Numerical analysis of influence of ship hull form modification on ship resistance and propulsion characteristics

Part III
Influence of hull form modification on screw propeller efficiency

Tomasz Abramowski, Ph. D.
Katarzyna Żelazny, D.Sc., Eng.
Tadeusz Szelangiewicz, Prof.
West Pomeranian University of Technology, Szczecin

ABSTRACT

After signing ship building contract shipyard's design office orders performance of ship resistance and propulsion model tests aimed at, apart from resistance measurements, also determination of ship speed, propeller rotational speed and propulsion engine power for the designed ship, as well as improvement of its hull form, if necessary. Range of ship hull modifications is practically very limited due to cost and time reasons. Hence numerical methods, mainly CFD ones are more and more often used for such tests. In this paper consisted of three parts, are presented results of numerical calculations of hull resistance, wake and efficiency of propeller operating in non-homogenous velocity field, performed for research on 18 hull versions of B573 ship designed and built by Szczecin Nowa Shipyard.

Keywords: ship hull geometry, numerical (computational) fluid dynamics (CFD),
resistance, wake current, propeller efficiency

SHIP PROPULSION EFFICIENCY

In design practice the overall propulsive efficiency is presented in the form of the product of efficiency components [1]:

$$\eta = \eta_{HT}\eta_0\eta_{RT}\eta_S\eta_G \qquad (3a)$$

or:

$$\eta = \eta_{HQ}\eta_0\eta_{RQ}\eta_S\eta_G \qquad (3b)$$

where:

η_{HT} — ship hull „efficiency" determined under the assumption that the open-water-propeller thrust T is equal to the behind-the-hull propeller thrust $\overline{T}$

η_{HQ} — ship hull „efficiency" determined under the assumption that the torque Q_D delivered to the open-water propeller is equal to the torque $\overline{Q_D}$ delivered to the behind-the-hull propeller

η_0 — open-water propeller efficiency

η_{RT}, η_{RQ} — rotative „efficiency" determined under the same assumption as for hull „efficiency"

η_S — shaftline efficiency

η_G — reduction gear efficiency.

The two components: η_S and η_G are mechanical efficiencies, not associated with water flow around ship's hull, propeller and rudder. Therefore they do not affect ship's hull-propeller - rudder collaboration.

The first three components, being of hydrodynamic character, are decisive of overall propulsive efficiency, and basin model tests to be performed have to provide ship designer with information necessary a.o. to determine their values.

However worth paying attention is that :

- for determining η_H and η_R are used averaged values obtained from measurements taken during model basin tests (the wake current velocity field measured during model tests is easily converted to ship scale, that not always brings good results)

- the presented efficiency components do not contain other factors affecting the overall propulsive efficiency (influence of some of them can be determined by conducting multiple model basin tests e.g. for various versions of ship hull stern part)

- in the above presented formulas is contained the open-water-propeller efficiency η_0 determined for the screw propeller operating in homogenous water velocity field without presence of ship hull, whereas the behind-the-hull screw propeller operates in a very non-homogenous velocity field, and the coefficients η_H, η_R do not reflect essence of the problem,

- also, in the above presented formulas ef fects of rudder , especially streamline one, which may increase efficiency of screw propeller, are lacking
- the above presented formulas do not contain information on mutual location of screw propeller and blade rudder relative to ship stern, and on its impact on propulsive efficiency.

The above described way of the determining of propulsive efficiency contains certain ambiguities (e.g. those associated with wake-fraction determining) hence in the publications [23] it is postulated to introduce the coefficients connected with the behind-the-hull propeller efficiency:

$$\xi_Q = \frac{Q_D}{\overline{Q_D}} \qquad (4a)$$

$$\xi_T = \frac{\overline{T}}{T} \qquad (4b)$$

called the torque modifier and thrust modifier, respectively.

Regardless of that which approach would be applied to determining the ship propulsive efficiency , it is rational to determine thrust and torque of the behind- the-hull screw propeller as well as its efficiency in non-homogenous water velocity field for mean working point equivalent to mean service speed of ship (the mean statistical ship speed was discussed in [4]).

To determine real propulsive efficiency of ship or also efficiency of propeller operating behind the hull in non-homogenous velocity field, is possible by using CFD techniques. Hence in this part of the paper are presented results of numerical computation of efficiency of screw propeller operating in non-homogenous water velocity field, performed for 18 modified hull versions of B 573 ship. For the computations use is made of the results of numerical calculation of wake currents, presented in the part II of the paper.

NUMERICAL CALCULATION OF HYDRODYNAMIC CHARACTERISTICS OF SCREW PROPELLER

Before the calculations of efficiency of a screw propeller operating in non-homogenous velocity field, hydrodynamic characteristics of a store screw propeller used to propulsion model tests of B 573 ship [5], were calculated (the screw geometry is presented in Fig. 30).

The calculations of the store screw propeller were performed in the scale 1:1 by modelling the flow with the use of RANS equations and RNG k -epsilon model was applied to turbulence phenomena. Boundary layer was modeled by means of standard flow approximating functions, where the parameter $y^+ = 50$.

To discretize domains a numerical non-structural network of prismatic elements within boundary layer (Fig. 31), which was further adjusted to polyhedral elements (Fig. 32). was applied. The non-structural network was elaborated by using Gambit system; and the conversion was performed by using Fluent system. All screw propeller blades were modeled, that demands on one hand a greater computer capacity, but on the other hand makes non-stationary calculations of screw propeller with taking into account non-design conditions, possible.

Calculation time step was equal to 0.00012 s, that was equivalent to about 1° of one screw-propeller revolution at its rotational speed of 17 rps. Two complete screw-propeller revolutions were covered by the calculations, hence the total time of the calculated flow was equal to 0.0864 s.

Results of numerical calculations:
- pressure distribution on screw propeller blades is presented in Fig. 33 and 34
- streamlines – in Fig. 35
- total velocity profiles – in Fig. 36
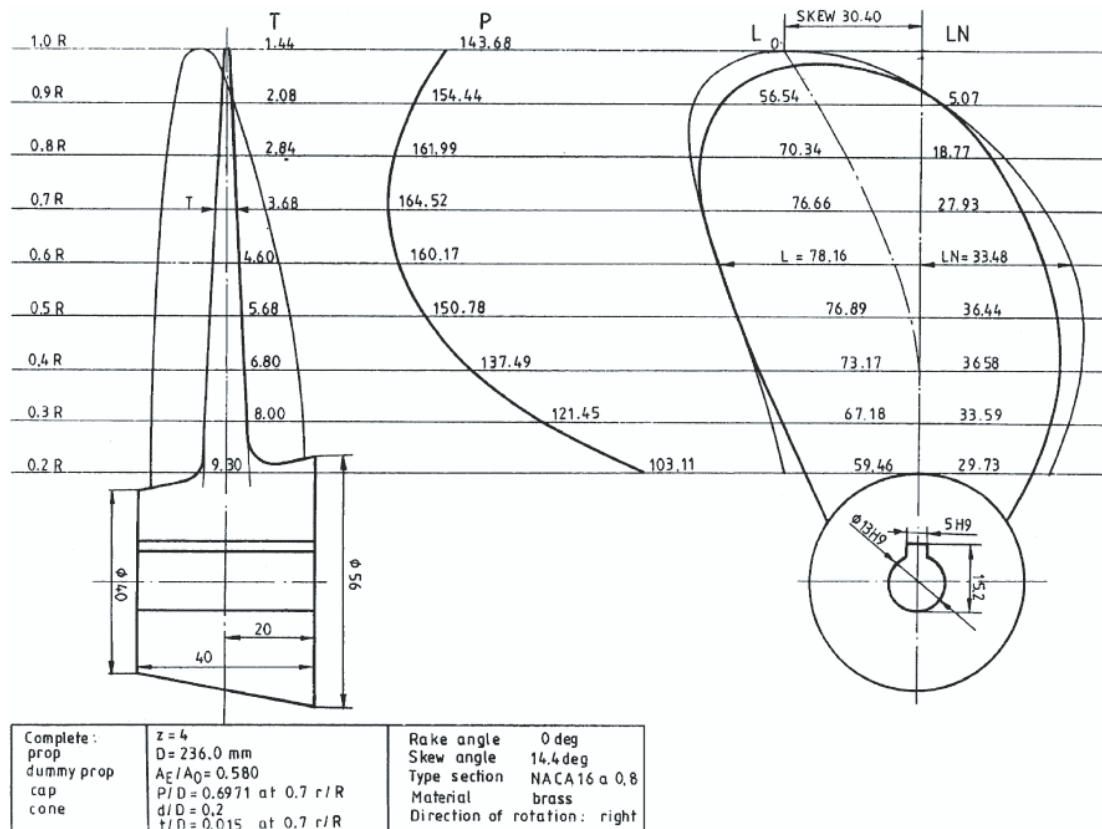- hydrodynamic characteristics – in Fig. 37 ÷ 39

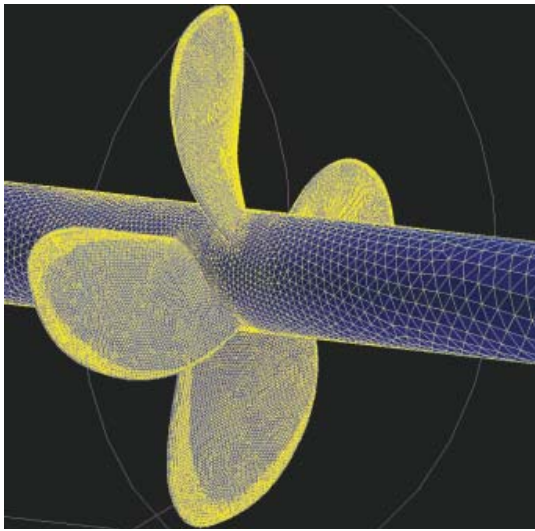**Fig. 30.** *Geometry of the store screw propeller No. P 355 [5]*

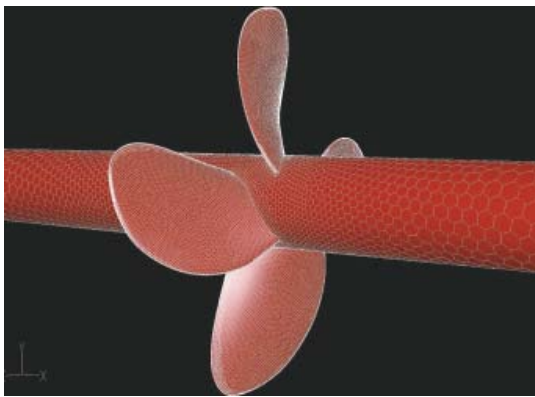**Fig. 31.** *Non-structural network of elements before conversion*

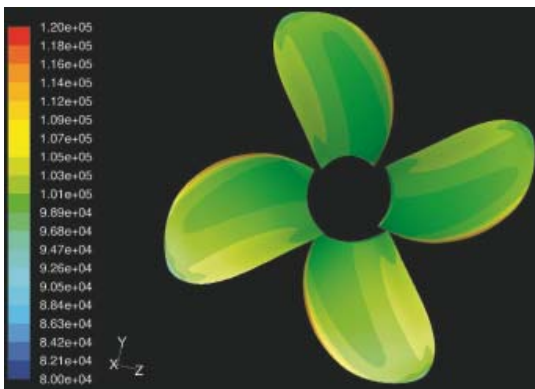**Fig. 32.** *Polyhedral network of elements converted from non-structural one*

Fig. 33. *Pressure distribution on driving face of screw propeller blades, the advance ratio J = 0.4*
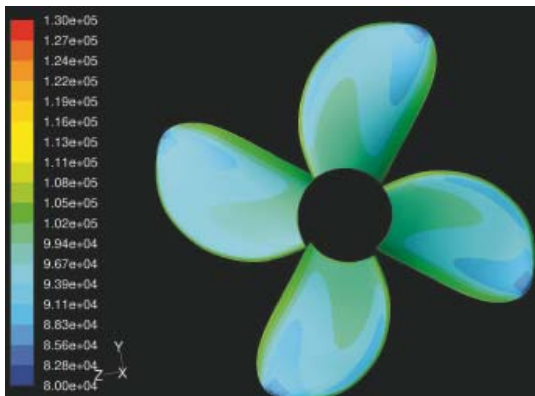

Fig. 34. *Pressure distribution on drag surface of screw propeller blades, the advance ratio J = 0.4*
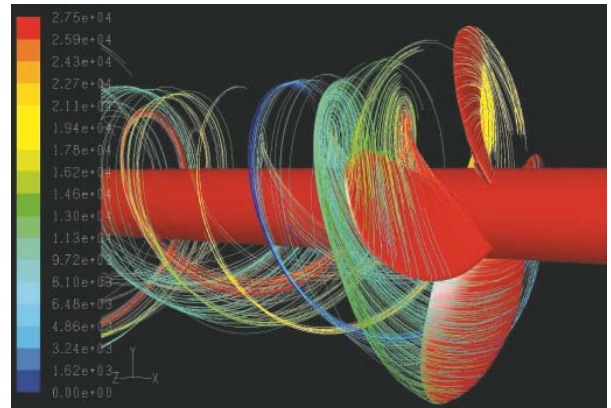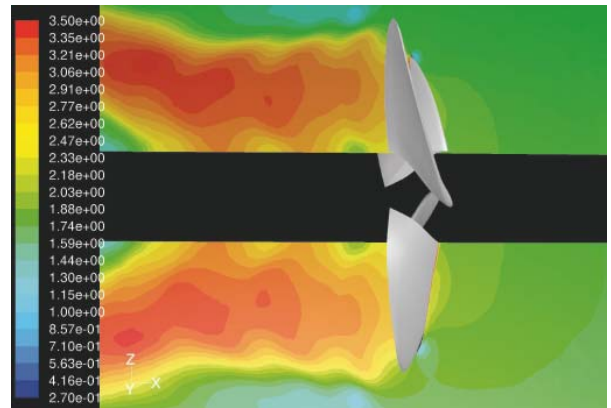

Fig. 35. *Streamlines behind the screw propeller*
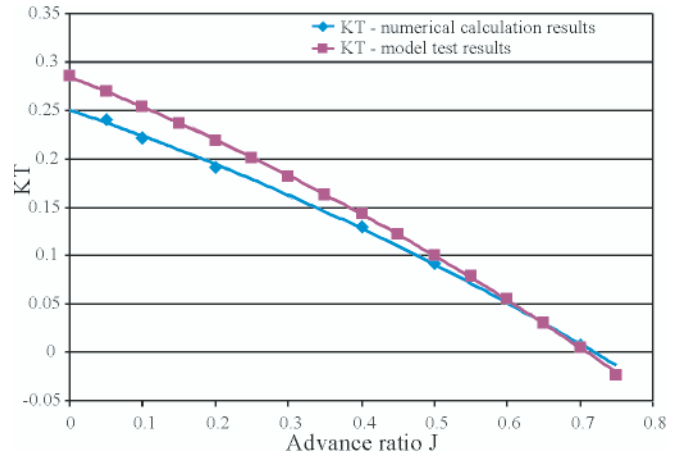

Fig. 36. Total velocity profiles

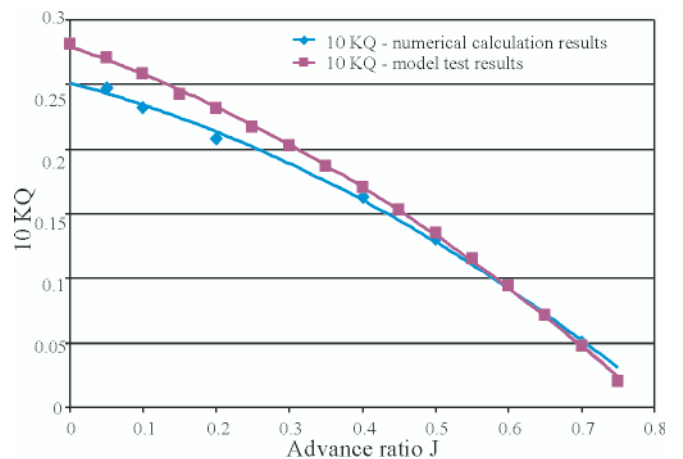**Fig. 37.** *Calculation results of the thrust coefficient KT compared with model test results [5]*

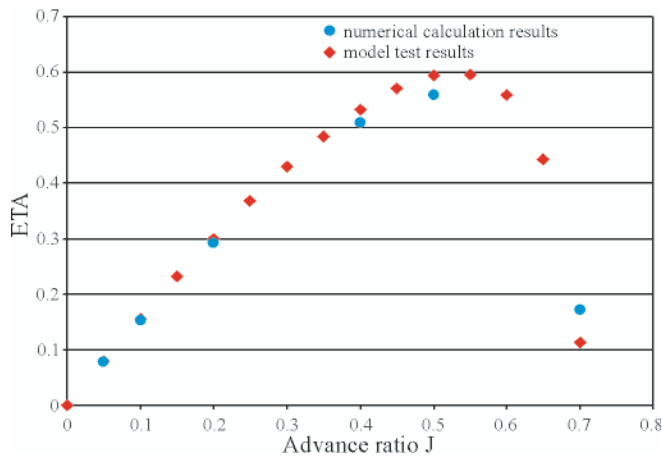**Fig. 38.** *Calculation results of the torque coeficient KQ compared with model test results [5]*

Fig. 39. *Calculation results of the screw propeller efficiency* **eta** *compared with model test results [5]*

MEAN EFFICIENCY OF FINAL SCREW PROPELLER IN NON-HOMOGENOUS WAKE CURRENT VELOCITY FIELD

The modification of B 573 ship's hull form was aimed at investigations of influence of the introduced hull form changes on the ship's resistance, wake current and screw propeller efficiency. The obtained distributions of wake current were used for determining the mean efficiency of the final screw propeller for B 573 ship.

The numerical calculations were performed for the final screw propeller of B 573 ship [6] in the same way as for the store screw propeller, however in the case of the final screw propeller the water velocity field (in which axial and circumferential components were taken into account), calculated for each of the modified version of the ship's hull form, was introduced. The final results of the analyses are presented in Fig. 40 in the form of the mean efficiency of screw propeller operating in non-homogenous wake current field. In the figure the mean efficiency values are shown for particular versions (variants) of the modified ship hull forms in compliance with Tab. 1. The case 0 is calculated for the screw propeller operating in the non-homogenous flow velocity field measured during model tests of the B 573 ship hull (of non-modified form). The continuous line (marked red) stands for the maximum efficiency of the final open-water screw propeller operating in homogenous flow velocity field.
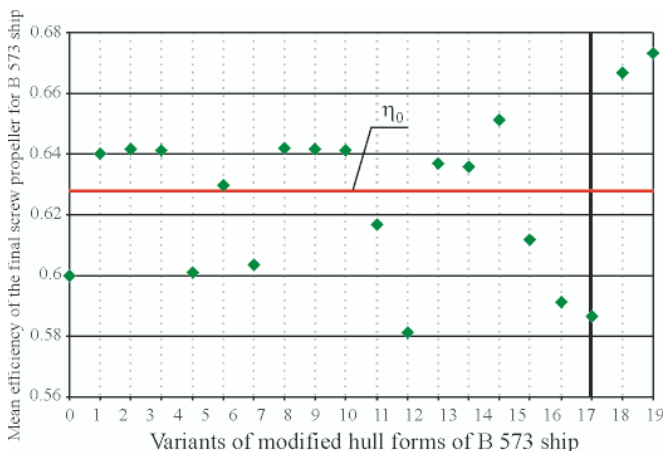

Fig. 40. *Mean efficiency of B 573 ship's screw propeller operating in non-homogenous wake current field, where:* η_0 – *maximum efficiency of the final screw propeller in homogenous flow velocity field,* **variant 0** – *original hull form (without modification) in wake current velocity field measured during model tests,* **variant 18** – *symmetrical hull form with manually modified stern part*

FINAL CONCLUSIONS

- The tests performed in advance each of the main calculations demostrated a good conformity of CFD calculations to model tests. Certain observed differences may result from various causes (some of them were discussed in the Part I of this work). The differences in hydrodynamic characteristics of the store screw propeller could also result from some, out of all necessary to elaborate a 3D model and numerical network, geometrical quantities lacking in [5]. Therefore it is not certain whether the computational model of the store screw propeller has represented exactly its real features. In the case of the final screw propeller there was no available results of model tests or other calculations to make verification of the CFD computation results possible.

- Numerical calculations of the mean efficiency of screw propeller for 18 th hull version of B 573 ship (Fig. 40) demonstrated that small modifications can have either favourable or unfavourable effect onto efficiency. Especially favourable effect in the form of elevated efficiency was obtained by using manual modification of only stern part of the ship's hull (18 th variant, Fig. 40). It means that by suitable modelling hull form in its stern part only it is possible to make flow velocity field before the propeller more favourable from the point of view of efficiency.

- Mean values of screw propeller efficiency for wake currents corresponding to particular versions of ship hull were calculated for the same final screw propeller. Investigations on searching for optimum screw propeller geometry for each of the ship's hull versions, are under way.

- Numerical methods based on the CFD provide even greater possibilities, e.g. investigations on propulsive efficiency of the whole system composed of ship hull, screw propeller and streamline rudder, that would make performing a more advanced optimization of ship propulsion system, possible.

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CONTACT WITH THE AUTHORS

Tomasz Abramowski, Ph. D.
Katarzyna Żelazny, D. Sc.
Tadeusz Szelangiewicz, Prof.
West Pomeranian University of Technology, Szczecin
Faculty of Marine Technology
Al. Piastów 41
71-065 Szczecin, POLAND
e-mail: tadeusz.szelangiewicz@ps.pl