Wind effect simulation system in model tests of ship manoeuvrability

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Abstract

Dependence on hydro-meteorological conditions in the test area is an "Achilles' heel" of physical experiment used for assessment of ship manoeuvrability. Aerodynamic forces and moments generated on the ship upperworks distort significantly the measured values. The paper presents new testing tool in the form of physical simulation of wind effect enabling quantitative evaluation of distortion of the measurement results. Another feature of the system enabling compensation of real atmospheric conditions prevailing during the experiment is also presented. The wind effects simulation arrangement includes board data acquisition and processing system, automatic control system and executive system consisting of industrial fans.

Keywords: *ship manoeuvrability, wind, wind effect simulation*

INTRODUCTION

Physical model experiment always entails not only a number of conditions resulting from the laws of modelling, but also some environmental conditions. The ship manoeuvrability cannot be attributed only to the underwater hull, even if the tests are carried out in ideal "no wind" conditions, because there is always a little known effect resulting from neglecting the friction deduction force or aerodynamic effect of apparent wind upon the ship upperworks, the shape of which is a compromise between assumed minimizing and symmetrization of the model surface exposed to the wind, and technical possibility of such realization.

The testing technique presented below, as well as the test equipment designed for this purpose seems to ensure elimination of these undesired effects on the model experiment.
Verification of the presented methodology and equipment is based on the mode of operation enabling compensation of the environmental effects on the ship model upperworks. The following scheme of proceeding has been assumed:

- the environmental effect on the ship upperworks will be represented by apparent wind vector,
- compensation of the generated aerodynamic forces and moments will be carried out with use of a set of fans being an integral part of the model upperworks (see Fig. 1).

Fig. 1 *Tested model equipped with a set of fans*

The second mode of testing included simulation of wind effect on virtual model upperworks. In this case the wind was represented by average velocity and function of power spectral density distribution. The upperworks were represented by experimentally found characteristics of a container carrier with full set of containers. In this case the following scheme of proceeding was applied:

- tests were carried out under "no wind" conditions,
- transportation velocity of the set of fans, equal to the model speed, was taken into account in the process of generating the aerodynamic forces and moments.

Input data, necessary for carrying out both operation modes, i.e.:

- model speed and drift angle,
- velocity and angle of relative wind,
- compass course,

came from the board system of data acquisition and processing.

Operation of the fan system was controlled by the control system combined with above-mentioned board system using the library of experimental aerodynamic characteristics of the real and virtual model, as well as control data matrix of the fan motors ensuring proper thrust of the fans.

Aerodynamic data

Wind

Within the confines of the carried out tests, "wind" was assumed as a flat stochastic process represented by turbulent wind velocity and its average angle. In such model the turbulent wind is described by function of power spectral density, by distance from the media parting face, as well as by the harmonic data frequency. Spectral model of wind presented by Ochi&Shina [1] was used in the tests.

Aerodynamic tests

The tests were made in wind tunnel T3 of the Aviation Institute in Warsaw. The following two aerodynamic characteristics of the ship model were used for the tests: (M509 CTO $\lambda = 55$, see Fig. 2A) for the ship with full set of containers, and (M467 CTO $\lambda = 25.7$, see Fig. 2B) used for tests on the lake. Air flow in the layer on the sea surface, velocity distribution, turbulence and boundary layer spectrum were represented during the tests. Reynolds number at the level of $6x10^6$ was used for the tests of M509 model. The upperworks characteristics for M467 model is a compilation of upperworks characteristics in

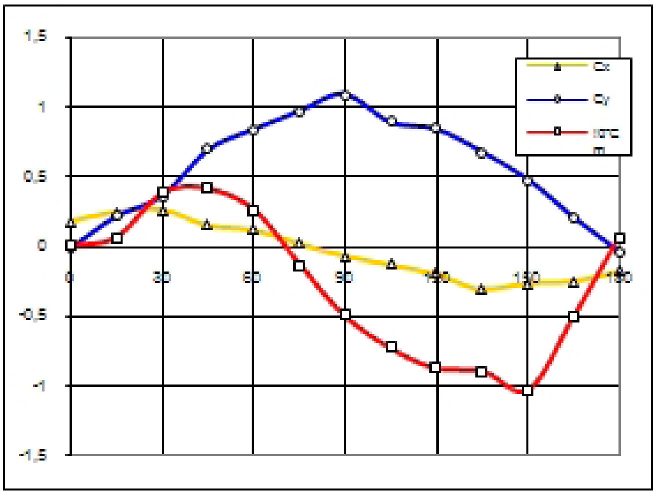

Fig. 2A *Aerodynamic characteristics of ship model M509 [2]*

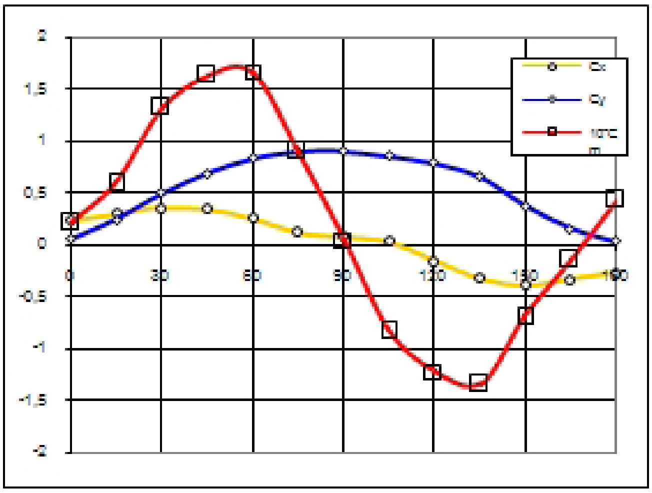

Fig. 2B *Aerodynamic characteristics of ship model M467 with the wind simulation system [3]*

scale 1:55 for specific freeboard, as well as the characteristics of natural set of fans.

Aerodynamic characteristics of the fan control system were prepared on the basis of the carried out test program, including measuring the fan thrust versus fan rotational speed with simultaneous variation of wind velocity in the tunnel . Within the measuring process in the input function simulation mode, the control system computed the values of signals controlling the operation of fans so that the virtual upperworks were the result of superposition of the following models:

- linear model, based on assumed dimensionless characteristics of the ship upperworks and on dimensionless characteristics of true upperworks of the model with stationary fan executing system,
- non-linear model (taking into account interaction of fans and fan thrust effects on the characteristics of the true upperworks)

Relative heading was measured with an accuracy of 1°. Comparison of assumed characteristics of the model shown in Fig. 3 with the simulation system composed of three fans was considered a proof of correct functioning of the system. Useful results of the tests in the form of matrix of coefficients were saved in microprocessor memory of the control system [4].

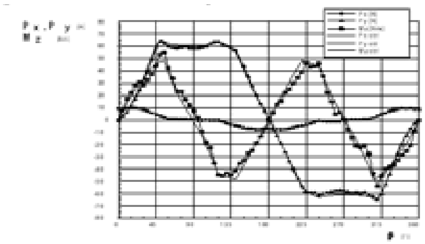

Fig.3 *Comparison of assumed characteristics of the ship model in the form of aerodynamic forces Px, Py, Mz (obl), represented by wind simulation system including 3 fans [3]*

Board system of data acquisition and processing

The system made by CTO is a combination of standard systems used for supporting ship manoeuvrability tests and of additional systems developed for realization of the present tests. The system includes a subsystem controlling automatically the manoeuvrability tests, pressure directional log, anemometer and special supporting software.

The measurement control system [5] took over the control of the model after a radio signal transmitted by the operator and introducing the model into the start trajectory after getting steady speed and heading of the model. The system enabled recording of the following measured data: model speed, drift angle, model heading, rudder angle, velocity and angle of relative wind. At the same time the system transmitted the data necessary for control of fan simulation system. In the mode of wind effect simulation, the system supported by additional software transmitted expected values of relative wind velocity and angle. These values depended on actual speed and drift of the model, model heading and assumed angle of simulated wind with respect to the resultant heading. Assumed operational frequency of 100 Hz enabled data transmission with the accuracy of heading equal to 0.1 degrees at least.

Pressure log [6] was installed at ¼ of the model length from the model bow. This location and the measuring head lowered to 0.4 m below the model bottom ensured the uncertainty of model speed measurement not exceeding 0.06 m/s, whereas the drift angle uncertainty did not exceed 1.5 degrees for model speed greater than 0.5 m/s and drift angles less than 20 degrees.

Wing anemometer of μAS type, made by Orogenic Institute of the Polish Academy of Sciences, with measuring range 0.2 – 20 m/s ensured an accuracy of 0.5%. The anemometer axis was aligned with the relative wind thanks to a directional fin interconnected with a potentiometer system. The system was statically balanced.

Manoeuvring tests

Scope of tests

The scope of manoeuvrability tests for both modes of operation: compensation and wind effect simulation included standard turning tests, as well as zigzag test [7]. Two angles of simulated and true wind were chosen from the entire compass rose: compatible with and opposite to the model heading during the straight-line phase before the start of the manoeuvre.

Test conditions

The tests were carried out on Lake Wdzydze near the Open Air Test Station of CTO in Joniny. Free running model M467 equipped with a self-propulsion system, as well as with radio controlled manoeuvring and control systems was used for the tests. In order to reduce as far as possible the fan generated heeling moments, the freeboard height was reduced to a minimum value ensuring the model safety with increased metacentric height.

Initial speed 1.85 m/s of the model was assumed. The turning tests were performed with the rudder angle equal to 20°. This value was the maximum acceptable rudder angle because drift angles appearing at rudder angles exceeding 20° caused instability of the pressure log indications. The zigzag tests were made for the rudder angle of 20° and the course change angle of 20°.

Test results

Tests of the true wind effect compensation

Tests of the natural wind compensation effects with the use of this wind simulation system were essential for verification of the correctness of system design assumptions.
The verification of system operation correctness was based on recorded results of manoeuvring tests, when distortion of the model trajectory (in turning test) or changes of heading (in zigzag test) induced by natural wind and compensated by the fan system are insignificant with respect to characteristic parameters of such tests made in "no wind" conditions.
Examples showing functioning of the wind effect compensation system are shown in the form of a record of the turning test trajectory (Fig. 4) and for the zigzag test (Fig. 5).

The presented results show correctness of the proposition assumed during formulation of the scientific project about possibility of the application of additional equipment making the model tests of manoeuvrability independent of the weather conditions.

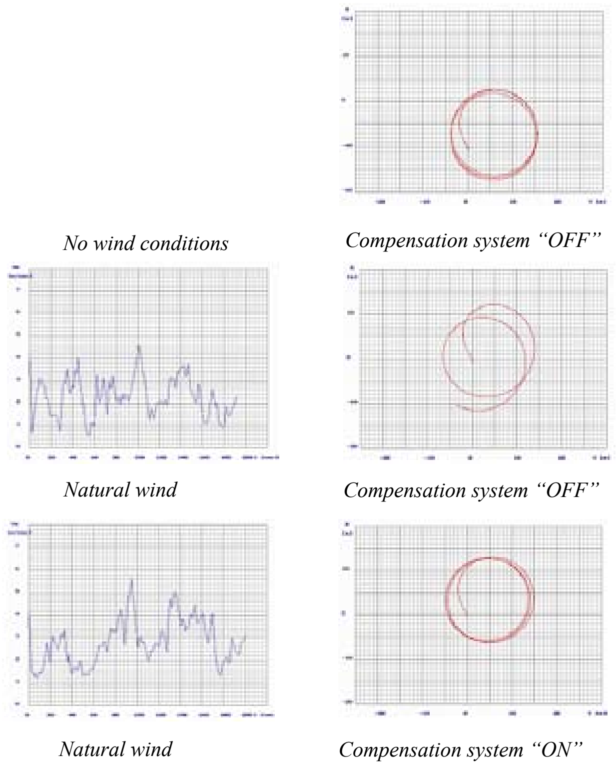

Fig. 4. *Examples of the turning tests*

Tests of simulated inputs

Interesting effect of the simulated wind on the advance (see Fig.6A) and on tactical diameter of circulation (see Fig. 6B) has been shown in a dimensionless form with respect to the values of these parameters for "no wind" conditions. Obvious asymmetry of the changes in these parameters for two different relative angles of simulated wind is a premise for the statement that prediction of the advance on the basis of the mean value may cause 10% error for wind velocity 3 m/s and 15% error for wind velocity 5 m/s. The value of tactical diameter of circulation turned out to be less sensitive to the angle and velocity of the simulated wind and it does not exceed normal dispersion of the measurment results.

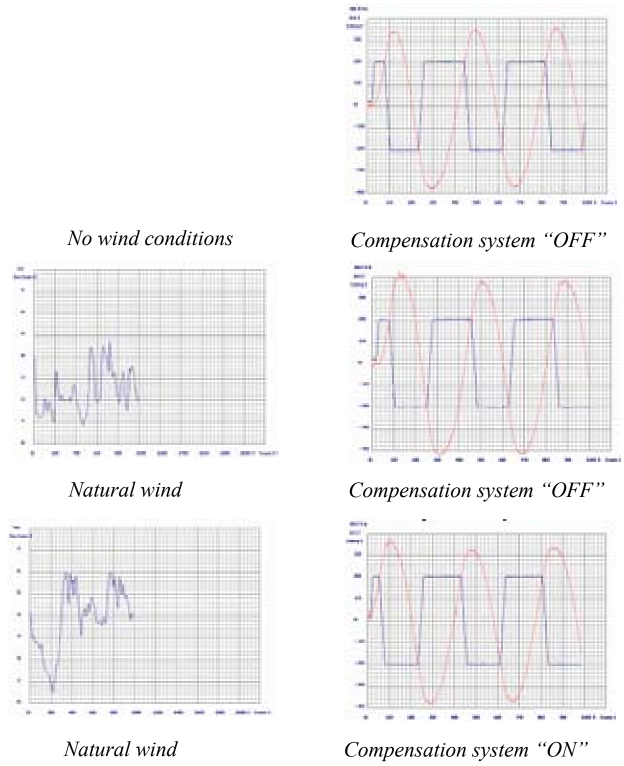

Fig. 5 *Examples of the zigzag tests*

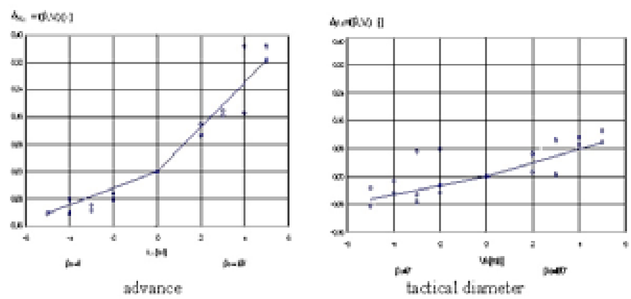

Fig. 6 *Dependence of advance and tactical diameter values on the wind angle and velocity*

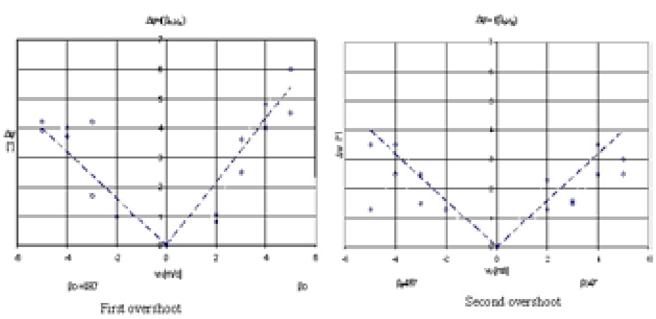

Fig. 7 *Dependence of change of the first and second overshoot angles in zigzag tests on the wind angle and velocity*

The wind velocity and wind angle effect on characteristic parameters of zigzag test is shown in Fig.7. In this case prediction of the overshoots on the basis of the mean value parameters for two different relative angles of simulated wind does not cause decreasing of measurement errors.

Conclusions

Experiments and test results indicate that:

1. The developed and implemented system of wind simulation can be used without restriction as true wind compensation system and can make up a standard equipment for model tests of ship manoeuvrability.
2. The system, when used for simulation of assumed weather conditions, may be useful in tests aimed at quantitative evaluation of wind effect on chosen manoeuvres.

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