{1}$$

where:
P_P – weather parameters;
P_G – geometric parameters of the vessel hull;
P_{GS} – geometric parameters of the propeller;
P_{SN} – the drive motor parameters;
t – suction coefficient, which takes into account the effect of the propeller on additional resistance of the hull of the ship.

To determine the speed of the vessel, which can be achieved with specific T_S thrust propeller, need to know the total resistance of the R_C, which occurs while sailing of the vessel in actual weather conditions. As can be seen from equation (1) weather parameters, in which vessel is operating, have an influence not only on the total resistance but also on the thrust of the propeller. Large swinging and arising from them – relative movements, induced undulation, will result in, among others, emerging propeller and the decrease in its thrust, as a consequence will also decrease speed of the vessel [3].

The total resistance of the vessel

The total resistance of the vessel is equal to:

$$R_C = R + \Delta R \tag{2}$$

where:
R – ship resistance in calm water;
ΔR – additional ship resistance, derived from the interaction of wind and wave, and from the steering system:

$$\Delta R = X_A + X_W + X_R \tag{3}$$

X_A – additional resistance from the wind;
X_W – additional resistance from the waves;
X_R – additional resistance of e.g. steering devices (e.g. rudder fin), that keep vessel on a given course (disturbance of the course are also caused by the impact of wind and wave).

Ship resistance in calm water without drift

In calm water, resistance, depend on the speed of the vessel, and optionally, on the size, shape and surface condition of the hull, and consists mainly of the pressure and friction resistance. Due to the fact, that both these components are in different ways depending on the speed, so in calm water, resistance, can be represented as a function of:

$$R = C_R(V) \cdot V^{m(V)} \tag{4}$$

where both the C_R factor and the exponent m for a particular ship have different values for individual compartments speed V from zero to maximum speed. In this situation the ship resistance in calm water will be presented in tabular form. In this situation, the ship resistance in calm water will be presented as a tabular in the form of small values of R, depending on the speed V, and in numerical calculations will be used relationship:

$$R = C_R(V) \cdot V^2 \tag{5}$$

Resistance in calm water, described by equation (4) or (5) is an important for the linear motion of the vessel in deep water. However, when operating on roughened water, especially the oblique action of wave and wind on the ship, will be present drift of the vessel (Fig. 1).

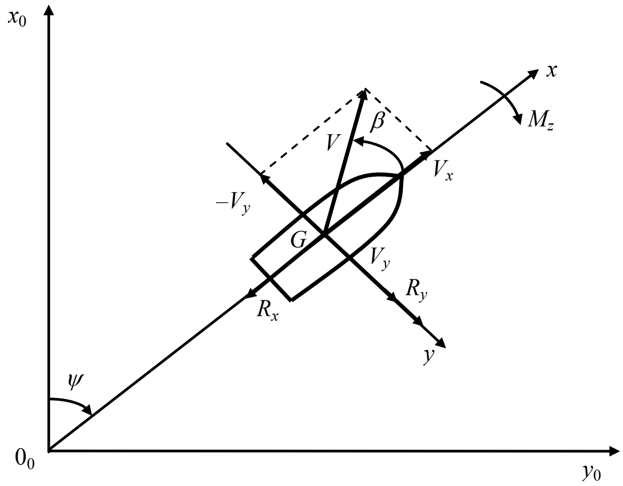

Fig. 1. Speed and drift angle of the vessel

The forces and the resistance torque of the vessel traveling on the deep water with a constant velocity V and the angle of drift β (Fig. 1), can be calculated from the equations:

$$\begin{aligned} R_x &= \frac{1}{2}\rho_w S V^2 C_x(\beta) \\ R_y &= \frac{1}{2}\rho_w S V^2 C_y(\beta) \\ M_z &= \frac{1}{2}\rho_w S L V^2 C_m(\beta) \end{aligned} \tag{6}$$

where:
R_x, R_y, M_z – components of force and torque resistance of the vessel in calm water, when operating with drift angle;
ρ_w – the density of water;
S – lateral projection of underwater ship hull surface onto ship's plane of symmetry;
V – speed of the vessel

$$V = \sqrt{V_x^2 + V_y^2} \tag{7}$$

β – drift angle (Fig. 1), it is the total angle, resulting from drift and leeway;
L – length of the vessel,

C_x, C_y, C_m – coefficients of forces and torque resistance.

The resistance of the vessel on the water with the flow

The presence of sea current, causing a change the water flow around the hull of a ship sailing around with a velocity V. The rising resultant flow will have a relative velocity of V_{RV}. The resultant flow, that appearing, will have a relative velocity of V_{RV}. The resistance of the vessel will therefore depend on the relative velocity V_{RV}, although the absolute speed of the vessel may continue to be V. Due to the current direction relative to the vessel β_C, can be optional, in addition to longitudinal resistance will be formed drift force rotating torque and relative angle of drift (Fig. 2).

Forces and moment resistance of a vessel sailing from the absolute velocity V on the water with the current, can be calculated from the same equation (6) as in the water without consumption:

$$
\begin{aligned}
R_{CVx} &= \frac{1}{2}\rho_w S V_{RV}^2 C_x(\beta_{RV}) \\
R_{CVy} &= \frac{1}{2}\rho_w S V_{RV}^2 C_y(\beta_{RV}) \\
M_{CVz} &= \frac{1}{2}\rho_w S L V_{RV}^2 C_m(\beta_{RV})
\end{aligned}
\tag{8}
$$

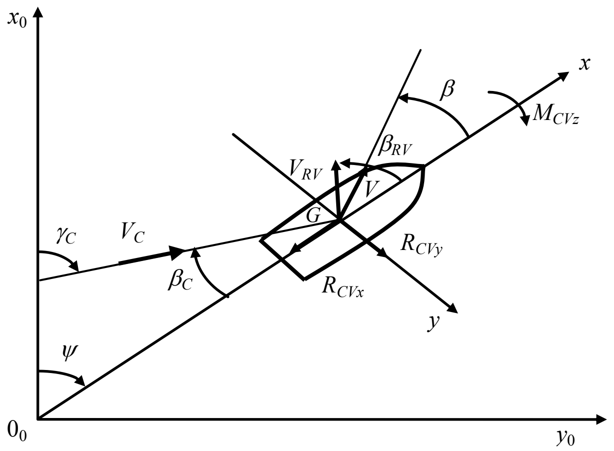

Fig. 2. Current direction and speed of the vessel to the angle of drift

In equations (8), for water supply instead of speed V and angle of drift β there are V_{RV} relative velocity and relative drift angle β_{RV} described by the following equations:

$$V_{RV} = \sqrt{(V_{RVx})^2 + (V_{RVy})^2} \tag{9}$$

$$\beta_{RV} = \arctan\frac{-V_{RVy}}{V_{RVx}} \tag{10}$$

$$
\begin{aligned}
V_{RVx} &= V_x - V_C\cos\beta_C \\
V_{RVy} &= V_y - V_C\sin\beta_C
\end{aligned}
\tag{11}
$$

where:

$V_x = V\cos\beta$, $V_y = -V\sin\beta$ – components of the absolute speed the ship;

V_C – speed of the current surface;

$\beta_C = \gamma_C - \psi$

β_C – current direction relative to the vessel;

γ_C – geographical direction of the surface current, ($\gamma_C = 0°$ current flows in a northerly direction, $\gamma_C = 90°$ current flows in an easterly direction);

ψ – geographical course of the vessel ($\psi = 0°$ heading north, $\psi = 90°$ heading east).

If the speed of the current $V_C = 0$,
so the equation (8) *reduces to equation* (6) (12)

The impact of wind on sailing vessel

Average impact force of the wind on a sailing vessel, can be calculated with the formulas:

$$
\begin{aligned}
X_A &= -\frac{1}{2}\rho_A S_x V_{RA}^2 C_{Ax}(\beta_{RA}) \\
Y_A &= \frac{1}{2}\rho_A S_y V_{RA}^2 C_{Ay}(\beta_{RA}) \\
M_A &= \frac{1}{2}\rho_A S_y L V_{RA}^2 C_{Am}(\beta_{RA})
\end{aligned}
\tag{13}
$$

ρ_A – air density;

S_x, S_y – surface projections of above-water portion of the ship (respectively, from the bowand lateral) on the plane of amidships and symmetry;

L – the length of the ship;

V_{RA} – relative wind speed (Fig. 3);

C_{Ax}, C_{Ay}, $C_{Am}(\beta_{RA})$ – aerodynamic resistance coefficients of the vessel above water surface, depending on the relative direction of the wind (β_{RA});

β_{RA} – relative wind direction (Fig. 3).

$$V_{RA} = \sqrt{V_{RAx}^2 + V_{RAy}^2} \tag{14}$$

$$
\begin{aligned}
V_{RAx} &= V_A\cos\beta_A - V \\
V_{RAy} &= V_A\sin\beta_A
\end{aligned}
\tag{15}
$$

$$\beta_A = \gamma_A - \psi + 180° \tag{16}$$

β_A – wind direction relative to the vessel ($\beta_{RA} = 0°$ wind from the stern of the ship, $\beta_{RA} = 90°$ wind at the bow of the ship);

$$\beta_{RA} = \arc\tan\frac{-V_{RAy}}{V_{RAx}} \quad (17)$$

V_A – wind speed;
γ_A – geographic wind direction, ($\gamma_A = 0°$ – the north wind, $\gamma_A = 90°$ – the east wind), geographic course of the ship);
ψ – geographic course of the ship.

In equations (13) omitted the drift angle β of the vessel, because it will have little value and will minimally affect the relative wind direction β_{RA} and therefore the force of the wind.

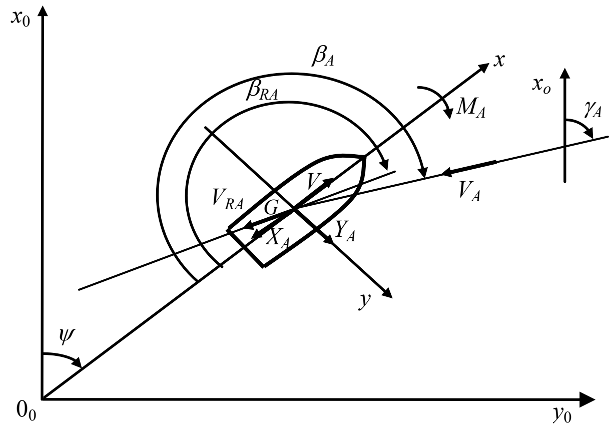

Fig. 3. Coordinate systems, speed and direction of the vessel and the wind

In equations (13) and in figure 3 assumes that where a ship is sailing into the wind, it is an additional effect of wind resistance, and if the wind is from the stern of the vessel, there is the effect of wind causes a reduction in the total resistance.

The impact of waves on a sailing vessel

Average the impact of irregular wave (medium wave of drift force) on the vessel sailing, can be calculated with the formulas:

$$\begin{aligned} X_W &= 2\rho_w g \frac{B^2}{L}\int_0^\infty C_{wx}(\omega/\beta_W, V) S_{\zeta\zeta}(\omega)\,\mathrm{d}\omega \\ Y_W &= 2\rho_w g \frac{B^2}{L}\int_0^\infty C_{wy}(\omega/\beta_W, V) S_{\zeta\zeta}(\omega)\,\mathrm{d}\omega \\ M_W &= 2\rho_w g B^2\int_0^\infty C_{wm}(\omega/\beta_W, V) S_{\zeta\zeta}(\omega)\,\mathrm{d}\omega \end{aligned} \quad (18)$$

where:
ρ_w – the density of water;
g – acceleration due to gravity;
B – width of the ship;
C_{wx}, C_{wy}, $C_{wm}(\omega/\beta_W,V)$ – coefficients of the wave drift force of a regular wave, depending on the direction of the wave relative to the vessel β_W and the vessel speed V;
ω – incidence of regular wave;
β_W – wave direction relative to the vessel (Fig. 4), $\beta_W = 0°$ wave coming to the stern of the ship (trailing wave), $\beta_W = 90°$ wave coming at the bow (lateral wave):

$$\beta_W = \mu - \psi + 180° \quad (19)$$

μ – geographical wave direction ($\mu = 0°$– wave northern, $\mu = 90°$ – wave east);
$S_{\zeta\zeta}(\omega)$ – power spectral density function of waves (depending on the significant wave height H_S and the average period of T_1).

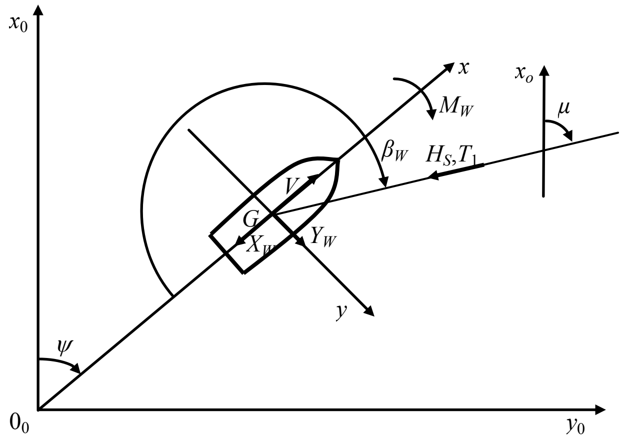

Fig. 4. Average the impact of waves on vessel

Additional resistance of the rudder blade

During the operation of the vessel after the roughened water, especially when per vessel obliquely affects wind and wave arise lateral forces and moments which have all changed the course of the vessel and formed drift. To maintain a steady course should be put the rudder blade out (Fig. 5), which creates additional resistance X_R.

The forces on the rudder blade are described by the following equations:

$$\begin{aligned} X_R &= \left|F_N \sin\delta_R\right| \\ Y_R &= a_y F_N \cos\delta_R \\ M_R &= a_z F_N \cos\delta_R \end{aligned} \quad (20)$$

where:
δ_R – rudder angle (Fig. 5 – rudder angle at boardside → $\delta_R > 0$, the rudder angle at starboard → $\delta_R < 0$);
a_y – impact factor of the hull on the force of Y_R at the rudder;
a_z – impact factor of the hull at the moment of M_R on the rudder

$$a_z = a_y \cdot x_R \quad (21)$$

x_R – rudder axis abscissa measured from ship mass centre G ($x_R < 0$);

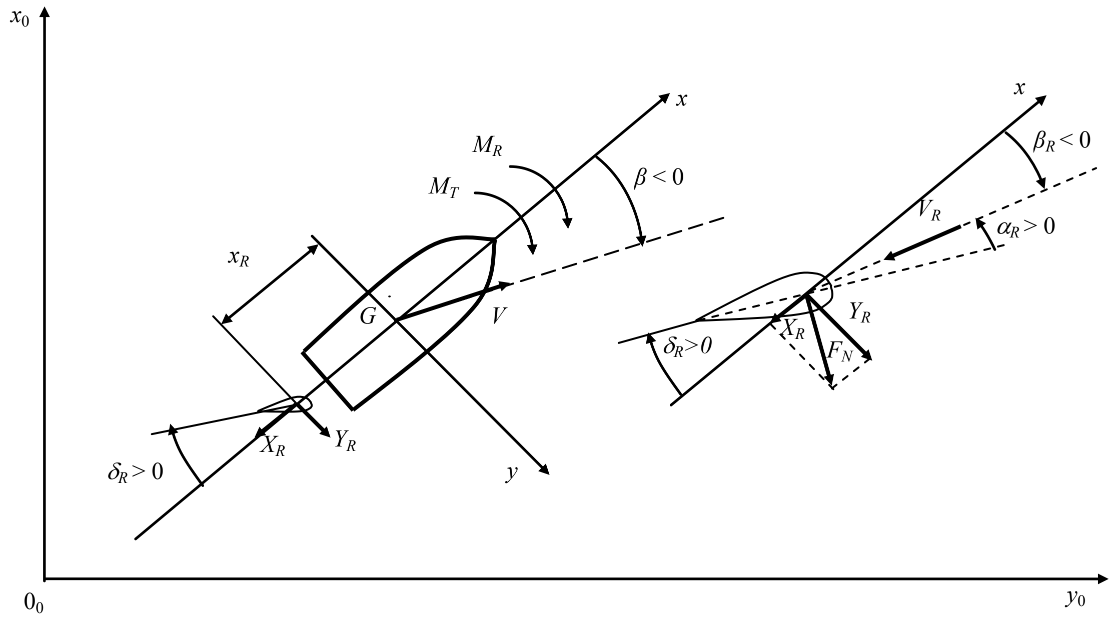

Fig. 5. Forces on the rudder blade

F_N – normal force on the rudder (Fig. 5)

$$F_N = \frac{1}{2}\rho_w \frac{6{,}13\lambda}{\lambda + 2{,}25} A_R V_R^2 \sin\alpha_R \tag{22}$$

λ – elongation of the rudder;
A_R – rudder area;
V_R – the speed of water flow to the rudder (Fig. 5);
α_R – effective angle of attack of rudder (Fig. 5).

As a result of passive rudder torque M_R which is formed from the force Y_R, and to maintain the desired course of the vessel, torque on the rudder should have the value to balance to the resultant moment, forcing from wind, wave and the moment of resistance (including the impact of current), during the movement of the angle of drift:

$$M_T = -M_R \tag{23}$$

where: M_T is the total moment of the marine environment (wind, waves and current or water from the sailing vessel with the angle of drift):

$$M_T = M_A + M_W + M_C \tag{24}$$

Therefore, the size of the rudder angle δ_R will be calculated from equation (23) for the current external torques acting on the vessel in the marine environment (24). Knowing the current value of δ_R from the first equation (20) will be calculated additional resistance from the passive rudder conditions.

Propulsion of the ship

Propeller

The thrust of the propeller must balance the total resistance of the ship R_C:

$$T = \frac{R_C}{1-t} \tag{25}$$

where t is the coefficient of suction (suction coefficient may depend on the speed of the vessel $t(V)$). The intrusion screws isolated can be calculated from the formula:

$$T = K_T \rho_w D_p^4 n_p^2 \tag{26}$$

where:
D_P – the screw diameter;
n_P – turnover of screw;
K_T – thrust coefficient, which for typical B-Wageningen screws of data parameters: (P/D_P) – stroke coefficient, (A_E/A_0) – the upright surface coefficient, Z – number of wings.

For working screw, there is a torque Q:

$$Q = K_Q \rho_w D_p^5 n_p^2 \tag{27}$$

where, K_Q is the coefficient of the torque and the thrust coefficient as it can be represented, for a given screw.

Energy input into the screw isolated is given by:

$$P_D = 2\pi n_p Q \tag{28}$$

The efficiency of screw isolated (without the hull of the vessel) is equal to:

$$\eta_0 = \frac{K_T}{K_Q} \cdot \frac{J}{2\pi} \tag{29}$$

The thrust efficiency and field of engine operation

The general thrust efficiency can be represented as:

$$\eta = \frac{P_E}{P_B} \tag{30}$$

where:

P_E – the towing power of vessel

$$P_E = V \cdot R_C \tag{31}$$

P_B – power at the clutch for the main drive motor.

Power is transmitted from the engine through shaft lines and propeller, where is generated by the such values of intrusion, so that the vessel can get the speed V. Thus the overall efficiency of the engine can be represented as [4]:

$$\eta = \eta_G \cdot \eta_S \cdot \eta_{HT} \cdot \eta_0 \cdot \eta_{RT} \tag{32}$$

where:

η_G – efficiency of the transmission, if it is put in place;

η_S – efficiency of shaft lines;

η_{HT} – "efficiency" of hull:

$$\eta_{HT} = \frac{1-t}{1-w_T} \tag{33}$$

η_0 – efficiency of propeller isolated;

η_{RT} – "efficiency" of rotational ("efficiency" of rotational-it can vary, depending on the speed of the ship $\eta_{RT}(V)$).

Between the moment on the screw isolated (27) and the power supplied to the screw isolated cone (P_D) is the following relationship:

$$P_D = Q \cdot 2\pi n_p \tag{34}$$

and between the power of the P_D and the power of the drive motor:

$$P_D = N \cdot \eta_G \cdot \eta_S \cdot \eta_{RT} \tag{35}$$

where: $N = P_B$ – the power of the drive motor.

Individual fields (Fig. 6) are limited by the engine characteristic in the form of:

$$N = k_m \cdot n^m \tag{36}$$

where:

N –engine power;

k_m – coefficient for a particular characteristic;

n – engine RPM.

Calculation of the instantaneous average operating speed of the ship in the selected weather conditions

During the movement of the ship by the roughened water, there is an action to the ship in addition to resistance in calm water, also additional forces of wind, waves, and optionally from the currents. These effects, in addition to additional resistance, give rise to a lateral force and moment, the vessel rotates about a vertical axis. The lateral force causes the drift of the ship, and the moment to change course – that, for a given water body provide a constant course of a vessel on to an external rotating torque, must be deflected rudder. Assuming that the course of the vessel should be kept,

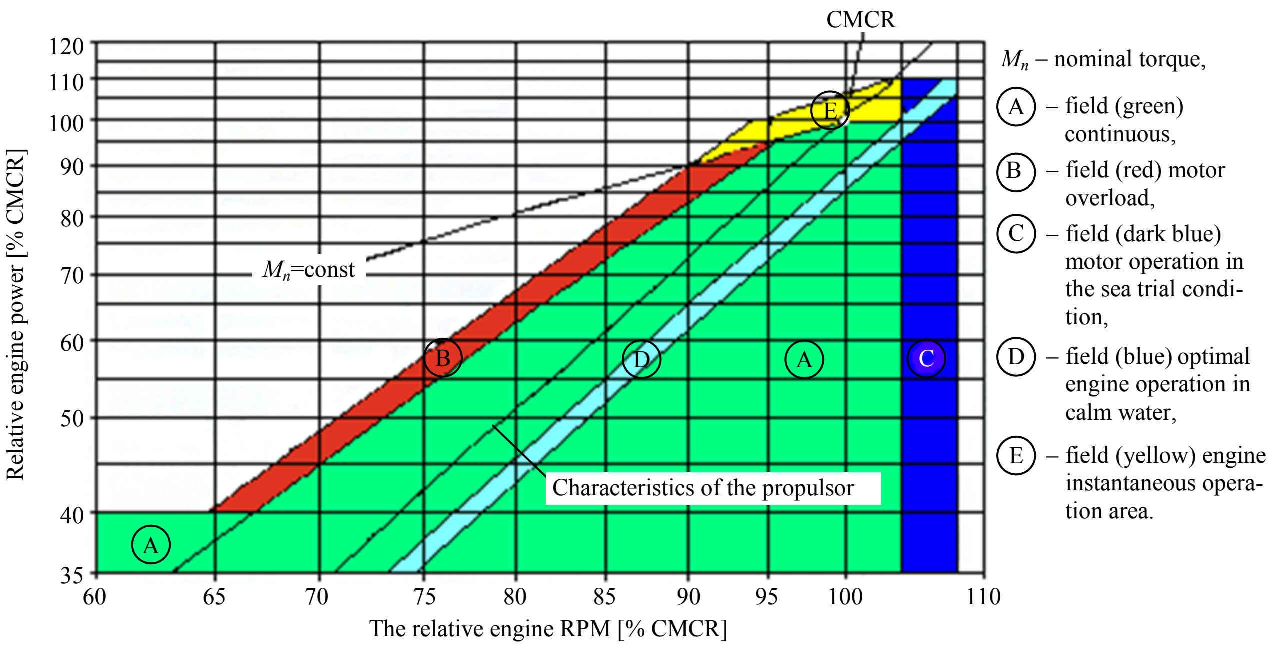

Fig. 6. The field operation Sulzer company engine [5]

then the solution of equation (1) calculating the instantaneous velocity and is implemented two stages. The first stage is solved a system of three nonlinear equations [6]:

$$R_C = R_X + X_A + X_W + X_R$$
$$Y_A(V) + Y_W(V) + R_y(V,\beta) + Y_R(V,\beta,\delta_R) = 0$$
$$M_A(V) + M_W(V) + M_z(V,\beta) + M_R(V,\beta,\delta_R) = 0 \quad (37)$$

of which for a given initially speed of the vessel V and the selected parameters of wind, wave and possibly sea current is obtained:

β – drift angle of the vessel;
δ_R – deflection angle of the fin rudder passive;
ΔR – additional resistance from the wind, current, waves and rudder passive;
R_C – total resistance of the vessel.

Then, it is checked whether the vessel propulsion system is able to maintain established speed V in the assumed weather conditions, then, it is checked, whether the vessel propulsion system is able to maintain established speed V in the assumed weather conditions, and if not, it looks to the speed at which the total resistance of the vessel will be balanced the pressure of the screw and torque on the screw will be equal to the torque of the drive motor, a drive motor operating point will lie in a particular field, which can be declared in the performance calculations. Wanted the instantaneous speed of the vessel in the selected weather conditions is calculated in the second step of the two successive nonlinear equations [6]:

$$\left[\left(A_0 + A_1 \cdot J + A_2 \cdot J^2 + A_3 \cdot J^3\right) + \Delta K_T\right] \cdot \rho_w D_p^4 \cdot n_p^2 \cdot \beta_T - \frac{R_C}{1-t} = 0$$
$$\left[\left(B_0 + B_1 \cdot J + B_2 \cdot J^2 + B_3 \cdot J^3\right) - \Delta K_Q\right] + - \frac{N \cdot \eta_G \eta_S \eta_{RT}}{2\pi \rho_w D_p^5 n_p^3} = 0 \quad (38)$$

where:

J – advance coefficient

$$J = \frac{V\left[1 - w_T(V)\right]}{D_p \cdot n_p} \quad (39)$$

ΔK_T – correction coefficient for the thrust on the vessel;
β_T – correction coefficient takes into account the decrease in the pressure of the ascent of the screw;
ΔK_Q – correction coefficient for the torque on the screw on the ship;
R_C – function of total resistance of the vessel depends on the speed V, the course of the vessel ψ, wave parameters H_S, T_1, μ and wind parameters V_A, γ_A;
N – motor power, the characteristics specified in the compartments of rotation n, in which these characteristics are valid.

Conclusions

The details of the presented model and algorithm for calculating the average of the instantaneous operating speed have been presented [6]. On the basis of developed mathematical model and its solution algorithm built a computer program to calculate the instantaneous average service speed of the vessel. This program also includes a special purpose vehicle speed reduction when the phenomenon arising from the impact of waves on the ship, threaten its security. One particular objective of the research was to determine the reduction in vessel speed or change course because of the dangerous phenomenon of waves. PRESTAT – computer program, was used in the tests in the selected weather conditions, is written in Delphi. The program, in addition to vessel speed is calculated parameters such as power and engine speed, screws, what is administered on a computer screen.

References

1. WIŚNIEWSKI B.: Problem wyboru drogi morskiej statku. Wydawnictwo Morskie, Gdańsk 1991.
2. WIŚNIEWSKI B.: Optymalizacja drogi morskiej statku z uwzględnieniem warunków pogodowych. Wydawnictwo Szkoły Morskiej w Szczecinie, Szczecin 1986.
3. SZELANGIEWICZ T., ŻELAZNY K.: The propeller thrust and speed reduction as a result of the propeller emergence on a given ocean route. Explo-Ship 2010, Zeszyty Naukowe nr 22(94), Akademia Morska w Szczecinie, Szczecin 2010.
4. DUDZIAK J.: Teoria okrętu. Fundacja Promocji Przemysłu Okrętowego i Gospodarki Morskiej, Gdańsk 2008.
5. General Technical Data for Marine Diesel Engines. SULZER, 1986.
6. ŻELAZNY K.: Numeryczne prognozowanie średniej długoterminowej prędkości eksploatacyjnej statku transportowego (Numerical prediction of the mean long-term sevice speed of trasport ship). Rozprawa doktorska, Politechnika Szczecińska, Szczecin 2005.