Scientific Journals
Maritime University of Szczecin

Zeszyty Naukowe
Akademia Morska w Szczecinie

2014, 38(110) pp. 131–135
ISSN 1733-8670

2014, 38(110) s. 131–135

Approximate method of calculation of the wind action on a bulk carrier

Katarzyna Żelazny

West Pomeranian University of Technology, Faculty of Maritime Technology and Transport
71-065 Szczecin, al. Piastów 41, e-mail: katarzyna.zelazny@zut.edu.pl

Key words: bulk carrier, approximate method of wind action, approximation of surface and resistance

Abstract

While a ship is sailing, wind is acting upon the ship hull above water. As a result, additional resistance, as well as transfer drift force and drift moment emerge. The article presents an approximate method of calculating these forces for bulk carriers, in the form useful at preliminary ship design, when only basis ship dimensions are known.

Introduction

While a transport vessel sails on a given shipping route in real life conditions, its service speed is affected by numerous factors, wind action among others. If the wind is acting upon a vessel from bow sectors, then additional resistance, as well as transfer drift force, as well as a drift moment appear (in order to keep the vessel on a present shipping route, this moment has to be counterbalanced by a rudder plane and resulting carrying helm. Knowledge of wind action on a vessel is important not only in anticipating its speed, but also its steering. There are various method of calculation of wind action on the ship part above water, available in the literature on the subject matter, most often, however, they require the knowledge of aerodynamic resistance coefficients, which depend – among others – the shape of the ship part above water including superstructures.

During preliminary ship design, when the shape of the ship part above water is not known yet, models based on basic geometrical ship hull parameters are highly useful. The article presents an approximate method of calculating wind action forces on a sailing vessel (bulk carrier) useful at preliminary ship design.

Wind action on a sailing vessel

Mean wind action forces on a sailing ship can be calculated from the formulas:

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

where:

ρ_A – air density;

S_x, S_y – projections of vessel surface above water (from bow and lateral respectively) onto midship plane and plane of symmetry;

L – ship length;

V_{RA} – relative wind speed (Fig. 1);

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

β_{RA} – relative wind direction (Fig. 1).

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

$$\begin{aligned} V_{RAx} &= V_A \cos\beta_A - V \\ V_{RAy} &= V_A \sin\beta_A \end{aligned} \tag{3}$$

$$\beta_A = \gamma_A - \psi + 180° \tag{4}$$

β_A – wind action against the vessel (β_A = 0° wind from the stern, β_A = 90° wind at the bow);

$$\beta_{RA} = \arctan\frac{-V_{RAy}}{V_{RAx}} \tag{5}$$

V_A – wind speed;
γ_A – geographical wind direction, (γ_A = 0° – north wind, γ_A = 90° – east wind);
V – ship speed;
ψ – geographical course of a ship.

In equations (1) drift angle β of a ship has been neglected, since it will only have small value and influence the relative wind direction β_{RA} and hence wind action only to a minimal degree.

Force R_{xA}, in equations (1), is an additional resistance resulting from wind action, while moment M_{zA} can cause drift and change in a vessel course, to counterbalance which steering devices have to be used.

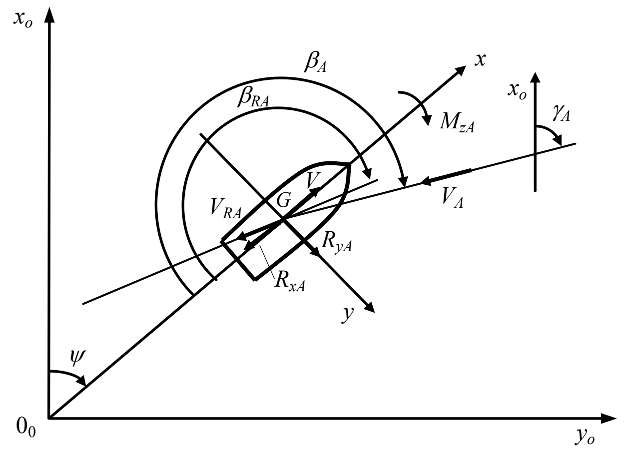

Fig. 1. Coordinates, forces, velocities, as well as directions of ship and wind

In equations (1) as well as in figure 1 it has been assumed, that if a ship sails upwind, then wind action is additional resistance, however, with wind from the stern, then wind action causes total resistance to decrease.

Approximation of ship additional resistance from wind action

Forces R_{xA}, R_{yA}, as well as M_{zA} moment of wind action on the ship part above water depend among other on the resistance of the ship shape above water (given by coefficients C_{Ax}, C_{Ay} and C_{Am} in equation (1)), as well as the surface of the ship part above water S_x, S_y. As a result, quantities C_{Ax}, C_{Ay}, C_{Am}, S_x and S_y for selected types of ships will be approximated here.

The coefficients C_{Ax}, C_{Ay} and C_{Am} are mostly determined during the model tests [1] above-water part of the ship in the aerodynamic tunnel or can be calculated from the approximate formulas [2, 3]. These coefficients for a specific type of a ship, e.g. bulk carriers, depend on a ship size to a small degree. Coefficients C_{Ax}, C_{Ay} and C_{Am} measured in aerodynamic tunnel for a bulk carrier [1] have been approximated by a polynomial dependent only on relative wind direction β_{RA}, (Fig. 1). Obtained relationships have the following form:

$$\begin{aligned}
C_{ax}(\beta_{RA}) &= 0.4770 + 0.01528\beta_{RA} + \\
&\quad - 3.202\cdot10^{-4}\beta_{RA}^2 + 1.060\cdot10^{-6}\beta_{RA}^3 \\
&\quad R^2 = 0.989 \\
C_{ay}(\beta_{RA}) &= -0.01529 + 0.01529\beta_{RA} + \\
&\quad - 8.710\cdot10^{-5}\beta_{RA}^2 \\
&\quad R^2 = 0.981 \\
C_{am}(\beta_{RA}) &= -0.01815 - 4.752\cdot10^{-3}\beta_{RA} + \\
&\quad + 5.868\cdot10^{-5}\beta_{RA}^2 - 1.783\cdot10^{-7}\beta_{RA}^3 \\
&\quad R^2 = 0.964
\end{aligned} \tag{6}$$

while exactness of approximation against aerodynamic tunnel measurements has been shown in figure 2.

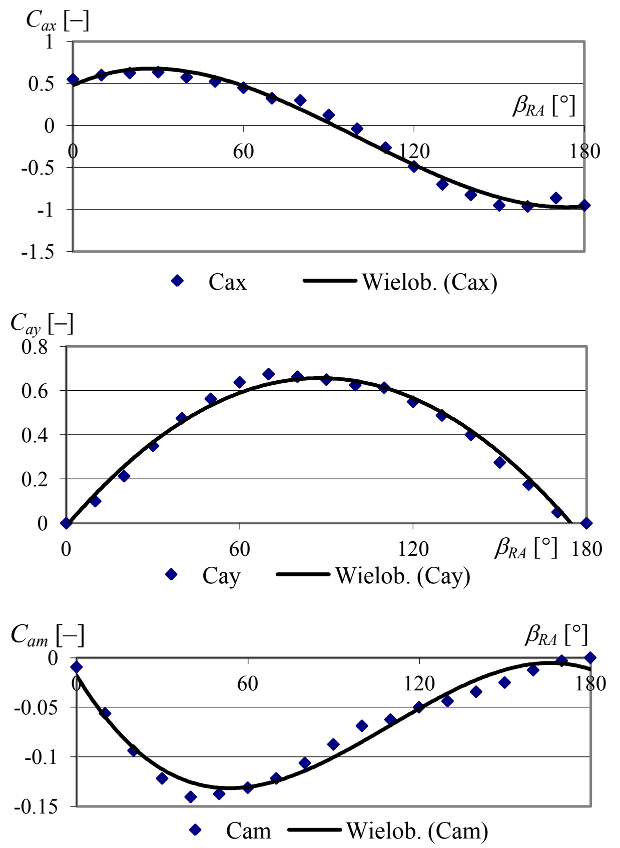

Fig. 2. Characteristics C_{Ax}, C_{Ay}, C_{Am} from aerodynamic tunnel [1] and those obtained from approximation (6)

Surfaces S_x i S_y for bulk carriers have been calculated for 33 ships, and then with the help of linear regression, an appropriate polynomial including only basic ship parameters (bulk carrier) has been searched. Examples of such polynomials are given in figures 3–12, while the degree of adjustment of these models depending on ship parameters in tables 1 and 2 respectively.

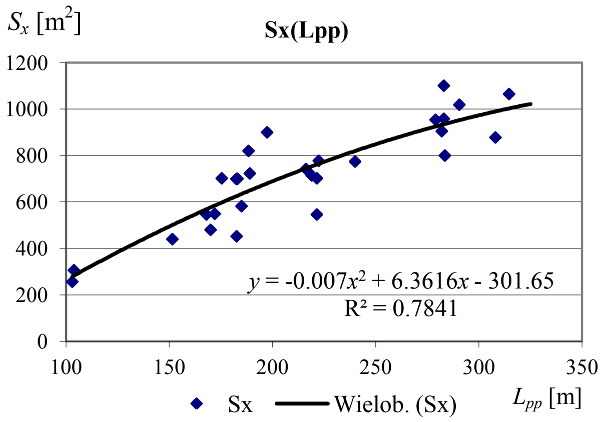

Fig. 3. Approximation of projection of the ship part above water from the bow S_x dependent on ship length between perpendiculars L_{PP}

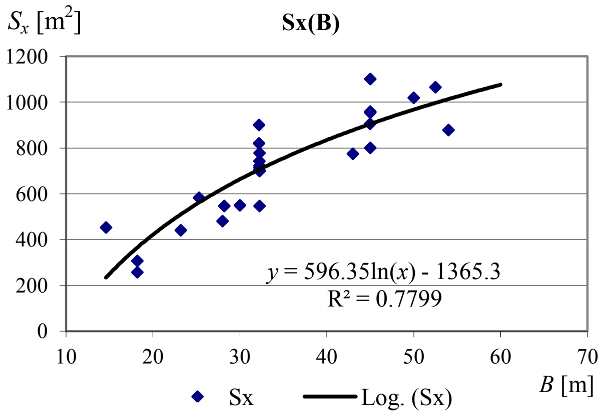

Fig. 4. Approximation of projection of the ship part above water from the bow S_x dependent on ship breadth B

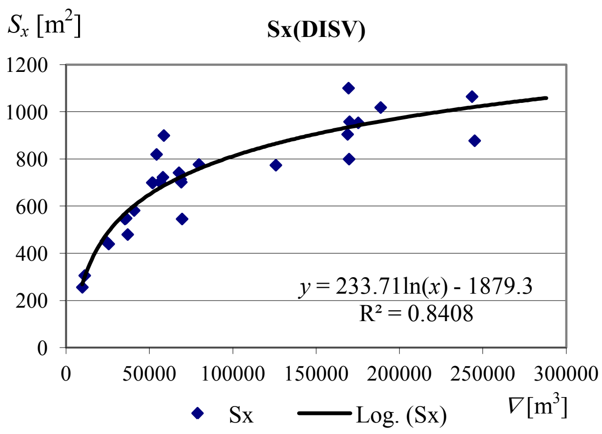

Fig. 5. Approximation of projection of the ship part above water from the bow S_x dependent on ship displacement ∇

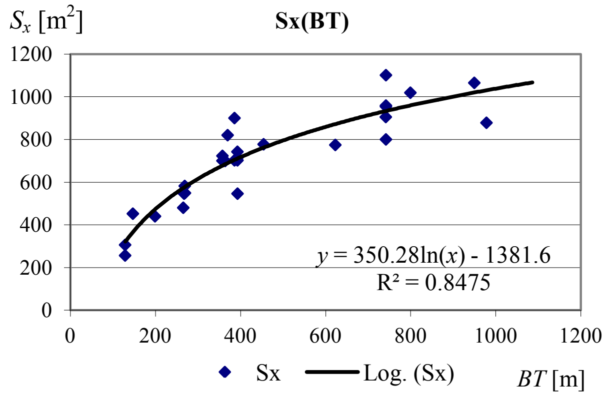

Fig. 6. Approximation of projection of the ship part above water from the bow S_x dependent on the product of the ship breadth B and draught T

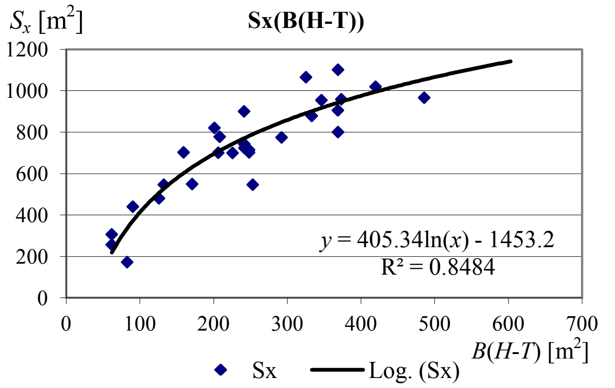

Fig. 7. Approximation of projection of the ship part above water from the bow S_x dependent on of the product of the ship breadth B draught T and the ship lateral height H

Table 1. The adjustment degree of a model for the approximation of the projection of the ship part above water from the bow S_x in relation to other ship parameters

	S_x=$f(L_{pp})$	S_x=$f(B)$	S_x=f(DISV)	S_x=$f(BT)$	S_x= $f(B(H–T))$
R^2 – the degree of adjustment of a model	0.784	0.780	0.841	0.848	0.848

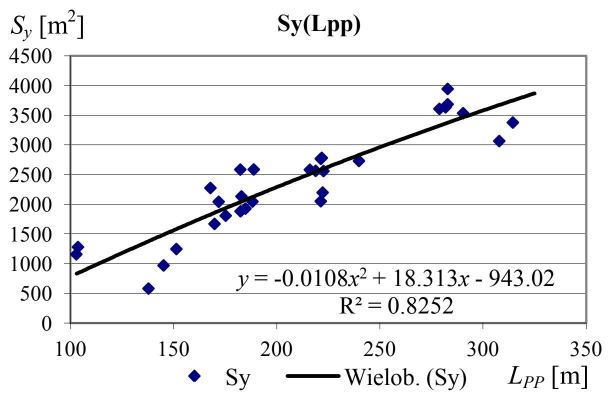

Fig. 8. Approximation of projection of the ship lateral part above water S_y dependent on length between perpendiculars L_{PP}

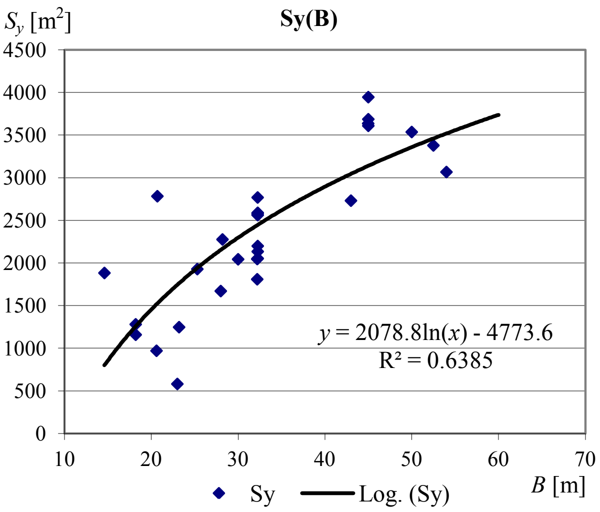

Fig. 9. Approximation of projection of the ship lateral part above water S_y dependent on ship breadth B

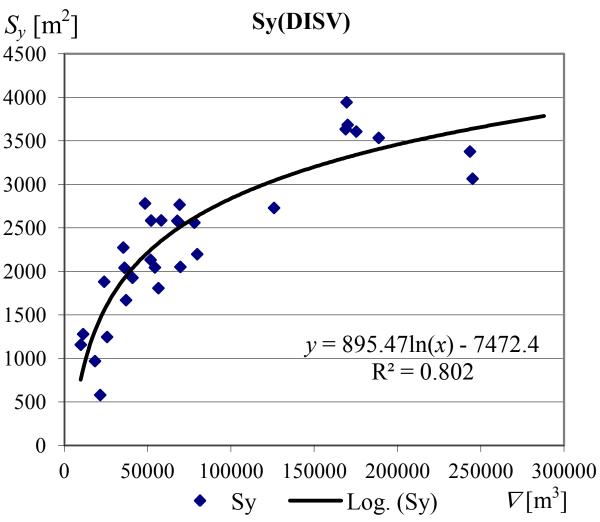

Fig. 10. Approximation of projection of the ship lateral part above water S_y dependent on ship displacement ∇

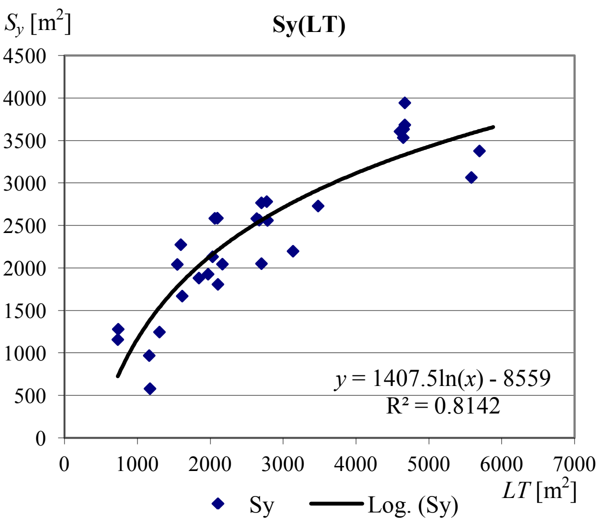

Fig. 11. Approximation of projection of the ship lateral part above water S_y dependent on the product of the ship length L and draught T

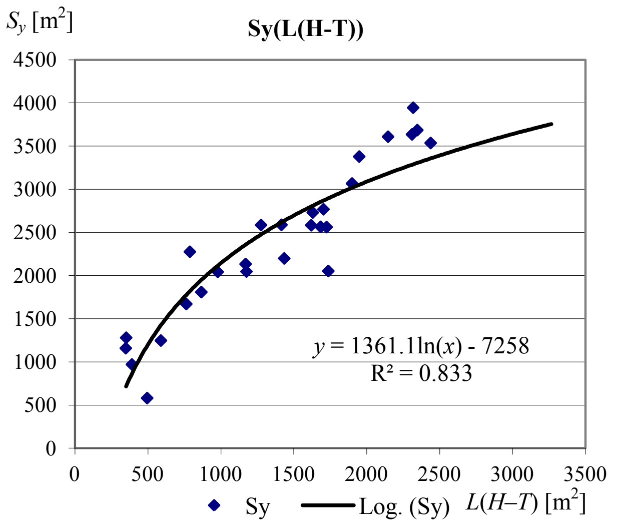

Fig. 12. Approximation of projection of the ship lateral part above water from S_y dependent on the ship length, draught T and the ship lateral height H

Table 2. The adjustment degree of models for the approximation of the projection of the ship lateral part above water S_y dependent on to ship parameters

	S_y=$f(L_{pp})$	S_y=$f(B)$	S_y=f(DISV)	S_y=$f(LT)$	S_y= $f(L(H–T))$
R^2 – the degree of adjustment of a model	0.825	0.639	0.802	0.814	0.833

Verification of a model and final conclusions

Having carried approximation for coefficients C_{Ax}, C_{Ay}, C_{Am}, as well as surfaces S_x, S_y equations (1) for bulk carriers take e.g. the form:

$$\begin{aligned}
R_{xA} &= -\frac{1}{2}\rho_A \cdot \left(233.71 \cdot \ln(\nabla) - 1879.3\right) \cdot V_{RA}^2 \cdot \\
&\cdot \left(0.4770 + 0{,}01528 \cdot \beta_{RA} - 3.202 \cdot 10^{-4} \cdot \beta_{RA}^2 + \right. \\
&\left. + 1.060 \cdot 10^{-6} \cdot \beta_{RA}^3\right) \\
R_{yA} &= \frac{1}{2}\rho_A \cdot \left(895.4 \cdot \ln(\nabla) - 7472.4\right) \cdot V_{RA}^2 \cdot \\
&\cdot \left(-0.01529 + 0.01529 \cdot \beta_{RA} + \right. \\
&\left. - 8.710 \cdot 10^{-5} \cdot \beta_{RA}^2\right) \\
M_{zA} &= \frac{1}{2}\rho_A \cdot \left(895.4 \cdot \ln(\nabla) - 7472.4\right) \cdot L \cdot V_{RA}^2 \cdot \\
&\cdot \left(-0.01815 - 4.752 \cdot 10^{-3} \cdot \beta_{RA} + \right. \\
&\left. + 5.868 \cdot 10^{-5} \cdot \beta_{RA}^2 - 1.783 \cdot 10^{-7} \cdot \beta_{RA}^3\right)
\end{aligned} \tag{7}$$

where ∇ – ship displacement.

In these equations only basic ship and wind parameters are known, hence they can be used already at preliminary ship design stage. The exactness of calculated forces R_{xA} and R_{yA}, as well as moment

M_{zA} from wind is shown on figures 13–15. On these graphs, points mark the value of forces and moment calculated according to equation (1) on the basis of measurements in aerodynamic tunnel [1], as well as measured surfaces, while a solid line represents the values for a chosen approximation (7) for different wind speeds and directions.

Additional resistance from wind action R_{xA} in total ship resistance constitute around 30% [4] depending on the ship size and wind speed on head wave. Taking this into account, it can be concluded, that the obtained exactness of approximation is on the sufficient level to determine wind action on the ship required at preliminary ship design.

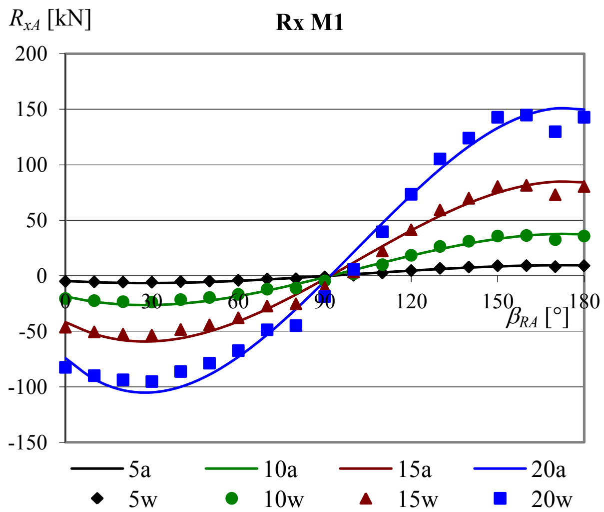

Fig. 13. Force R_{xA} – additional resistance from wind calculated on the basis of measurements in aerodynamic tunnel [1] and measured surfaces obtained from approximation (7) for different wind speeds and directions

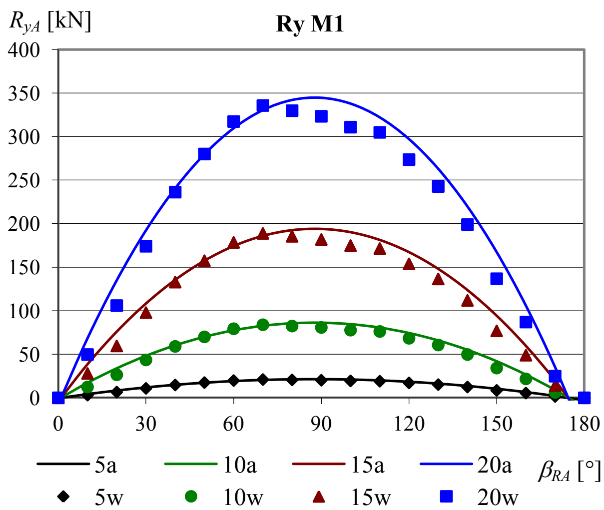

Fig. 14. Wind force R_{yA} calculated on the basis of measurements in aerodynamic tunnel [1] and measured surfaces obtained from approximation (7) for different wind speeds and directions

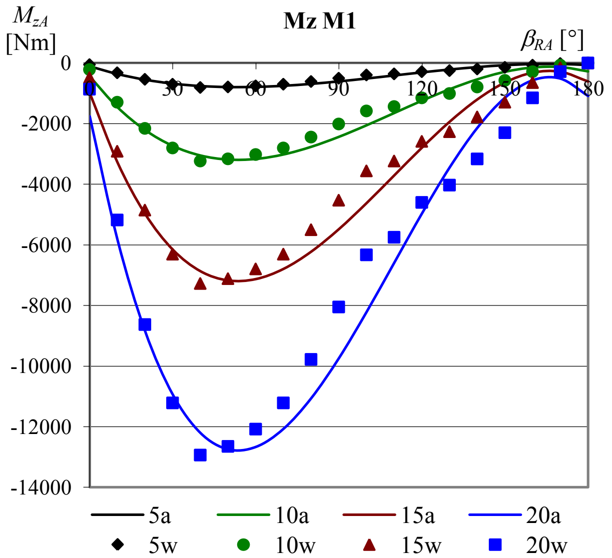

Fig. 15. Moment M_{zA} from wind calculated on the basis of measurements in aerodynamic tunnel [1] and measured surfaces obtained from approximation (7) for different wind speeds and directions

References

1. Blendermann W.: Manoeuvring Technical Manual. Shiff und Hafen, Heft 3/1990, Heft 4/1991.
2. Isherwood M.R.: Wind resistance of merchant ships. The Royal Institution of Naval Architects, Vol. 115, 1973, 327–338.
3. Vorabjew Y.L., Guliev Y.M.: Application of aerodynamics test results in ships and floating structures at sea problems. SMSSH '88, The Proceedings of the 17th Session, Varna, Vol. 1, 17–22 October 1988, 32-1–32-7.
4. Dudziak J.: Teoria okrętu. Fundacja Promocji Przemysłu Okrętowego i Gospodarki Morskiej, Gdańsk 2008.

Other

5. Ralston A.: Wstęp do analizy numerycznej. Państwowe Wydawnictwo Naukowe, Warszawa 1971.