The Geometry of JBC Above Water Surface and the Wind Tunnel Test Results

by

KUME Kenichi*

Abstract

As CFD calculations and model tests are used to assess ship performance, certain standardised procedures are necessary to ensure that there is minimal discrepancy in the estimation results between the implementing organisations, testing and calculation personnel. Non-governmental organisations such as the International Towing Tank Conference (ITTC) are contributing to such efforts. Test and calculation results using the same ship shape are also being compared in research projects and international workshops to establish a performance evaluation procedure that can lead to better estimation results. Benchmark hull forms are required for these comparisons, and several major and common ship types such as KVLCC, KCS, DTC and JBC have been published and are widely used. However, they only include the shape below the water surface and not the shape above the water surface, which is necessary for wind force assessment. Therefore, with the aim of increasing the value of the JBC as a benchmark hull form, the above-water shape of the JBC is published in this report along with the results of wind tunnel tests. This enables comparative verification of the wind forces as well as hydrodynamic forces received from the water, and provides a benchmark hull form that can be used for actual sea performance assessment that comprehensively considers the shape of the upper structure and the lower hull across the water surface.

* Fluids Engineering & Hull Design Department

Received　June　21st, 2022
Accepted　November　7th, 2022

Contents

1. Introduction

In the project on the evaluation of actual ship performance at sea (OCTARVIA-PJ, Oct. 2017-Mar. 2021), in which 25 domestic organisations participated, several ship types were selected to develop standardised procedures for tank tests in waves and CFD calculations necessary for the evaluation of actual ship performance at the design stage, and tank tests and CFD calculations have been carried out. The selected ship types include the Japan Bulk Carrier (JBC), which has been published as a benchmark hull form and is widely used worldwide. Furthermore, OCTARVIA-PJ has developed procedures for wind tunnel tests and CFD calculations for estimating wind forces acting on a hull, the above-water geometry of the JBC has been created and used for wind tunnel testing and CFD calculations. The results of the wind tunnel tests and CFD calculations of wind forces have been published in papers[1)2)] and provided to the International Towing Tank Conference (ITTC), contributing to the development of various ITTC guidelines[3)4)].

As the name suggests, JBC is a hull form of bulk carrier designed in Japan for a use of benchmark. The three-dimensional geometry of the hull below the water surface has already been published[5)], but the projected shape (contour lines) of the hull and upper structures above the water surface was only published in the aforementioned documents[1)-3)].

Benchmark hull forms are often used together with their test results, particularly for validation of CFD calculations, and many comparisons[6)] with tank test results have been carried out. In order to promote their use by more organisations, this paper presents basic data on the geometry above water surface of JBC and the wind tunnel test results.

CFD is a highly valuable tool that provides a lot of information on hydrodynamic forces and flow fields, but the ITTC requires each organisation to prepare best practice guidelines[7)], including procedures for conducting CFD calculations and results of verification of calculation accuracy, when CFD is used as a substitute for model tests. The use of CFD with guaranteed estimation accuracy is expected to progress in the future. This paper provides the necessary set of validation data for this.

2. Geometry above water surface

The JBC has a geometry designed as a capesize bulk carrier, but not a real hull form. Therefore, the shape above the water surface was designed with reference to the actual capesize bulk carriers. Relatively small structures such as handrails, winches, masts and so on, which have a negligible effect on wind forces, were omitted from the reproduction. This chapter describes the principal dimensions of the JBC in designed full load condition, as well as the input data required for the use of the vessel performance evaluation tool in actual seas "VESTA"[8)9)], the life cycle fuel consumption evaluation program "OCTARVIA Index/Prediction"[10)] developed by OCTARVIA-PJ and the regression formula by Fujiwara et al.[11)] for the wind resistance coefficient estimation, plus, the three-view drawing of the shape above the water surface and the three-dimensional geometry required for model manufacturing and computational grid generation for CFD.

2.1 Principal dimensions and input data for some calculation program

The input data required to use VESTA, OCTARVIA Index/Prediction and the regression formula by Fujiwara et al. as well as the principal dimensions of JBC in designed full load condition are shown in Table 1. The definitions of each variable are given in Eq. (1) and Fig. 1.

$$H_L = \frac{A_L}{L_{OA}} \tag{1}$$

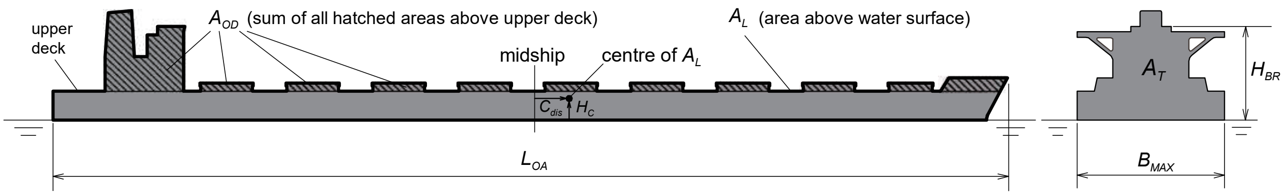

Fig. 1 Definition of input parameters for wind force calculations.

Table 1 Principal dimensions at designed full load condition.

Item		Unit	Value
Length overall	L_{OA}	[m]	291.293
Length between perpendiculars	L_{PP}	[m]	280.000
Maximum breadth	B_{MAX}	[m]	45.000
Draught at midship	d_M	[m]	16.500
Trim		[m]	0.000
Freeboard height		[m]	8.720
Transverse projected area above water line	A_T	[m^2]	965.3
Lateral projected area above water line	A_L	[m^2]	3 373.4
Lateral projected area above upper deck	A_{OD}	[m^2]	799.1
Height to bridge top from water line	H_{BR}	[m]	28.420
Height of the equivalent rectangle for A_L	H_L	[m]	11.580
Distance from the midship section to the centre of A_L (+ means fore from midship)	C_{dis}	[m]	-12.985
Height to centre of A_L from water line	H_C	[m]	7.028

2.2 Three-view drawing

A three-view drawing of JBC in designed full load condition is shown in Fig. 2. It can be seen that the detailed parts are omitted and only the superstructures, hatch covers and a funnel, which have a dominant influence on the aerodynamic forces acting on the hull, are reproduced. The dimensions of the various parts can be obtained from the 3D geometry data described in the next section and are therefore omitted from the three-view drawing.

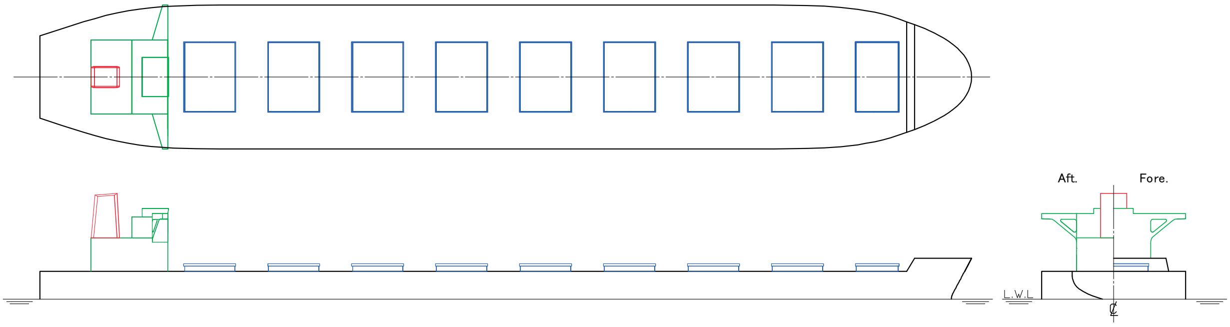

Fig. 2 Three-view drawing of JBC above water surface at designed full load condition.

2.3 Three-dimensional geometry

The 3D geometry of the JBC above water surface at designed full load condition is stored in IGES format in the "NMRI DB" at the URL below. The IGES data is created at full ship scale shown in Table 1, with the origin of the x, y and z coordinates being the aft perpendicular, the centre line and the original baseline of the hull.

URL for getting 3D geometry of JBC above water surface:

https://www.nmri.go.jp/en/study/intellectual/db/jbc/

3. Wind tunnel test results

OCTARVIA-PJ carried out wind force measurements in a wind tunnel at National Maritime Research Institute (NMRI) using the JBC model. This chapter reports on the model used in the wind tunnel test, the wind tunnel itself, the boundary layer distribution on the wind tunnel floor, the height averaged wind velocity used as the representative wind velocity in the analysis and the coefficients of wind forces and moment as the test result.

3.1 Ship model specification for wind tunnel test

For the wind tunnel tests, the L_{PP} was set at 1.200 m in the model compared to 280.0 m in the actual ship, taking into account the size of the wind tunnel measurement section and other limitations such as the capacity of the force balance. The scale ratio is 1.2/280. Fig. 3 shows the JBC model on the wind tunnel floor, which has the same 3D geometry as presented in the previous chapter.

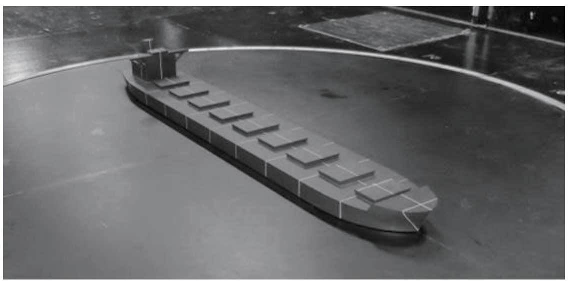

Fig. 3 Ship model on wind tunnel floor.

3.2 Wind tunnel specification

Wind force measurements are carried out in the wind tunnel at NMRI shown in Fig. 4, which has the following specifications.

- Göttingen-type horizontal recirculation system

- Wind tunnel measuring part: Closed type, 3 m width, 2 m height and 15 m length
- Steady wind velocity: 1.0 ~ 30 m/s
- Turbulence intensity: less than 0.5 %

The cross-sectional area of the measurement section is 6.0 m^2, which gives a blockage ratio of 1.0 % with respect to the maximum projected area of the model ship, A_L of 0.0620 m^2. This is a smaller blockage ratio than the recommended 5.0 % to reduce the influence on measurements, and it can be said that there is less influence of the closed wind channel on wind force measurements.

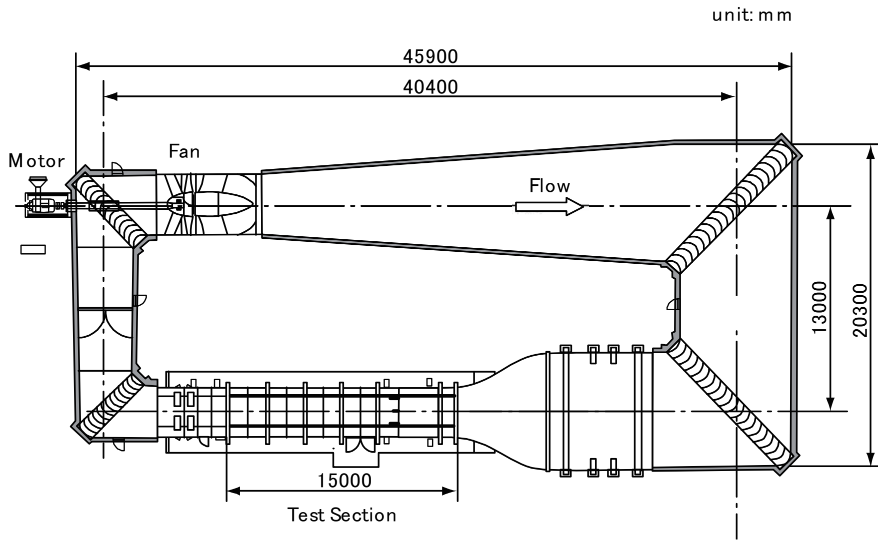

Fig. 4 Plan view of wind tunnel at NMRI.

3.3 Location of the model in the wind tunnel and the wind profile

The model ship used for wind force measurements is placed on the wind tunnel floor so that the midship is at 7500 mm downstream from the most upstream position of the wind tunnel measurement section, as shown in Fig. 5. In order to measure the forces acting on the ship model, the hull is fixed to the force balance with 3 mm clearance above the floor so that it does not touch to the floor. The vertical distribution of the wind speed at the centre of the turntable, that is where the midship is located, is shown in Fig. 6. Although the wind profile is shown in Fig. 6 when the ship model is not present in the wind tunnel, the front view of the ship is also shown in the figure for convenience to contrast with the size of the model. The wind profile is normalised by the reference wind speed U_{ref} in the wind tunnel, which is measured by a pitot tube fixed upstream in the wind tunnel. No objects are installed in the wind tunnel to simulate arbitrary boundary layers or to adjust the turbulence intensity. The thickness of the naturally developed boundary layer at the wind tunnel floor is about 130 mm at the centre of the turntable, indicating an almost uniform flow outside this boundary layer.

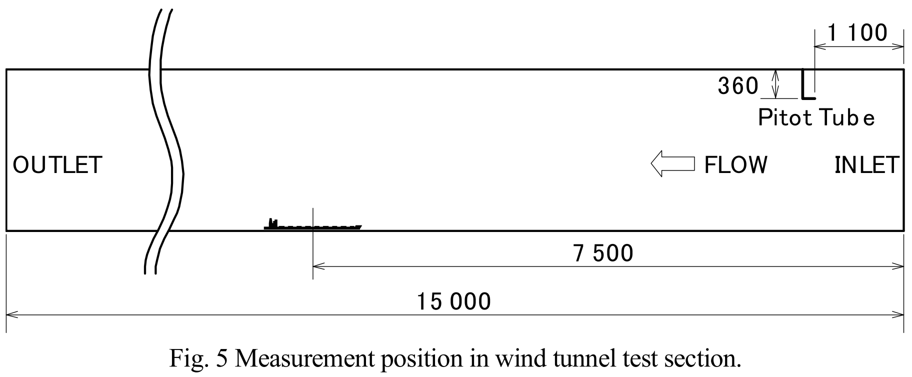

Fig. 5 Measurement position in wind tunnel test section.

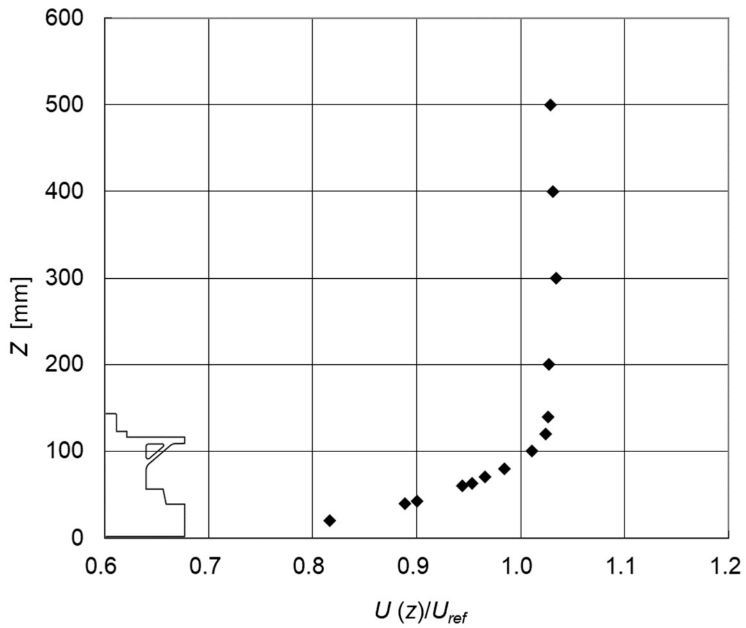

Fig. 6 Vertical distribution of wind speed at centre of turntable (U_{ref} =25 m/s).

3.4 Height averaged wind velocity

The measured wind forces and moment are normalised using air density, projected area of the model and representative wind speed, but for the representative wind speed, the height averaged wind velocity[1)2)] is used, which has been shown to reduce the effect of differences in boundary layer distribution. U_{A1} is used for normalisation of longitudinal force and U_{A2} for lateral force and yaw moment. The equations for calculating U_{A1} and U_{A2} are shown in Eqs. (2) and (3), and a conceptual diagram of the height averaged wind velocity is shown in Fig. 7. Where, H_{BR} is the height of the top of the navigation bridge from the sea surface and H_L is the average height which is derived from dividing the side projected area A_L of a ship by the ship overall length as given in Eq. (1). Note that U_{A1} and U_{A2} for the JBC model (L_{PP} =1.200 m) calculated using Fig. 6 and Eqs. (2) and (3) are 23.32 m/s and 20.98 m/s respectively when the reference wind speed in the wind tunnel U_{ref} is 25.00 m/s.

$$U_{A1}^2 = \frac{1}{H_{BR}} \int_0^{H_{BR}} U(z)^2 \, dz \tag{2}$$

$$U_{A2}^2 = \frac{1}{H_L} \int_0^{H_L} U(z)^2 \, dz \tag{3}$$

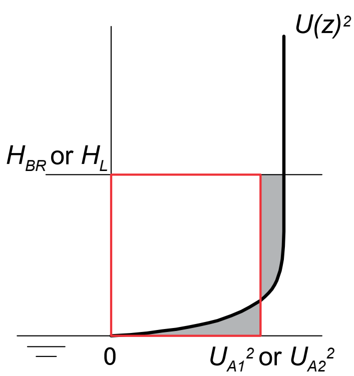

Fig .7 Conceptual diagram of height averaged wind velocity.

3.5 Coefficients of wind forces and yaw moment

The forces and yaw moment measured in the NMRI wind tunnel are normalised using Eqs. (4) to (6) and are shown in Figs. 8 to 10 and Table 2 for each wind direction angle. As the ship shape is symmetrical, only port side of the measurement is shown.

$$C_X = F_X \Big/ \left(\frac{1}{2} \rho U_{A1}{}^2 A_T \right) \tag{4}$$

$$C_Y = F_Y \Big/ \left(\frac{1}{2} \rho U_{A2}{}^2 A_L \right) \tag{5}$$

$$C_N = M_Z \Big/ \left(\frac{1}{2} \rho U_{A2}{}^2 A_L \; L_{OA} \right) \tag{6}$$

Where F_X, F_Y and M_Z are the longitudinal force, lateral force and yaw moment acting on the ship model, respectively, as defined by the coordinate system shown in Fig. 11, and ρ is air density.

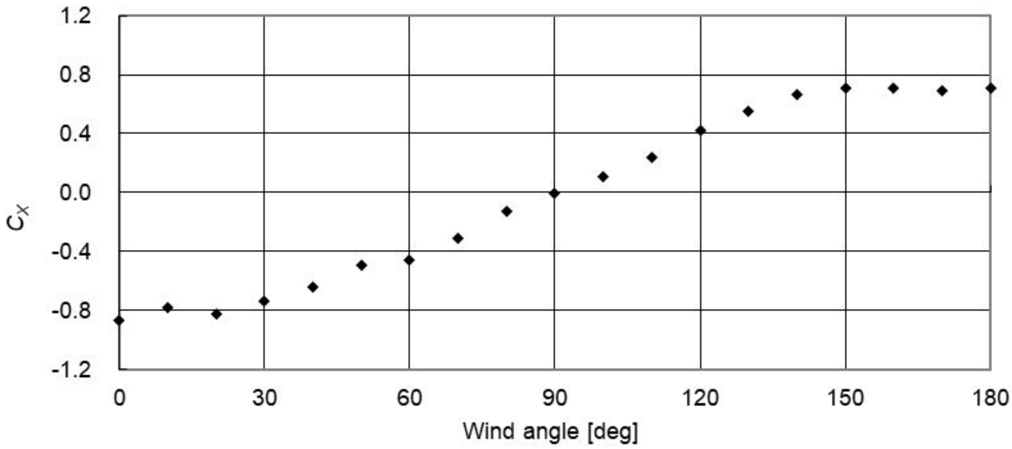

Fig. 8 Coefficient of longitudinal wind force.

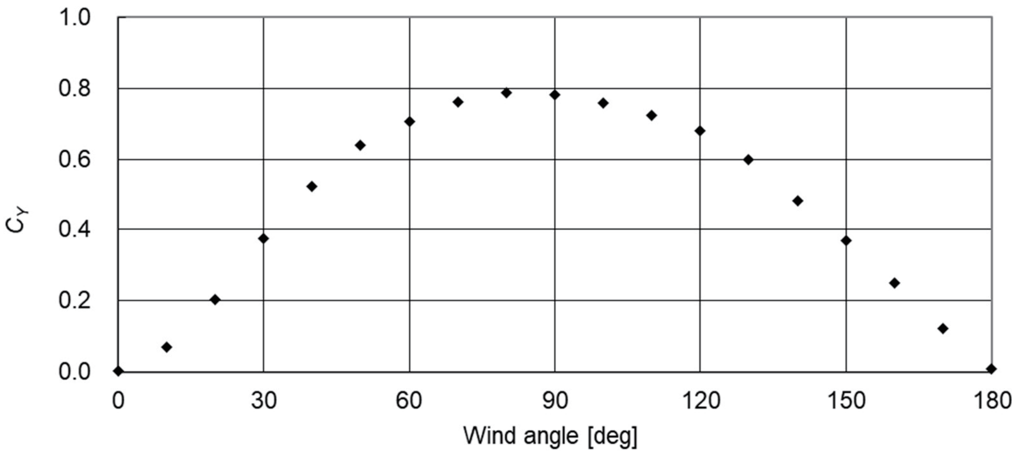

Fig. 9 Coefficient of lateral wind force.

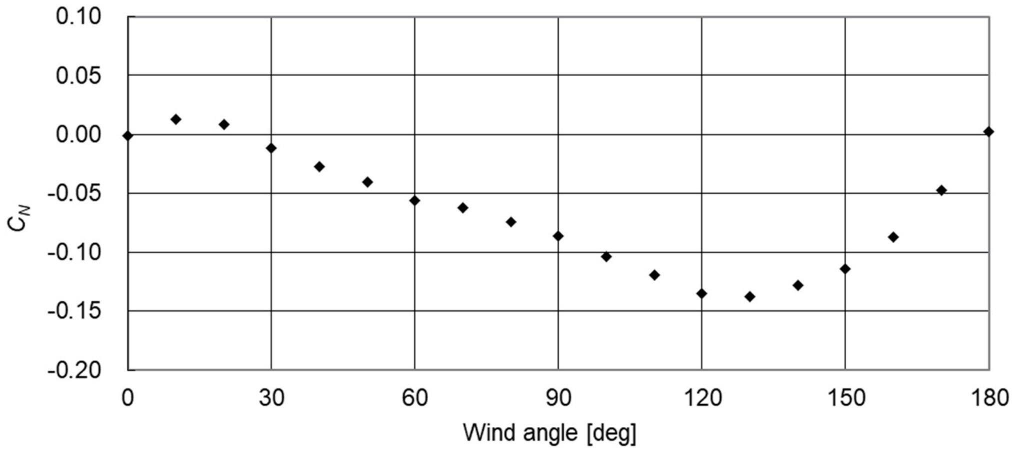

Fig. 10 Coefficient of yaw moment around midship.

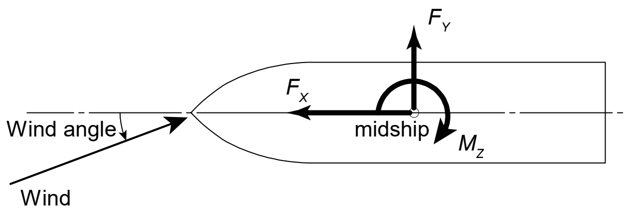

Fig. 11 Coordinate system.

Table 2 Coefficients of wind forces and yaw moment obtained by wind tunnel tests.

Wind angle [deg]	C_X	C_Y	C_N
0	-0.871	0.003	-0.001
10	-0.782	0.071	0.013
20	-0.825	0.204	0.009
30	-0.733	0.374	-0.011
40	-0.641	0.524	-0.027
50	-0.493	0.639	-0.040
60	-0.457	0.707	-0.055
70	-0.309	0.762	-0.062
80	-0.130	0.787	-0.074
90	-0.003	0.780	-0.086
100	0.110	0.759	-0.104
110	0.238	0.722	-0.119
120	0.420	0.680	-0.135
130	0.551	0.598	-0.137
140	0.666	0.482	-0.128
150	0.705	0.368	-0.114
160	0.706	0.249	-0.087
170	0.695	0.123	-0.047
180	0.705	0.008	0.003

4. Conclusions

This paper shows the geometry of the JBC created by OCTARVIA-PJ and presents the wind tunnel test results as well. The JBC is a benchmark hull form whose underwater geometry has been published and has been used mainly to validate CFD calculations. The publication of the geometry of JBC above water surface here, together with the results of wind force measurements from wind tunnel tests, will enable comparative verification of not only the hydrodynamic forces received from the water, but also wind forces, and increase its value as a benchmark hull form for assessing the performance in actual seas.

Acknowledgements

The geometry of JBC above water surface and wind tunnel test results presented in this paper were created by a Japan Maritime Cluster Collaborative Research Project (OCTARVIA-PJ) with the initiative on evaluation of ship performance in actual seas. The author would like to express my deepest gratitude to all organisations involved.

References

1) Kume, K., Ohba, H., Orihara, H. and Mizokami, S.: Wind Velocity Profile and Representative Wind Velocity for Wind Resistance Measurement of Ship Models, Journal of the Japan Society of Naval Architects and Ocean Engineers, Vol. 30 (2019), pp. 1-13.
2) Kume. K., Bielicki, S., Kobayashi, H. and Ohba, H.: Validation of Dimensionless Method Using Height Average Wind Velocity for Wind Forces, Journal of the Japan Society of Naval Architects and Ocean Engineers, Vol. 31 (2020), pp. 39-46.
3) ITTC Association: Preparation, Conduct and Analysis of Speed/Power Trials, ITTC Recommended Procedures and Guidelines 7.5-04-01-01.1, Rev. 7 (2022).
4) ITTC Association: Guideline on the CFD-based Determination of Wind Resistance Coefficients, ITTC Recommended Procedures and Guidelines 7.5-03-02-05, Rev. 1 (2021).
5) Tokyo 2015 A Workshop on CFD in Ship Hydrodynamics (2015), https://www.t2015.nmri.go.jp/
6) Proceedings of Tokyo 2015 A Workshop on CFD in Ship Hydrodynamics (2015).
7) ITTC Association: Quality Assurance in Ship CFD Application, ITTC Recommended Procedures and Guidelines 7.5-03-01-02, Rev. 2 (2021).
8) Tsujimoto, M., Sogihara, N., Kuroda, M. and Sakurada, A.: Ship Performance Simulator in Actual Seas -VESTA- [in Japanese], Research Report of National Maritime Research Institute, Vol. 15, No. 4 (2015), pp. 55-65.
9) Tsujimoto, M., Kuroda, M., Sogihara, N., Sakurada, A., Matsuzawa, T., Uto, S., Ohba, H., Ichinose, Y., Sakamoto, N., Hoshino, K., Shimoda, H., Fujisawa, J., Goto, H., Ikemoto, Y., Wako, D., Fukasawa, R., Kaneko, A., Hirata, K., Niki, Y., Fukuda, T., Muraoka, E.: Development on Ship Performance Simulator in Actual Seas [in Japanese], Research Report of National Maritime Research Institute, Vol. 16, No. 3 (2016), pp. 17-41.
10) Kuroda, M., Sugimoto, Y.: Development of the Evaluation Method for Life Cycle Ship Performance, Journal of JASNAOE, Vol. 34 (2021), pp. 19-27.
11) Fujiwara, T., Ueno, M. and Ikeda, Y.: A New Estimation Method of Wind Forces and Moments acting on Ships on the basis of Physical Component Models [in Japanese], Journal of the Japan Society of Naval Architects and Ocean Engineers, Vol. 2 (2005), pp. 243-255.