Calculation of the mean long-term service speed of transport ship

Part I
Resistance of ship sailing on regular shipping route in real weather conditions

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ABSTRACT

Service speed obtainable by a ship in real weather conditions when sailing on a given shipping route, is one of the major parameters which have great impact on ship operation costs. The so far used, very approximate method of service speed prediction based on "service margin", is very little exact. In this paper a new method based on additional ship resistance dependent on mean statistical parameters of wave and wind occurring on a given shipping route, is presented. The mean long-term service speed is calculated on the basis of the calculated additional resistance and the screw propeller and propulsion engine parameters. Also, a new definition of service margin and a way of its calculation is presented apart from the results of the mean service speed calculation depending on ship's type and size and shipping route.

Keywords : ship service speed, wind, waving, shipping route, service margin, long-term prediction.

INTRODUCTION

The ship owner, when planning building a new ship, on the basis of his experience and knowledge of shipping market, determines the ship's deadweight and predicts its service speed to be reached by the ship on a given shipping route. The service speed obtainable by a ship in real weather conditions (mainly wind and waves) is one of the most important parameters greatly influencing ship's profitability on a given shipping route. In the design algorithms used today in ship design offices, ship's deadweight is determined with a satisfactory exactness, but calculation of ship's service speed is rather inexact and practically known already after ship's delivery and some time of its service. Hence in the ship building contract, is given another speed, so called contract speed which the ship has to achieve in still-water conditions. On the basis of still-water resistance characteristics and rated output of propulsion engine, the obtainable ship service speed is predicted by accounting for relevant coefficients, Fig.1.

In that prediction an increase of ship resistance in service conditions in relation to that in still water conditions (represented by the service margin SM in Fig.1) is not exactly determined as it depends on real weather conditions occurring on a given shipping route.

Basing on known statistical data on winds and waves possible to occur on a given shipping route, one is capable in determining a long-term distribution function of additional resistance, and next, for an assumed main engine output, a long-term distribution function of ship's speed possible to be obtained on a given shipping route. Such approach makes it possible not only to exactly determine the mean statistical service speed of the ship, but also to investigate the influence of power output of a selected main engine on the ship's service parameters including its long-term service costs.

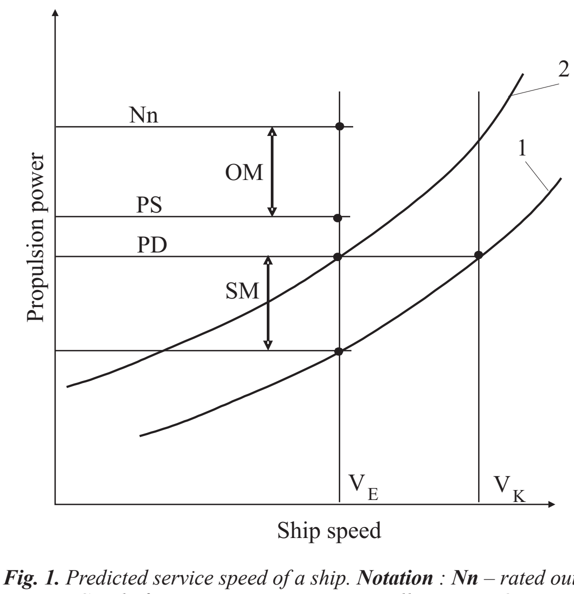

*Fig. 1. Predicted service speed of a ship. **Notation** : **Nn** – rated output of engine, **PS** – shaft power, **PD** – power at propeller's cone, **OM** – operational margin, **SM** – sea margin, V_K – contract speed, V_E – predicted service speed, **1** – propeller curve for still-water conditions, for non-fouled hull, **2** – predicted propeller curve with service margin, for real conditions .*

Attempts to determine the service speed of ship in real weather conditions have been already reported in [4, 23, 24], however there were not accounted for statistical distributions of wind and wave parameters met on a given shipping route.

STATISTICAL LONG-TERM PARAMETERS OF WINDS AND WAVES ON SHIPPING ROUTES

In order to determine the mean long-term ship service speed the ship's resistance in real weather conditions should be determined in advance. The statistical long-term wave parameters, namely : H_S - the significant wave height, T_1 - the mean characteristic period, μ - the mean geographical direction, were determined on the basis of multi-year measurements. Results of the measurements are contained in the atlas of wave parameters [10] and in extended form in [11], in which seas and oceans have been divided additionally into the set of sea areas shown in Fig.2 (where each sea area is characterized by its own statistical wave parameters).

The atlases [10] and [11] contain sample size of waves characterized by H_S and T_1 parameters and recorded in a given area for a given season and wave direction μ, as exemplified in Tab.1. On the basis of these data, was elaborated a computer database on the waves met on seas and oceans, which contains the occurrence probabilities of waves with H_S, T_1 parameters, f_{HT} , and the occurrence probabilities of μ directions , f_μ , for all the sea areas (split into seasonal data), as exemplified in Tab.2 and 3.

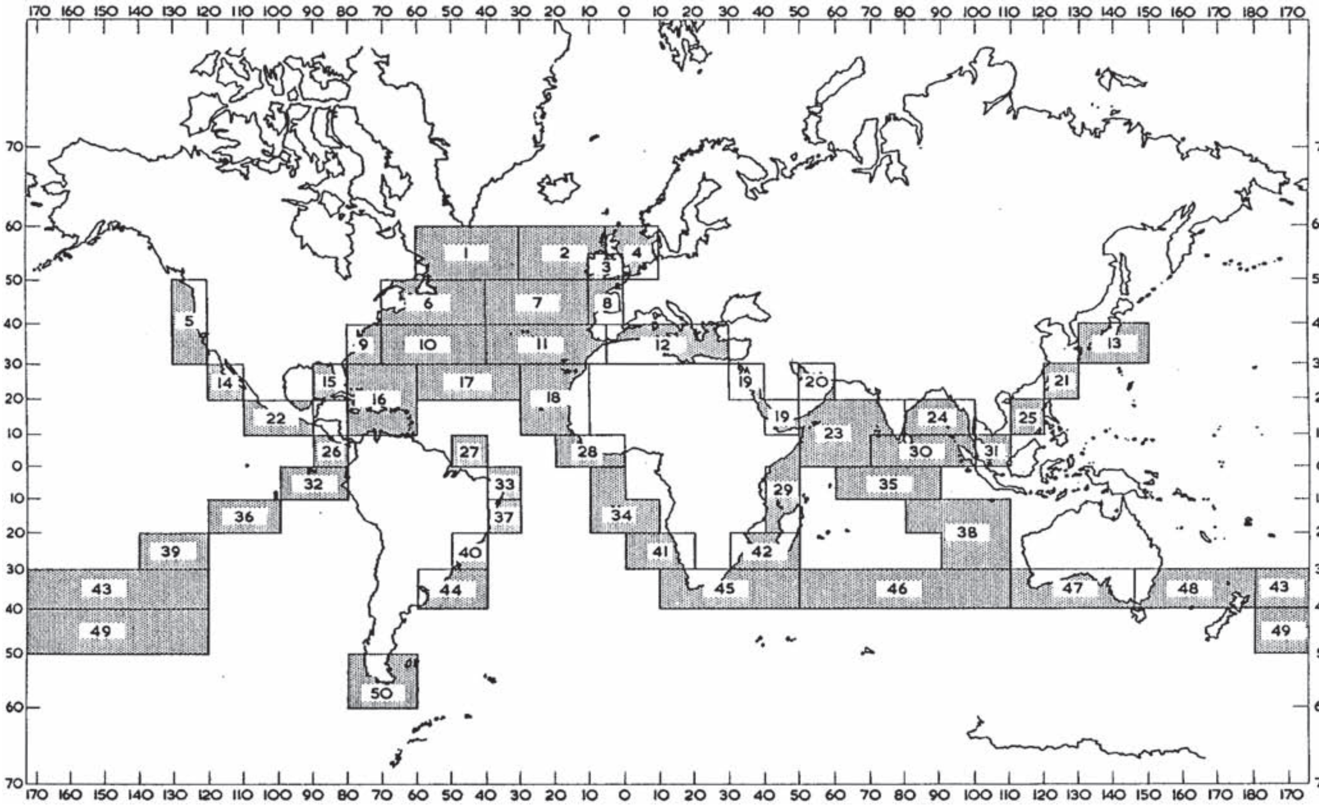

Fig. 2. Oceans divided into set of sea areas, acc. [10] .

***Tab. 1.** Sample size of waves of H_S height and T_1 period for a given μ direction and sea area [10] .*

Sea area : 1											
Season of the year : December – February (winter)											
Wave direction : μ = 000 deg											
H_S [m] \ T_1 [s]	**calm**	**< 5**	**6 ÷ 7**	**8 ÷ 9**	**10 ÷ 11**	**12 ÷ 13**	**14 ÷ 15**	**16 ÷ 17**	**18 ÷ 19**	**20 ÷ 21**	**> 21**
0.25		2									
0.5		1	1	1							
1.0		8	2	1	1						
1.5		2	4	5		2					
2.0			5		3						
2.5		1	5	4	3						
3.0			1	3	2	1					
3.5			1	4	5						
4.0				1	1	4	1	1			
4.5				4	2		1	1			
5.0					1						
6.0				1							
6.5				1	2						
7.5					1						

***Tab. 2.** The occurrence probabilities , f_{HT} , of wave of H_S height and T_1 period for a given μ direction and sea area [10] .*

Sea area : 1											
Season of the year : December – February (winter)											
Wave direction : μ = 000 deg											
H_S [m] \ T_1 [s]	**calm**	**< 5**	**6 ÷ 7**	**8 ÷ 9**	**10 ÷ 11**	**12 ÷ 13**	**14 ÷ 15**	**16 ÷ 17**	**18 ÷ 19**	**20 ÷ 21**	**> 21**
0.25		0.023									
0.5		0.011	0.011	0.011							
1.0		0.091	0.023	0.011	0.011						
1.5		0.023	0.045	0.057		0.023					
2.0			0.057		0.034						
2.5		0.011	0.057	0.045	0.034						
3.0			0.011	0.034	0.023	0.011					
3.5			0.011	0.045	0.057						
4.0				0.011	0.011	0.045	0.011	0.011			
4.5				0.045	0.023		0.011	0.011			
5.0					0.011						
6.0				0.011							
6.5				0.011	0.023						
7.5					0.011						

***Tab. 3.** The combined probability, $f_{HT} \cdot f_\mu$, of occurrence of wave of H_S height and T_1 period,*
with taking into account the probability f_μ for each direction μ in a given sea area, [10] .

Sea area: 1											
Season of the year : December – February (winter)											
Wave direction : all											
H_S [m] \ T_1 [s]	**calm**	**< 5**	**6 ÷ 7**	**8 ÷ 9**	**10 ÷ 11**	**12 ÷ 13**	**14 ÷ 15**	**16 ÷ 17**	**18 ÷ 19**	**20 ÷ 21**	**> 21**
0.25	0.0021	0.0064	0.0009								
0.5	0.0004	0.0137	0.0026	0.0013							0.0017
1.0	0.0043	0.0321	0.0160	0.0026	0.0026	0.0013					0.0004
1.5	0.0064	0.0180	0.0570	0.0206	0.0038	0.0026					0.0009
2.0	0.0086	0.0073	0.0450	0.0364	0.0193	0.0051	0.0017	0.0004	0.0004		
2.5	0.0073	0.0056	0.0385	0.0501	0.0308	0.0069	0.0030	0.0009	0.0004		
3.0	0.0137	0.0009	0.0175	0.0377	0.0287	0.0112	0.0017	0.0004	0.0004		
3.5	0.0060	0.0009	0.0124	0.0334	0.0347	0.0167	0.0043	0.0013			
4.0	0.0060	0.0017	0.0043	0.0248	0.0180	0.0116	0.0034	0.0009			
4.5	0.0043	0.0009	0.0051	0.0257	0.0218	0.0111	0.0060	0.0051			0.0004
5.0	0.0017		0.0013	0.0013	0.0030	0.0026		0.0009			
5.5	0.0004		0.0021	0.0017	0.0043	0.0039	0.0021	0.0009			
6.0	0.0004	0.0009	0.0026	0.0094	0.0099	0.0034	0.0030	0.0013			
6.5	0.0009		0.0034	0.0094	0.0081	0.0069	0.0039				
7.0	0.0004			0.0009	0.0051	0.0017	0.0009		0.0004		
7.5	0.0017		0.0004	0.0017	0.0073	0.0064	0.0013	0.0004			0.0004
8.0	0.0013	0.0004	0.0009	0.0009	0.0056	0.0030	0.0004	0.0009			
8.5			0.0004	0.0013	0.0038	0.0017	0.0004	0.0004			
9.0			0.0004	0.0013	0.0034	0.0004	0.0004		0.0004		
9.5	0.0009			0.0026	0.0026	0.0034	0.0009	0.0013	0.0021		0.0004
15					0.0004						

The statistical wave parameters used for calculation of ship resistance due to wind and waves should be correlated with the wind parameters: V_A - mean wind speed, γ_A - mean statistical geographical direction of wind. As such atlases for wind do not exist the appropriate relations between wind and wave parameters were elaborated on the basis of measurements [3 , 25].

Basing on literature sources, one elaborated the relations $V_A = V_A(H_S , T_1)$ for the purposes of this work, assuming that :

✦ Wind direction coincides with wave direction :

$$\gamma_A = \mu\ ^* \tag{1}$$

✦ The occurrence probability of wind direction, $f_{\gamma A}$, is the same as that of wave direction , f_μ :

$$f_{\gamma A} = f_\mu \tag{2}$$

✦ The occurrence probability of mean wind speed , f_{VA} , is the same as that of wave of H_S , T_1 parameters , f_{HT} :

$$f_{VA} = f_{HT} \tag{3}$$

Results of calculations of the relations $V_A = V_A(H_S , T_1)$ for the wave parameters contained in [10], were published in [25].

* in the literature on wind-generated sea waves it is assumed that if the difference between wind and wave directions does not exceed 30° then both the directions are the same; such state occurs during 80% time of observations on seas and oceans [6, 22]

SHIP RESISTANCE IN REAL WEATHER CONDITIONS

In real weather conditions during sea voyage of a ship on a given shipping route, its total resistance consists of still-water resistance and additional components :

$$R_C = R + \Delta R \tag{4}$$

where :

R − still-water resistance of ship (accounting for the drift angle and possible surface sea current)

ΔR − additional ship resistance resulting from real sailing conditions :

$$\Delta R = R_{xA} + R_{xW} + R_{xR} \tag{5}$$

R_{xA} − additional wind-generated resistance

R_{xW} − additional wave-generated resistance

R_{xR} − additional resistance resulting from e.g. rudder action to keep a given ship course.

STILL-WATER RESISTANCE OF SHIP

The ship's still-water resistance is usually measured (by model testing) or calculated for the ship in rectilinear motion. In real weather conditions the ship sails under a certain drift angle due to oblique action of wind and waves or/and possible surface sea current. Hence the still-water response for the ship at steady speed, is composed of :

$$\begin{aligned} R_x &= \frac{1}{2}\rho S V_{RV}^2 C_x(\beta_{RV}) \\ R_y &= \frac{1}{2}\rho S V_{RV}^2 C_y(\beta_{RV}) \\ M_z &= \frac{1}{2}\rho S L V_{RV}^2 C_m(\beta_{RV}) \end{aligned} \tag{6}$$

where :

R_x , R_y , M_z − components of still-water resistance forces and moment of ship sailing at drift angle β_{RV} , and surface sea current, respectively, (Fig.3)

ρ − water density

S − lateral projection of underwater ship hull surface onto ship's plane of symmetry (PS)

V_{RV} − relative ship speed

β_{RV} − relative drift angle

L − ship length

C_x , C_y , C_m − coefficients of resistance forces and moment.

In Eqs. (6) the relative speed and relative drift angle is as follows :

$$V_{RV} = \sqrt{V_{RVx}^2 + V_{RVy}^2} \tag{7}$$

$$\beta_{RV} = \operatorname{arc\,tg} \frac{-V_{RVy}}{V_{RVx}} \tag{8}$$

$$\left.\begin{aligned} V_{RVx} &= V_x - V_C \cos\beta_C \\ V_{RVy} &= V_y - V_C \sin\beta_C \end{aligned}\right\} \tag{9}$$

where :

V − absolute ship speed

$V_x = V\cos\beta$, $V_y = -V\sin\beta$ − absolute ship speed components

β − drift angle at absolute speed

V_C − surface sea current velocity

β_C − sea current direction relative to ship

$$\beta_C = \gamma_C - \psi \tag{10}$$

γ_C − geographical direction of surface sea current, (γ_C = = 0° northbound current, γ_C = 90° eastbound current)

ψ − geographical course of ship, (ψ = 0° northward course, ψ = 90° eastward course).

If the sea current velocity V_C = 0 then the absolute ship speed V and absolute drift angle β is valid for Eqs. (6).

In the subject-matter literature can be found various empirical formulae based on the tests of many ship models, by means of which values of the coefficients C_x , C_y , C_m (β_{RV}) can be calculated. In [20], the coefficients C_x, C_y, C_m for the directions defined in Fig.3, have the following form :

$$\begin{aligned} C_x &= 0.075\sin\left[\left(180° - \arcsin\frac{C_{x_0}}{0.075}\right)\left(1 - \frac{\beta_{RV}}{k_x}\right)\right] \\ C_y &= 0.5C_1\sin 2\beta_{RV}\cos\beta_{RV} + \\ &+ C_2\sin^2\beta_{RV} + C_3\sin^4 2\beta_{RV} \\ C_m &= m_1\sin 2\beta_{RV} + m_2\sin\beta_{RV} + \\ &+ m_3\sin^3 2\beta_{RV} + m_4\sin^4 2\beta_{RV} \end{aligned} \tag{11}$$

where :

C_{x_0} , k_x ,C_1 , C_2 , C_3 , m_1 , m_2 , m_3 , m_4 − the coefficients dependent on ship hull parameters, and S = L · T · σ (where : T − ship draught, σ − reduction factor for underwater hull surface side area) is the surface used in this method.

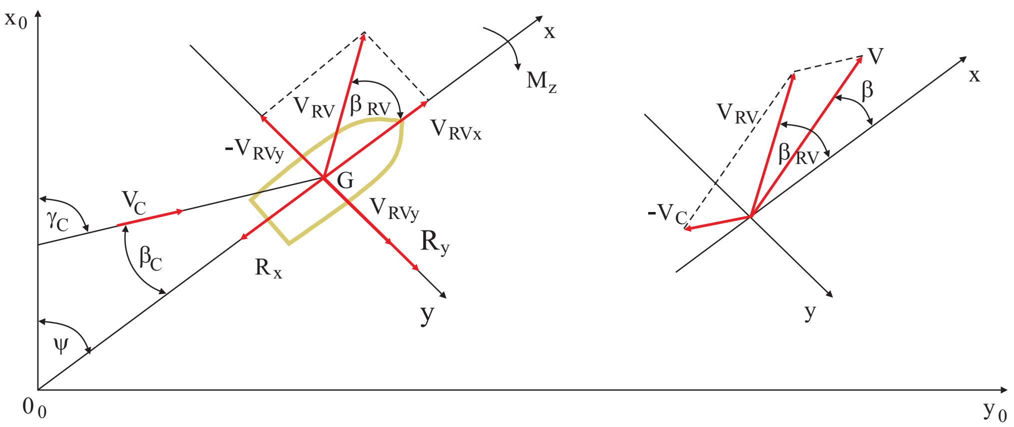

Fig. 3. Relative ship speed and drift angle in still water with surface sea current .

An example of calculated values of the coefficients C_x, C_y, $C_m(\beta_{RV})$ acc. [7] is shown in Fig.4. The shown coefficients were determined from the model tests [18] but only for small values of the drift angle β_{RV} (where, as often used, the angles are linearly dependent on the angle β_{RV}).

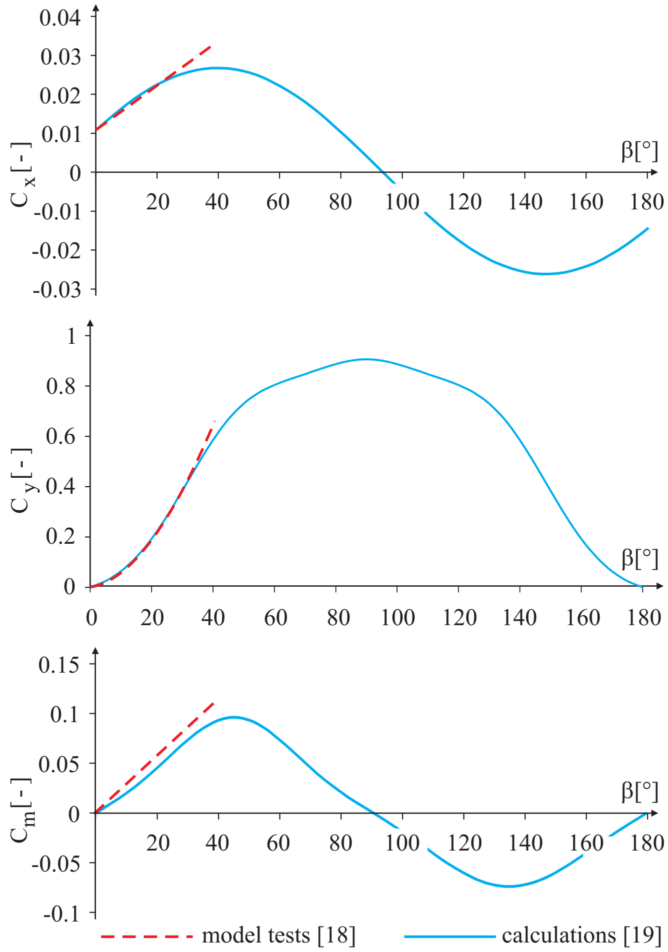

Fig. 4. *Ship resistance coefficients for the ship K1* during motion at the speed V = 8.4 m/s and a drift angle, as calculated, acc. [20] .*

Inserting the relations between the drift angle β_{RV} and the ship speed V_{RV} into Eq. (11) one obtains :

$$C_x = 0.075\sin\left[\left(180^\circ - \arcsin\frac{C_{x_0}}{0.075}\right)\left(1 - \frac{\arccos\frac{V_{RVx}}{V_{RV}}}{k_x}\right)\right]$$

$$C_y = -C_1\frac{V_{RVx}^2 V_{RVy}}{V_{RV}^3} - C_2\frac{V_{RVy}\left|V_{RVy}\right|}{V_{RV}^2} + -16C_3\frac{V_{RVx}^4 V_{RVy}^3\left|V_{RVy}\right|}{V_{RV}^8} \qquad (12)$$

$$C_m = -2m_1\frac{V_{RVx}V_{RVy}}{V_{RV}^2} - m_2\frac{V_{RVy}}{V_{RV}} + -8m_3\frac{V_{RVx}^3 V_{RVy}^3}{V_{RV}^6} - 16m_4\frac{V_{RVx}^4 V_{RVy}^3\left|V_{RVy}\right|}{V_{RV}^8}$$

* the parameters and dimensions of the ships for which the relevant calculations will be presented in Part III of this paper.

The coefficients C_x, C_y, C_m in the form (12) make it possible to easily calculate the drifting speed V_y and thus the drift angle, provided the components of the external forces exciting ship drift are known.

The coefficient C_{x_0} which appears in the first of Eqs (12), can be calculated from still-water resistance for ship in rectilinear motion and without drift :

$$C_{x_0} = \frac{C_R(V)}{\frac{1}{2}\rho S} \qquad (13)$$

where :

$C_R(V)$ – the still-water resistance coefficient for ship in rectilinear motion :

$$C_R(V) = \frac{R}{V^2} \qquad (14)$$

and

R – still-water resistance for ship in rectilinear motion.

As the coefficient $C_R(V)$ has no constant value (Fig. 5) hence the resistance R or coefficient C_{x_0} will be provided for a given ship also in the form of the table of discrete values dependent on the speed V. For a given ship its resistance can be approximately measured by means of model testing or derived from approximate formulae e.g. those provided by Holtrop-Mennen method [13, 14, 15] or Hollenbach method [12].

The resistance R to a large extent depends on hull surface state. The above mentioned methods make it possible to take into account a real state of hull surface and thus to investigate its impact on ship's service speed, that has been used in the presented method.

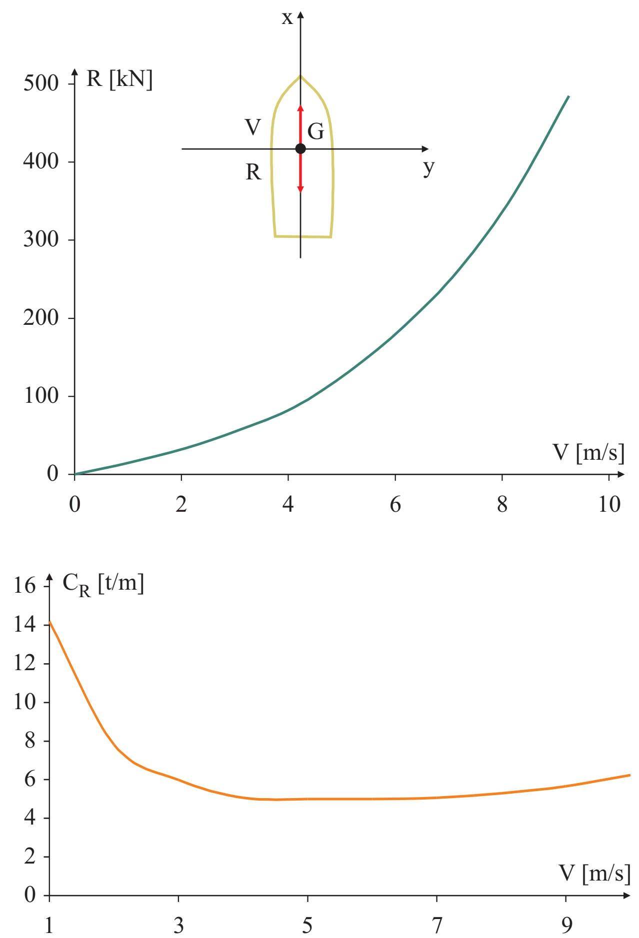

Fig. 5. *Example characteristics* R(V) *and* $C_R(V)$ *for the ship* K1 .

WIND INFLUENCE ON SHIP IN MOTION

The mean wind forces acting on the ship in motion can be calculated by using the following formulae :

$$R_{xA} = -\frac{1}{2}\rho_A S_x V_{RA}^2 C_{Ax}(\beta_{RA})$$
$$R_{yA} = \frac{1}{2}\rho_A S_y V_{RA}^2 C_{Ay}(\beta_{RA}) \qquad (15)$$
$$M_{zA} = \frac{1}{2}\rho_A S_y L V_{RA}^2 C_{Am}(\beta_{RA})$$

where :

ρ_A – air density
S_x , S_y – areas of front and side projections of above water part of ship onto midship and symmetry plane of ship, respectively
L – ship length
V_{RA} – relative wind speed (Fig.6)
C_{Ax} , C_{Ay} , C_{Am} (β_{RA}) – aero-dynamical drag coefficients of the above-water part of ship surface, dependent on the relative wind direction (β_{RA})
β_{RA} – relative wind direction (Fig.6)

$$V_{RA} = \sqrt{V_{RAx}^2 + V_{RAy}^2} \qquad (16)$$

$$\left.\begin{aligned} V_{RAx} &= V_A \cos\beta_A - V \\ V_{RAy} &= V_A \sin\beta_A \end{aligned}\right\} \qquad (17)$$

$$\beta_A = \gamma_A - \psi + 180° \qquad (18)$$

where : β_A – wind direction relative to ship

$$\beta_{RA} = \mathrm{arctg}\frac{-V_{RAy}}{V_{RAx}} \qquad (19)$$

V_A – absolute wind speed
γ_A – geographical direction of wind ($\gamma_A = 0°$ – north wind, $\gamma_A = 90°$ – east wind)
V – ship speed
ψ – geographical course of ship.

In Eqs. (15) the ship drift angle β was omitted because of its small value and very low influence on the relative wind speed β_{RA} and thus on the wind impact forces.

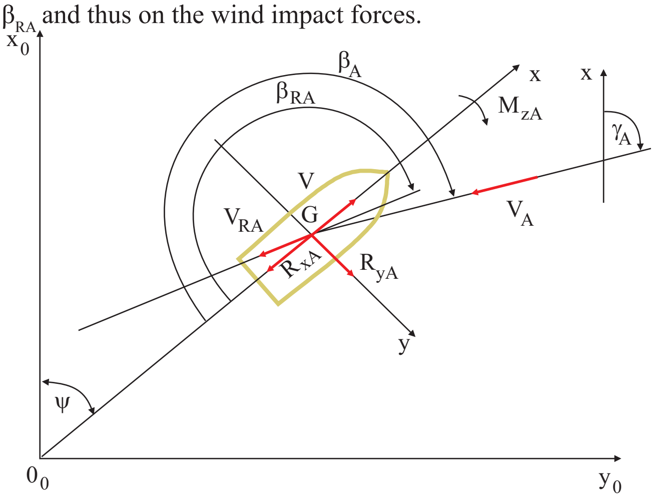

Fig. 6. *The reference frames of coordinates, speeds and directions of ship and wind .*

One can calculate the wind forces acting on the ship in motion at a given ship speed V and course ψ, assuming the wind parameters (V_A , γ_A), the aero-dynamical drag coefficients C_{Ax} , C_{Ay} , C_{Am} calculated by means of the approximate formulae given in [17, [21] or derived from the model tests [2] for the ship K1 as shown in Fig.7. In Eqs. (15) the force R_{xA} represents the additional resistance due to wind, and the force R_{yA} and moment M_{zA} may induce ship drift and change of its course, and ship's steering gear must be used to balance it, and due to the gear action the additional resistance R_{xR} will be then produced.

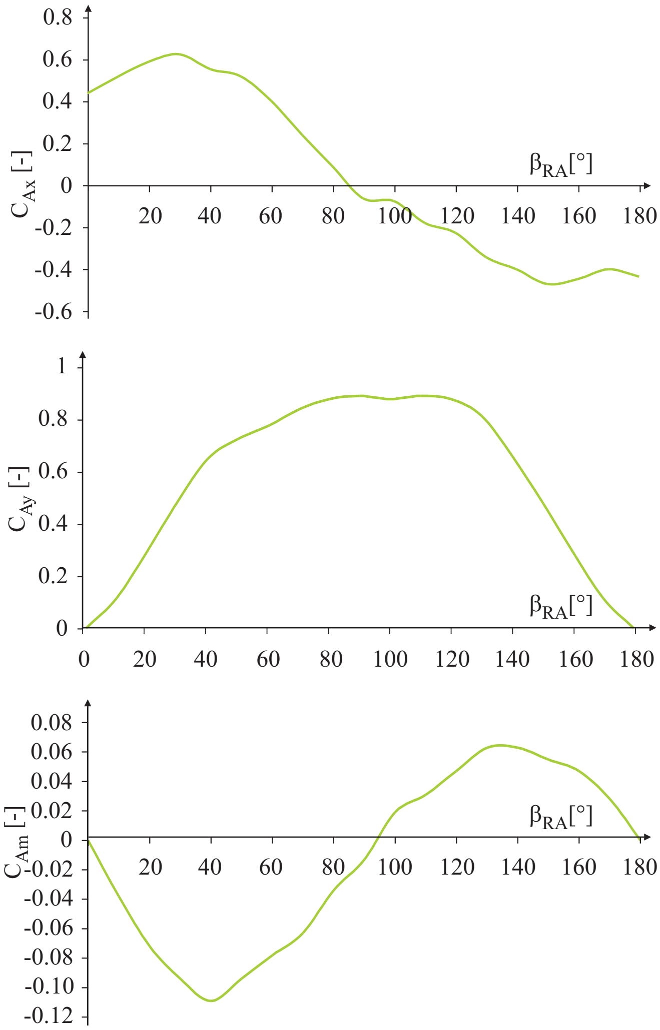

Fig. 7. *The aero-dynamical drag coefficients* C_{Ax} , C_{Ay} , C_{Am} *for the ship* K1*, acc. [2] .*

WAVE INFLUENCE ON SHIP IN MOTION

The mean irregular-wave–generated forces (i.e. mean wave-generated drift forces) acting onto ship in motion can be calculated by using the formulae :

$$\left.\begin{aligned} R_{xW} &= 2\rho g\frac{B^2}{L}\int_0^\infty C_{Wx}(\omega/\beta_W, V)S_{\zeta\zeta}(\omega)d\omega \\ R_{yW} &= 2\rho g\frac{B^2}{L}\int_0^\infty C_{Wy}(\omega/\beta_W, V)S_{\zeta\zeta}(\omega)d\omega \\ M_{zW} &= 2\rho g B^2\int_0^\infty C_{Wm}(\omega/\beta_W, V)S_{\zeta\zeta}(\omega)d\omega \end{aligned}\right\} \qquad (20)$$

where :

ρ – water density

g – acceleration of gravity

B – ship breadth

C_{Wx} , C_{Wy} , C_{Wm} (ω / β_W , V) – coefficients of regular- wave-generated drift force dependent on the wave direction relative to ship, β_W, and ship speed V

ω – regular wave frequency

β_W – wave direction relative to ship (Fig.8)

$$\beta_W = \mu - \psi + 180° \qquad (21)$$

μ – geographical direction of waves, (μ = 0° - north wave, μ = 90° - east wave)

$S_{\xi\xi}(\omega)$ – wave energy spectral density function (dependent on the significant wave height H_S and mean wave period T_1).

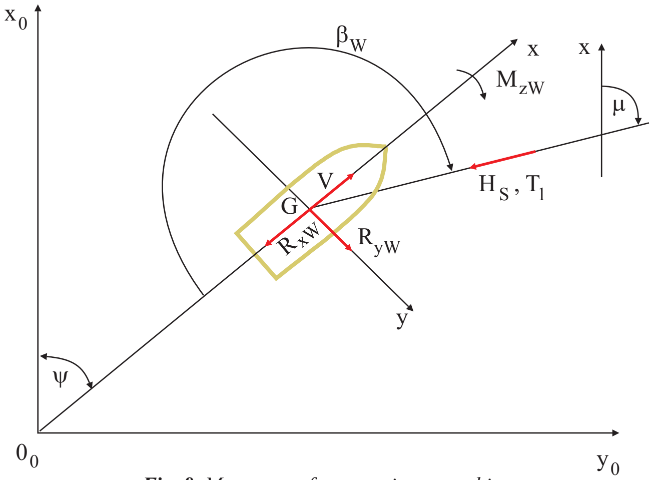

Fig. 8. *Mean wave forces acting onto ship .*

Assuming the wave parameters (H_S , T_1, μ), and the coefficients of wave – generated drifting force, C_{Wx} , C_{Wy} , C_{Wm} , (calculated acc. [1 , 5] or derived from the model tests as for the ship K1, shown in Fig.9), one can calculate, for a given ship speed V and course ψ, the wave-generated forces acting on the ship in motion. As in the case of wind action the force R_{xW} represents the additional ship resistance due to wave action, and the force R_{yW} and moment M_{zW} may cause ship drift and change its course.

ADDITIONAL SHIP RESISTANCE DUE TO PASSIVE RUDDER

When ship sails in waves, especially when oblique wind and waves influence the ship's motion, are generated lateral forces and moments which force the ship's course changing

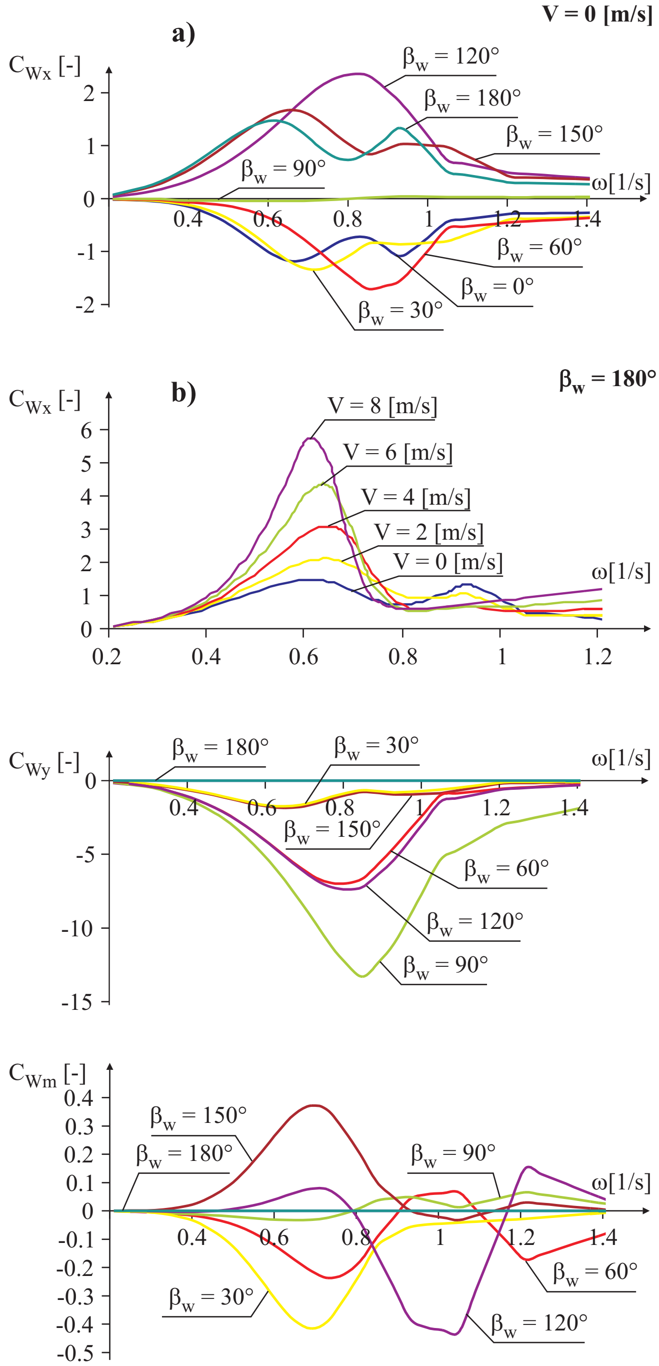

Fig. 9. *Wave-generated drift force coefficients* C_{Wx} , C_{Wy} , C_{Wm} *for the ship* K1*, acc. [8]:*
a) *for various wave directions relative to ship at* V *= const,*
b) *for various ship speed at* β_W *= const .*

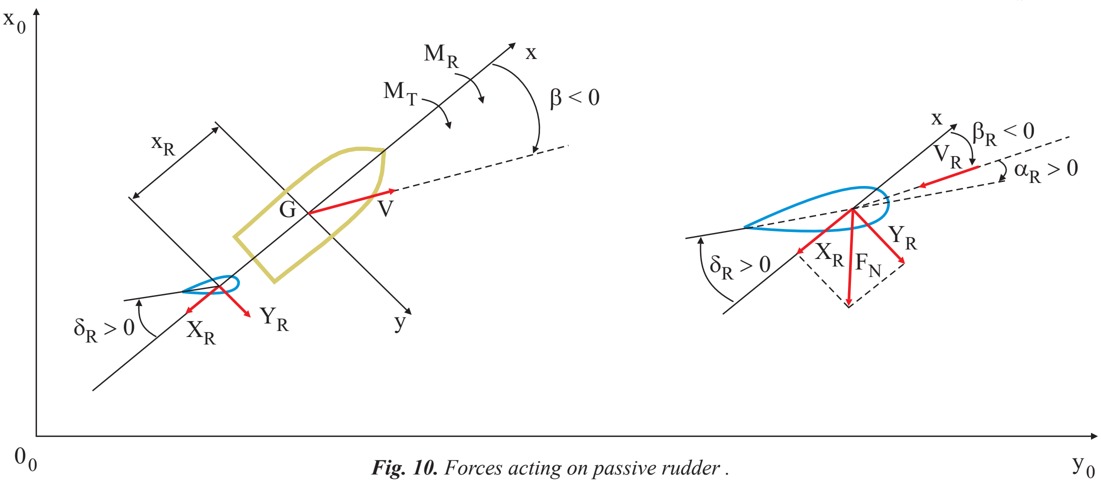

Fig. 10. *Forces acting on passive rudder .*

and drifting. In order to keep the ship's course constant the rudder blade must be inclined, that produces the additional resistance R_{xR}.

In the literature on ship manoeuvring several algorithms for calculation of hydro-dynamical forces on passive rudder, including those dealing with additional resistance , can be found, e.g. in [9 , 16]. According to [16], the passive rudder forces can be calculated by using the formulae :

$$R_{xR} = |F_N \sin \delta_R| \\ R_{yR} = a_y F_N \cos \delta_R \\ M_{zR} = a_z F_N \cos \delta_R \quad (22)$$

where :

δ_R – passive rudder angle
a_y – coefficient of hull influence on the rudder force R_{yR}
a_z – coefficient of hull influence on the rudder moment M_{zR}

$$a_z = a_y X_R \quad (23)$$

X_R – abscissa of rudder axis measured from the ship mass centre G ($X_R < 0$)
F_N – rudder normal force

$$F_N = \frac{1}{2}\rho \frac{6.13\lambda}{\lambda + 2.25} A_R V_R^2 \sin \alpha_R \quad (24)$$

λ – rudder aspect ratio
A_R – rudder surface area
V_R – water inflow velocity to rudder
α_R – effective rudder angle of attack.

As a result of passive rudder inclination the moment M_{zR} of force R_{yR} appears, and in order to keep the set course of the ship, the rudder moment should have such value as to balance the resultant forcing moment due to action of wind, water flow and waves:

$$M_{zT} = - M_{zR} \quad (25)$$

where :

$$M_{zT} = M_{zA} + M_{zW} + M_z \quad (26)$$

Hence, value of the rudder angle δ_R, calculated by using Eq. (22) under assumption of keeping the ship course constant, will be dependent on the wind and wave parameters and ship's drift angle.

NOMENCLATURE

A_R – rudder surface area
a_z , a_y – coefficients of hull influence on rudder forces
B – ship breadth
C_{Ax} , C_{Ay} , C_{Am} – aero-dynamical drag coefficients
C_R – still-water ship resistance coefficient
C_x , C_y , C_m – water resistance coefficients of forces and moments
C_{Wx} , C_{Wy} , C_{Wm} – coefficients of regular -wave -generated drift force
C_1 , C_2 , C_3 , C_{x0} – approximation coefficients dependent on form of underwater part of ship hull
F_N – rudder normal force
f_{HT} – occurrence probability of wave of H_S and T_1 parameters, coming from μ direction
f_{VA} – occurrence probability of mean wind speed
$f_{\gamma A}$ – occurrence probability of wind direction
f_μ – occurrence probability of wave direction
g – acceleration of gravity
H_S – significant wave height
k_x – approximation coefficient dependent on form of underwater part of ship hull
L – ship length
M_{zT} – resultant forcing moment due to wind, water flow and waves
m_1 , m_2 , m_3 , m_4 – approximation coefficients dependent on form of underwater part of ship hull
R – still-water resistance of ship
R_C – total resistance of ship
R_x , R_y , M_z – still-water ship resistance components of force and moment during sailing at drift angle β, respectively
R_{xA} , R_{yA} , M_{zA} – mean wind forces and moment acting on ship in motion (where R_{xA} - additional wave-generated ship resistance), respectively
R_{xR} , R_{yR} , M_{zR} – passive rudder forces and moment (where R_{xR} - additional rudder-generated resistance), respectively
R_{xW} , R_{yW} , M_{zW} – mean wave-generated drift forces and moment (where R_{xW} - additional wave-generated resistance), respectively
S – area of side projection of underwater part of ship hull onto its plane of symmetry
S_x , S_y – areas of front and side projections of above water part of ship onto midship and symmetry plane of ship, respectively
$S_{\zeta\zeta}(\omega)$ – wave energy spectral density function
T – ship draught
T_1 – mean characteristic wave period
V – ship speed
V_A – wind speed
V_C – sea current speed
V_R – water inflow velocity to rudder
V_{RA} – relative wind speed
V_{RV} – relative ship speed
V_x , V_y – ship speed components
X_R – rudder axis abscissa measured from ship mass centre

α_R – effective rudder angle of attack
β – ship drift angle
β_A – wind direction relative to ship
β_C – current direction relative to ship
β_{RA} – relative wind direction
β_{RV} – relative drift angle
β_W – wave direction relative to ship
γ_A – geographical direction of wind
γ_C – geographical direction of sea current
ΔR – additional resistance due to rough weather
δ_R – passive rudder angle
λ – rudder aspect ratio
μ – geographical direction of wave
ρ – water density
ρ_A – air density
ψ – geographical angle of ship course
ω – regular wave frequency

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FOREIGN *conference*

SHIP STABILITY WORKSHOP

On 6-7 October 2005 Faculty of Naval Architecture and Ocean Engineering, Istambul Technical University (ITU) organized :

8th International Ship Stability Workshop

which was initiated by the keynote address on :

Effects of initial bias on the roll response and stability of ships in beam seas
by A.Y. Odabasi and E.Ucer (ITU).

Program of the scientific meeting consisted of 6 topical sessions :

- ***Theoretical prediction of intact stability*** (4 papers)
- ***Experimental investigation of intact stability*** (4 papers)
- ***Special problems on ship stability*** (4 papers)
- ***Theoretical development in damage stability*** (3 papers)
- ***Assessment of ship stability safety*** (5 papers)

as well as the special session on :

- Regional issues and activities with one paper on : *Anatomy of a capsize : then and now* – by M. Tyalan (ITU).

The papers presented during the topical sessions were prepared by representatives of the universities and scientific research centers from Japan and USA (4 papers each), Greece and UK (3 papers each), Poland and Russia (2 papers each), Brazil, Holland, Italy, Korea, Norway, Sweden and Turkey (1 paper each).

Polish scientific workers contributed in preparation of the following papers :

- *Appraisal of risk assessment approach to stability of ships* – by L. Kobyliński (Foundation for Safety of Navigation and Marine Environment Protection, Poland)
- *Risk characterization of the requires index R in the New Probabilistic Rules for Damage Stability* – by M. Pawłowski (Academic Visitor to Ship Stability Research Centre (SSRC); Gdańsk University of Technology, Poland), and D. Vassalos (SSRC; The Universities of Glasgow and Strathclyde, UK).