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INCREASING SHIP PROPULSION EFFICIENCY AS AN ALTERNATIVE TO HELP REDUCE FUEL CONSUMPTION AND CO_2 EMISSION

Part II

Research on hull and propeller design optimalisation in order to decrease the EEDI value

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Abstract

From 2013 onwards EEDI for newly built ships will become mandatory. Ships meeting the CO_2 emission standards will be granted energy certificate for needed for exploitation. The article presents the EEDI in the current form, energy certification procedure as well as reduction of CO_2 emission planned for coming years (Part I). The majority of ships built at present, meets the CO_2 emission standards for 2013, yet their further decrease in subsequent years will consequently necessitate further actions as well. One of them is ship hull design of smaller resistance values and higher propulsion efficiency. The article (Part II) presents calculation results of the numerical analyses (CFD) performed for an actually built ship, aiming at decreasing propulsion power and therefore the EEDI value as well.

***Key words**: Energy Efficiency Design Index, International Energy Efficiency Certificate for the ship, ship hull geometry, propeller efficiency, streamline rudder, computational fluid dynamics (CFD)*

1. Introduction

The first part of the article presents a few ways of decreasing CO_2 emission in new ship design and construction.

Optimalisation of hull and propeller design aimed at reduction of propulsion efficiency and thus resulting decrease in fuel consumption and CO_2 emission, is one of the methods which make it possible to meet the IMO standards of EEDI values for newly designed and built transport ships, in force since 2013. Such research in design is also indispensable bearing in mind that CO_2 reduction standards will become stricter in subsequent years from 2015 onwards according to a schedule presented in (Table 3 [2]).

Optimalisation of ship hull and screw propeller design should be carried out in the following stages:

- global optimalisation of the main design parameters of a ship, aimed at maximum reduction of resistance (and thus propulsion power) for a given service speed and ship capacity, taking account of other necessary parameters, e.g. technical;

- local optimalisation, which means local modification of hull design geometry, e.g. at the stern in order to facilitate propeller contact with water (wake current field);
- optimalisation of propeller efficiency for a modified stern design of a ship;
- optimalisation of geometrical parameters of spade rudder located behind the propeller in order to increase their efficiency.

All the above actions together should result in a simultaneous reduction of a ship's resistance and an overall increase of propulsion efficiency hull-propeller – spade rudder.

There are several ways to achieve the above goal :

- optimalisation based on approximate methods (formulas resulting from systematic model testing); such formulas, however, do not contain a number of specific geometrical parameters, hence their application for the above goal is severly limited or – as in case of local optimalisation – even impossible;
- optimal hull design resulting from model testing – such method calls for a number of hull design models, which generates high costs and is therefore not used in practice;
- using CFD method and tools which have a full potential to succeed in such design project.

This part of the article presents the initial results numerical analysis aimed at decreasing ship resistance of a real, built ship and increasing its propulsion efficiency so as to reduce propulsion power at the same time reducing the EEDI value as well.

2. Modified ship and the scope of calculations

Hull modification and subsequent numerical analyses were performed for a B 573 ship (Table 4) built in Szczecin shipyard with a complete design documentation, basin model test and sea trials.

Table 4. Main parameters of B 573 ship in various loading conditions

Length between perpendiculars	L_{PP}	172 m
Waterline length	L_{WL}	176.41 m
Hull breadth	B	32.2 m
Draught	T	11.0 m
Deadweight	P_N	45000 t
Speed	V	14.5 w
Volumetric displacement	∇	50500 m^3
Wetted surface area	S	8200 m^2
Block coefficient	C_B	0.807

Body lines, rudder location and dimensions of a real ship (shown in Fig. 4 and 5) were treated as input values for further modification in the ship geometry.

The scope of research covered:

- modification of hull geometry in order to determine the influence of such modification on:
  - resistance of a ship's hull model,
  - distribution of the wake current field velocity,
- propeller efficiency calculation for new wake currents field,
- propeller geometry was modified for the working conditions (behind the ship's hull)
- geometry of the spade rudder was modified in order to:

- increase steering efficiency,
- increase propeller efficiency by its relations to spade rudder.

Hull modification was performer in such a way as to maintain ship constant displacement, deadweight tonnage, length and breadth. Changing given parameters within these particular groups, the remaining values were left stable.

Their scope covered the following (Table 5):

- change of the ship's hull block coefficient C_B,
- change of the ship's hull prismatic coefficient C_P
- change of location of the longitudinal centre of buoyancy LCB,
- manual change of the entire ship's hull form or its stern part only.

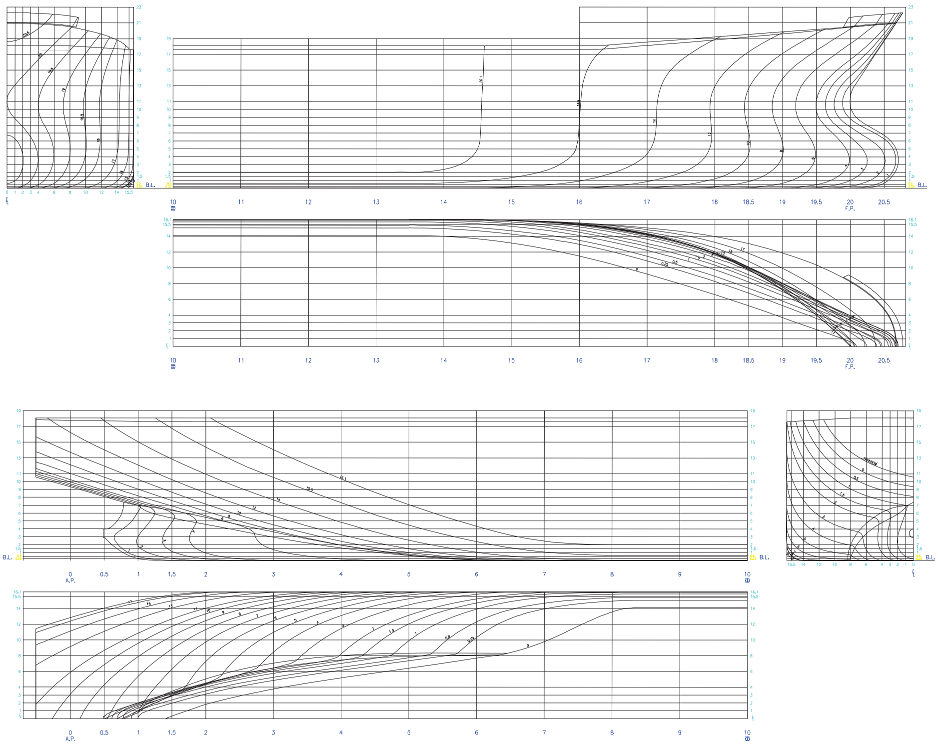

Fig. 4. Body lines of the analyzed hull form of B 573 ship

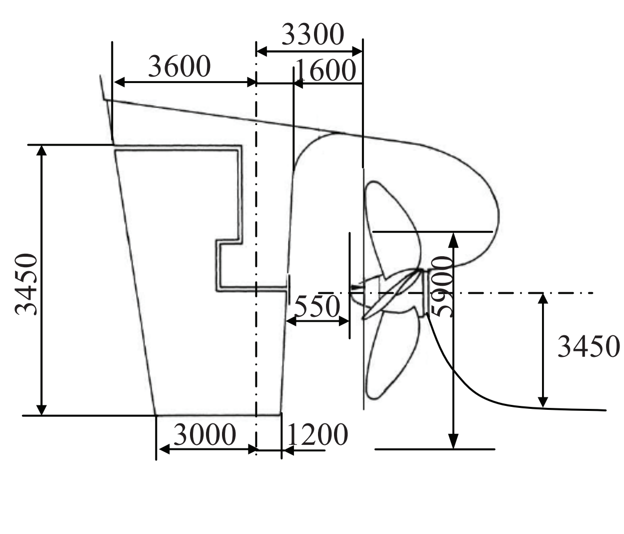

Fig. 5. The semi-spade rudder behind the screw propeller of B 573 ship [8].

Table 5. Range of changes of B573 ship hull form

Number of variant		Change of parameter	Parameter
1.	Change of the block coefficient C_B; its initial value $C_B = 0{,}800$	-0,01	0,79
2.		-0,005	0,795
3.		-0,015	0,785
4.		+0,01	0,81
5.		+0,005	0,805
6.		+-0,015	0,815
7.	Change of the the prismatic coefficient C_P; its initial value $C_P = 0{,}790$	-0,01	0,78
8.		-0,02	0,77
9.		-0,03	0,76
10.		+0,01	0,8
11.		+0,02	0,81
12.	Change of longitudinal location of the centre of buoyancy LCB. its initial location: equal to 48% Lwl measured aft from FP	-1% shift fore	47%
13.		-2% shift fore	46%
14.		-3% shift fore	45%
15.		+1% shift aft	49%
16.		+2% shift aft	50%
17.		+3% shift aft	51%
18.	Manual hull form modification of its stern part only – symmetric hull form	-	-
19.	Manual hull form modification of its stern part only – asymmetric hull form	-	-

For each of the hull versions new body lines and next numerical computational grids were prepared, and finally calculations of resistance and wake distribution were performed. Example frame sections of modified hull form variants are shown in Fig. 6 ÷ 8.

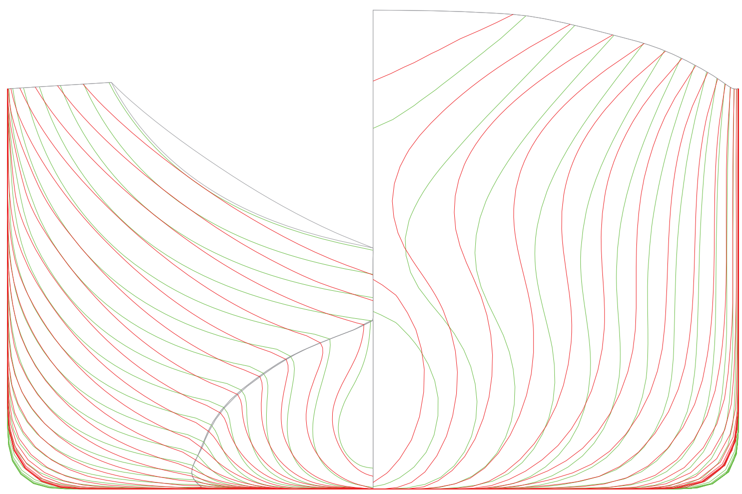

Fig. 6. Variant no.1 – original hull form - marked green; modified hull form – marked red

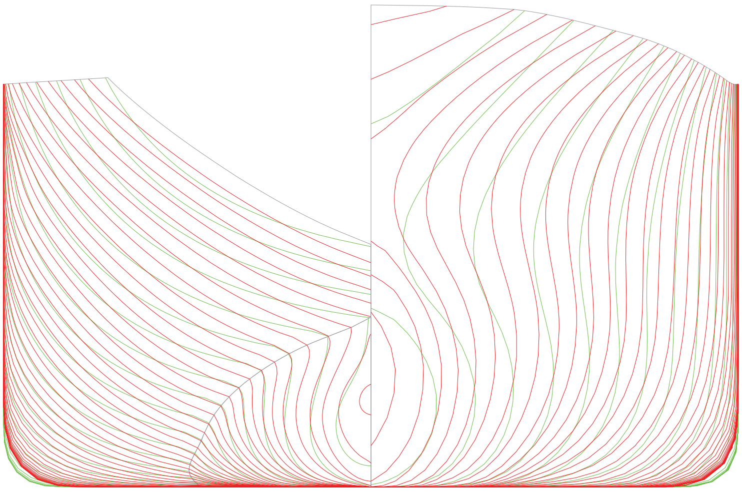

Fig. 7. Variant no.2 – original hull form - marked green; modified hull form – marked red

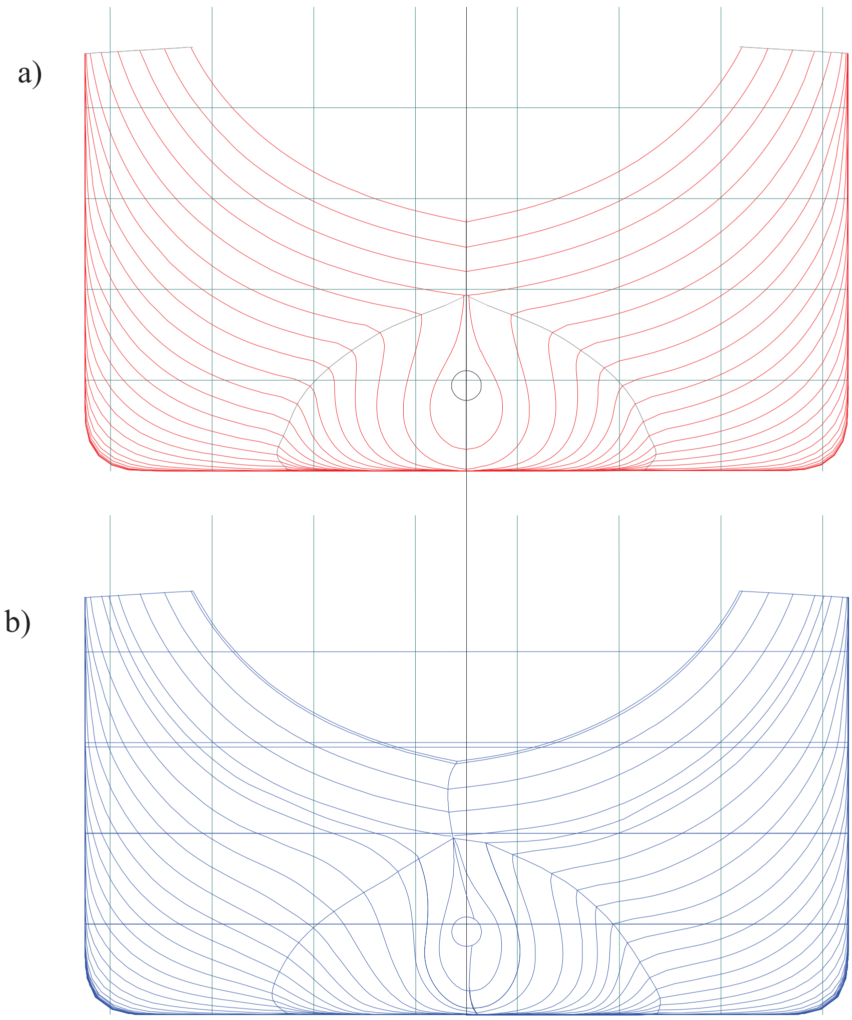

Fig. 8. Variant no.19 – body lines of stern part of B 573 ship hull: a) before modification (symmetric stern), b) after modification (asymmetric stern)

3. Numerical analysis of the ship body, screw propeller and spade rudder

All the numerical analyses have been performed using computer cluster NEPTUN (owned by the Chair of Ocean Technology and Marine System Design, Faculty of Marine Technology and Transport, West Pomeranian University of Technology, Szczecin) with the help of FLUENT software.

Numerical analysis has been performed for the ship in the same model scale, as for the model tests (scale ratio 1:25).

For the ship model have been defined and a numerical computational grid of non-structural type with prismatic elements in boundary layer (Fig. 9) has been created, in order to subsequently convert it into polyhedron-type elements (Fig. 10). Non-structural grid was created using the Gambit system, with FLUENT software used for conversion.

Conversion of non-structural grids into the polyhedron-type makes it possible to reduce the number of grid elements 3 up to 5 times as well as to improve grid parameters, - especiall the element skewness parameter. Ultimately, the total number of all elements used in calculations for individual ship movements fell within the range of 650.000 – 750.000.

For each calculation, the convergence of iteration for residual values of all calculations and ship's body coefficient forces has been controlled.

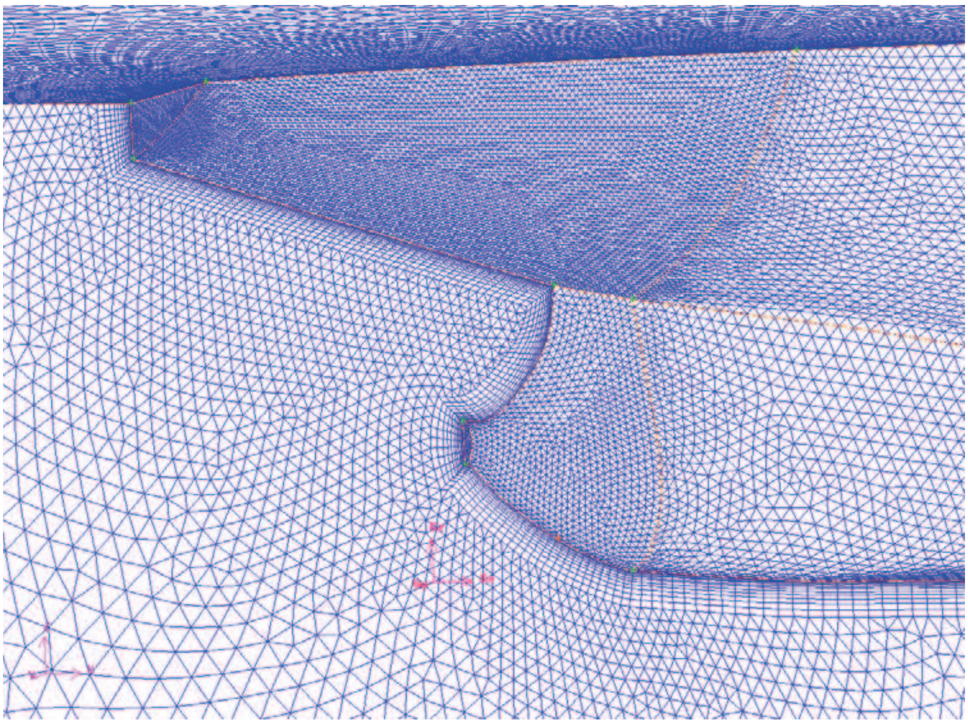

Fig. 9. Non-structured tetrahedral grid of the ship's stern section before the conversion

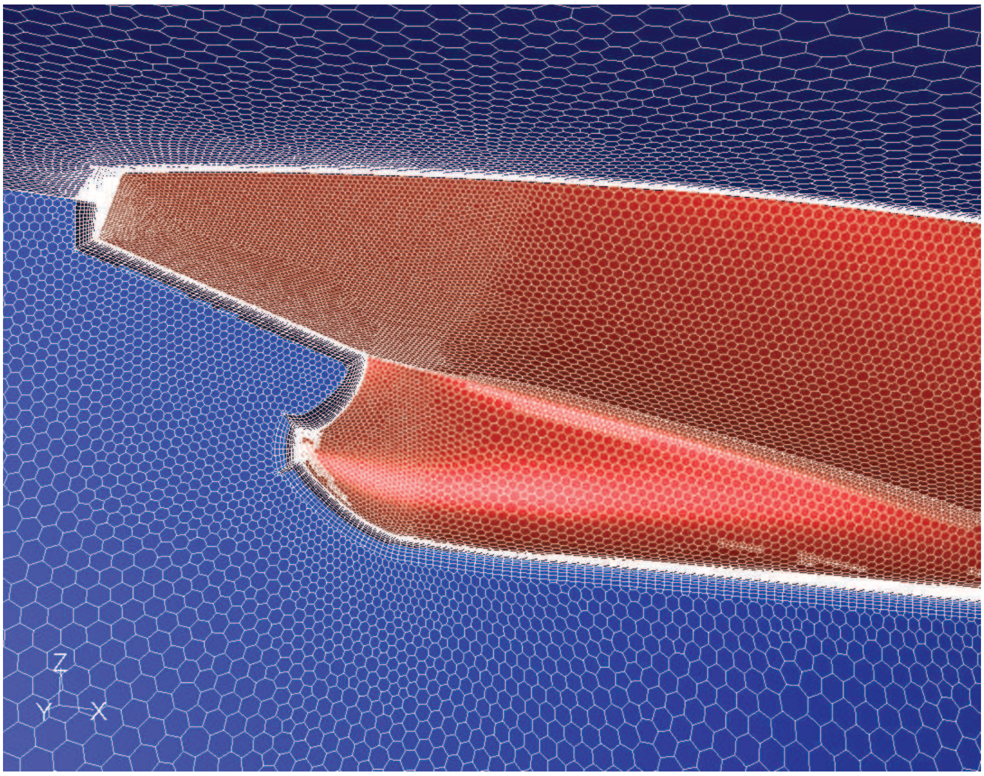

Fig. 10. Polyhedral grid obtained from a conversion of non-structured tetrahedral one

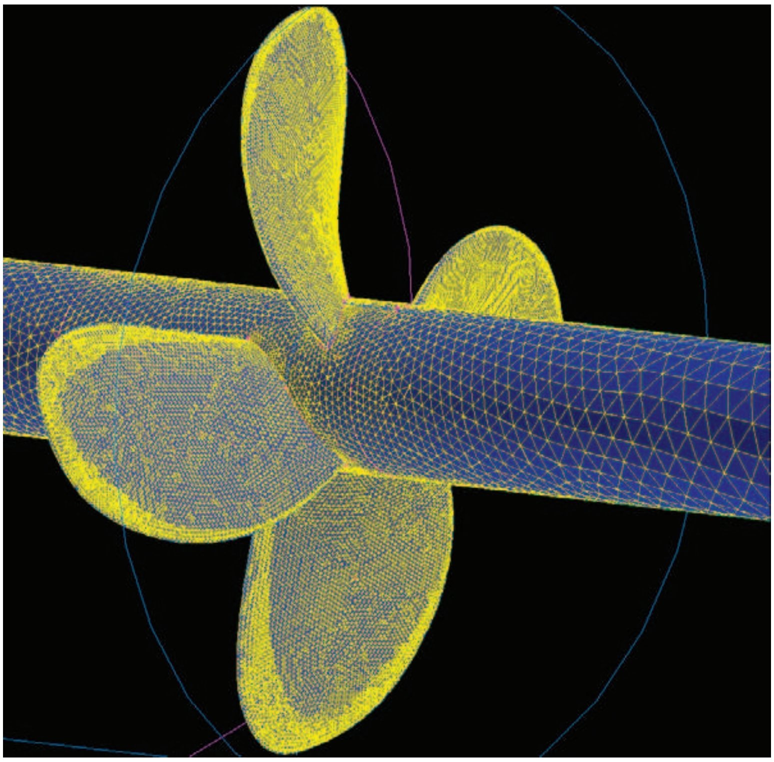

Fig.11. Non-structural grid of a propeller installed in the B 573 ship before conversion

Prior to numerical analyses proper, several other tests have been performed:

- comparison of resistance calculation results for the analysed ship form (Fig. 4) and model test results [1] using CFD methods,

- comparison of calculations of the actual propeller and rudder hydrodynamical characteristics against the model ones.

The test results can be found in a separate report [3].

4. Calculation results

In numerical analyses of the hull-screw propeller-rudder system the following parameters have been studied:

- 19 versions of the B 573 hull design (the final – 19th version with an asymmetric stern design),
- 2 versions of a screw propeller,
- 5 versions of the spade rudder.

Ship resistance for a modified hull versions (Table 5) has been calculated from the general formula in the form below:

$$\vec{R} = \int_S \vec{p}_n dS \,, \tag{5}$$

where $\vec{p}_n$ is a resultant elemental stress on dS element of wetted hull surface area (in Fluent calculations $\vec{p}_n$, stresses made up from normal stresses $\vec{p}$ and stresses tangent (viscous stresses) $\vec{\tau}$ to elemental surfaces, which have been replaced by finite surfaces ΔS resulting from a created numerical grid – Fig. 10).

Screw propeller efficiency has been calculated as a mean value of a propeller working in a non-homogenous wake currents field, calculated for each version of a ship's hull individually:

$$\overline{\eta} = \frac{\int_{d/2}^{D} dT \cdot V_S}{\int_{d/2}^{D} dQ \cdot \omega} \,, \tag{6}$$

where D – screw diameter, d – hub diameter, dT, dQ – local elemental thrust and moment calculated on propeller surface element (Fig. 11), V_S – local speed of water influx to a screw propeller element surface, ω – screw propeller angular speed.

Selected calculation results have been presented in [5]÷[10] with a more detailed account in [3]. Propeller efficiency results calculated for wake currents in all 19 versions of hull design (Fig. 12) seem most interesting in this respect, since some variants of the modified hull design resulted in lower propeller efficiency, with the majority of the modifications, however, resulting in higher propeller efficiency.

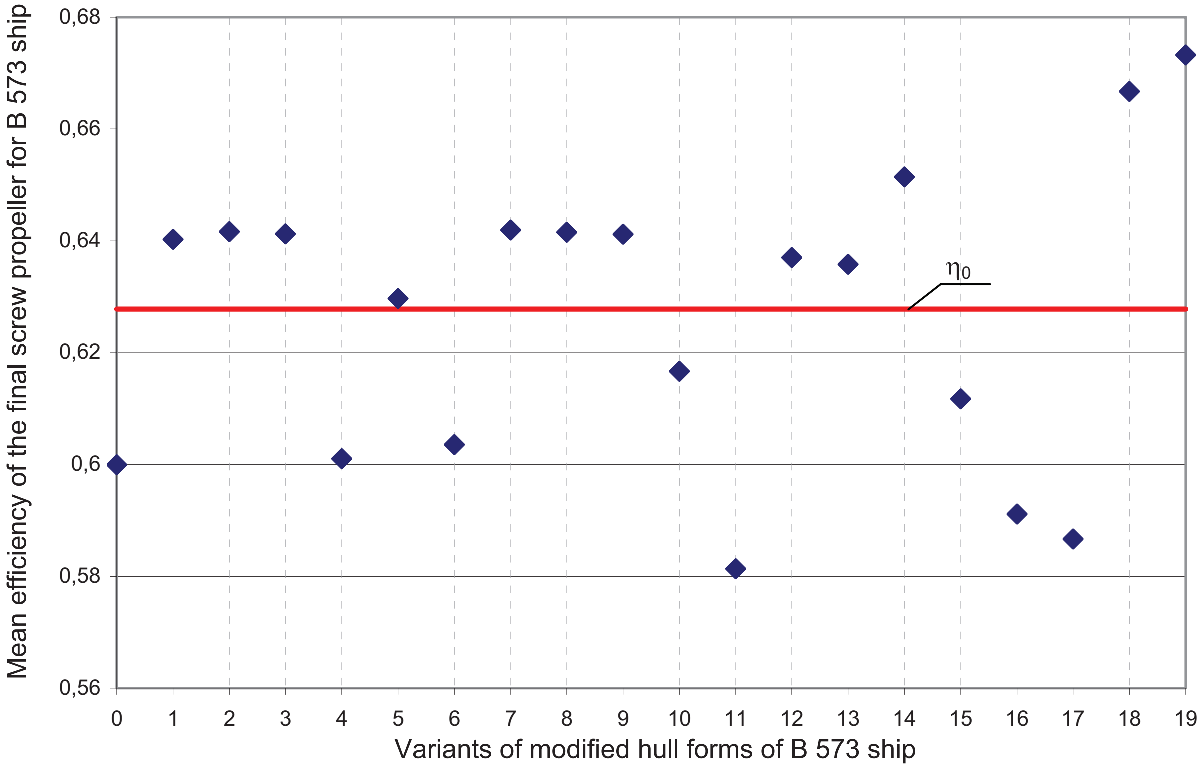

Fig. 12. Mean efficiency of B 573 ship's screw propeller operating in nonhomogenous wake current field, where:
η0 - maximum efficiency of the finalscrew propeller in homogenous flow velocity field,
variant 0 – original hullform (without modification) in wake current velocity field measured duringmodel tests,
variant 18 – the manually modified stern part of ship's hull – symmetric hull form
variant 19 – the manually modified stern part of ship's hull – asymmetric hull form

Finally, having analysed all the calculation variants, the results thus obtained present as follows:

- 2% decrease in ship's hull resistance,
- 4.5% increase of screw propeller efficiency (by more optimal wake current field),
- additional increase of 2% in screw propeller efficiency resulting from streamlining the profile as well as rudder location in relation to the propeller.

Subsequently, the influence on EEDI value of the optimal results of numerical analyses against the EEDI value of the actual ships have been compared:

- the EEDI value for B 573 ship prior to modifications EEDI = 5,6308
- with the modifications: $EEDI_{max}$ = 5,1803 (to reduce 8 %).

5. Conclusions

- EEDI although mandatory from 2013 onwards, seems to need some further discussion in order to ensure that the International Energy Certificate is awarded without impeding the ship safety and in full transparency as to avoid dishonest practices (i.e. possible taking advantage of some lack of precision in current regulations).
- Meeting the standards for CO_2 emission required for the International Energy Certificate for the ships built and designed at present is by no means difficult.

- Meeting such standards (CO_2 emission) in the coming years will require more effort resulting in an improved ship design (resistance-propulsion relationship, propulsion system, overall ship energy consumption).
- Ship body modelling together with the analysis of the hull- propeller- rudder system working together has a wide potential of reducing ship propulsion efficiency thus reducing its EEDI value as well..
- The results of numerical analyses of the ship's hull, screw propeller and rudder design presented here by CFD results are preliminary and do not cover all possible relationships between the ship system parameters of the hull- screw propeller – rudder type. Since the results look promising, further research in this field has been continued.

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