

Influence of rudder location on propulsive characteristics of a single screw container ship

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ABSTRACT

This paper presents the experimental study on the influence of the rudder location on propulsive characteristics of a single screw, single rudder container ship. A wide model tests program was carried out in accordance with the standard ITTC procedure. The towing velocity, propeller revolutions, thrust and torque were measured. Six types of rudders were tested during the experiments: spade, Schilling with fishtail, horn type, Becker type, horn and Becker type with efficiency bulb. During the tests the rudderstock was located in three different positions along the hull centreline in the distance to propeller equal to 59, 65, 71 percent of propeller diameter.

The different combinations of the rudder-propeller arrangement allowed to formulate some conclusions about the influence of the rudder location on the propulsive characteristics. The wake fraction, thrust deduction fraction, hull-, rotative- and propulsive efficiency are compared.

Keywords

rudder location, propulsive efficiency, model tests

1 INTRODUCTION

Minimizing fuel consumption was always important during exploitation of ships. One of the reasons was environment protection, which is connected with emission of exhaust gases like NO_x, SO_x and CO₂, but the main cause was costs minimization. During last years the necessity of fuel consumption reduction was intensified because of increasing of oil prices and the financial crisis.

The shipbuilding industry is one of the victims of the global crisis as well. Therefore it is very important to minimize costs of design, production and exploitation of ships and other floating structures.

Many shipowners made efforts to reduce the energy consumption of their vessels, what have led to various studies and subsequent decisions to invest in fuel saving projects.

The best way to reduce costs of ship exploitation is increase of total efficiency of propulsion system. This will guarantee the same ship speed with lower fuel consumption. It is well known that rudder behind the hull

and the propeller has a great influence on the propulsive performance. Some experiments, which determine influence of rudder profile thickness on propulsive characteristics, have been carried out (Moriyama & Sugai, 1981). It is also known that rudder profile has an influence on the propulsive characteristics and fuel consumption (Hasegawa et al. 2006). Following assumption could be made, that besides the thickness and profile of the rudder blade, also the location of rudder could have large influence on propulsive characteristics.

A set of self-propulsion model tests with various rudder types have been carried out to determine the influence of rudder location on the propulsive characteristics. On this basis some conclusions regarding propulsive efficiency for different ship speeds are formulated.

2 PROPULSIVE CHARACTERISTICS

For the analysis of propulsive characteristics changes caused by rudder location and for description of model test results, standard coefficient forms are used:

- wake fraction

$$w = \frac{J \cdot D \cdot n}{V} \quad (1)$$

- thrust deduction fraction

$$t = \frac{R_T - F_D}{T} \quad (2)$$

- hull efficiency

$$\eta_H = \frac{1-t}{1-w} \quad (3)$$

- rotative efficiency

$$\eta_R = \frac{K_{Q0}}{K_Q} \quad (4)$$

- propulsive efficiency

$$\eta_D = \eta_R \cdot \eta_H \cdot \eta_0 \quad (5)$$

Where J = advance coefficient, D = propeller diameter, n = propeller revolutions, R_T = model total resistance, F_D = additional towing force, K_{Q0} = torque coefficient in open water conditions, K_Q = torque coefficient in behind hull conditions, η_0 = free stream propeller efficiency.

3 MODEL TESTS

Experiments were carried out using a wooden model of a panamax containership built to a scale of 1:27.2. All model tests were conducted at Ship Hydromechanics Division of Ship Design and Research Centre in Gdańsk according to the standard ITTC procedure.

3.1 Ship and rudder models

The principal particulars of the containership model are presented in the Table 1. The wooden model shown in the Figure 1 had no appendages, but was equipped with one bow thruster. A wire on the frame 19, with a diameter of 1mm was used for turbulence simulation.

Stern part of the model was designed in a way, which allowed to move the rudderstock in different positions along the hull centreline. Three locations for rudderstock have been chosen, with the distance to propeller, shown in the Figure 2, equal to 59, 65, 71 percent of propeller diameter.

Table 1. Principal particulars of the containership model

Length between perpendiculars (m)	L_{PP}	6.985
Breadth (m)	B	1.184
Draft (m)	T	0.381
Displacement (m^3)	V	1.916
Block coefficient	C_B	0.607
Scale	λ	1:27.2

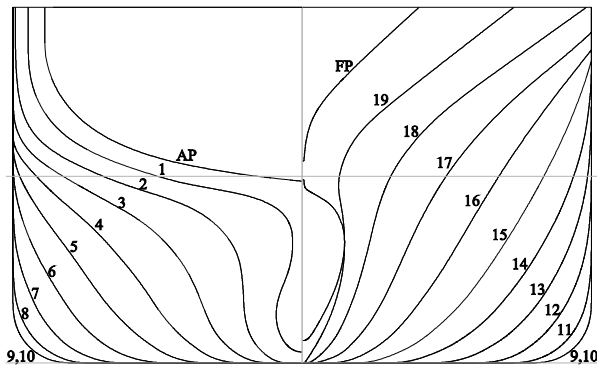


Figure 1. Hull sections of tested containership

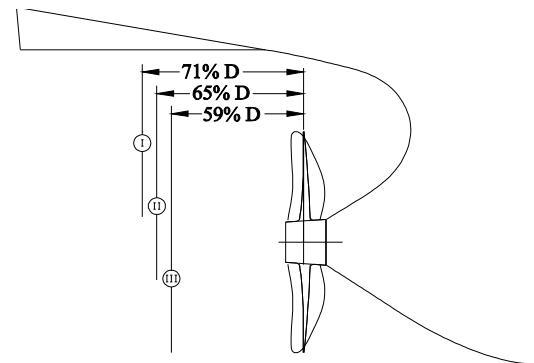


Figure 2. Rudderstock positions towards propeller

The whole research project dealt both with propulsive and manoeuvring characteristics of a containership fitted with different rudder types. Therefore the rudders, which could be favourable on the one hand from propulsive and from the other hand from manoeuvring point of view, were chosen for experiments. Six types of rudders were tested during the experiments: spade (SPA), Schilling with fishtail (SCH), horn type (HOR), Becker type (BEC), horn and Becker type with efficiency bulb (HOR_E, BEC_E). Geometry of rudder blades and profiles at shaft height is shown in the Figure 3.

Generally for all rudder types the same lateral area and aspect ratio (Λ) was assumed. However, size of the efficiency bulb on the HOR_E and BEC_E rudders varied according to actual distance between the rudderstock and the propeller disk. This has involved different values of fixed part (A_{RX}) and total rudder area (A_{RT}). Particulars of rudders and differences in lateral areas are shown in the Table 2.

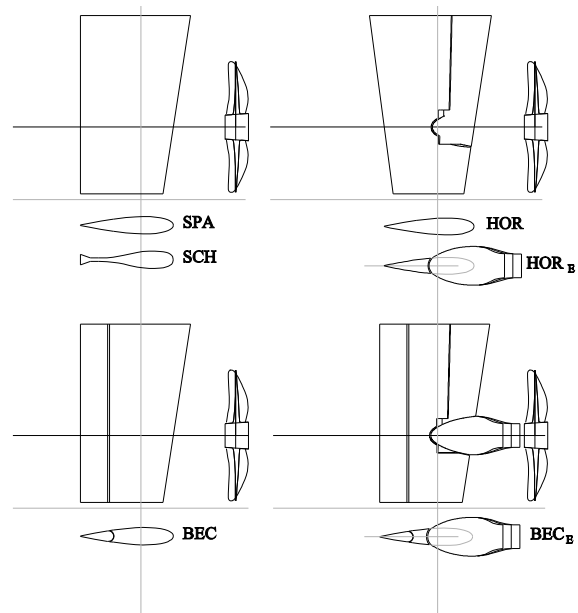


Figure 3. Rudder blades and profiles

Table 2. Particulars of rudders

Coefficients	A_{RT} (m^2)	A_{RX} (m^2)	A_{Rmov} (m^2)	A_{RF} (m^2)	Λ
SPA	0.0609	-	0.0609	-	1.878
SCH	0.0609	-	0.0609	-	1.878
HOR	0.0609	0.0158	0.0451	-	1.878
HOR _E	0.0644 - 0.0662	0.0193 - 0.0211	0.0451	-	1.878
BEC	0.0609	-	0.0609	0.0171	1.878
BEC _E	0.0644 - 0.0662	0.0193 - 0.0211	0.0451	0.0171	1.878

3.2 Propeller Data

For the experiments a five-bladed fixed-pitch propeller was used. The propeller was designed in a combined way, using lifting surface theory and a data base of similar ships. The particulars of the propeller are shown in the Table 3.

Table 3. Particulars of propeller

Diameter (mm)	D	248.16
Pitch ratio at $r = 0.7 R$	$P_{0.7}/D$	0.9735
Expanded blade area ratio	A_E/A_0	0.6345
Hub diameter ratio	d_H/D	0.201
Number of blades	z	5
Direction of rotation	-	right

The open water characteristics of the designed propeller are shown in the Figure 4.

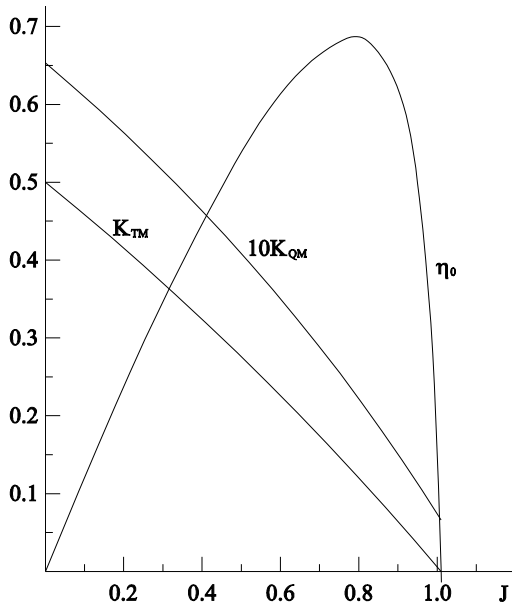


Figure 4. Open water characteristics of used propeller

3.3 Tests setup and experiment program

The whole test program consisted of three stages: the open water tests of rudder blades, resistance tests of the hull and self-propulsion tests.

The open water experiments of rudder blades were carried out at water inflow velocity of 1.5 m/s and the Reynolds number approximately 2.4×10^5 . During these tests the drag (D) and lift (L) forces and moment (N) about the vertical axis have been measured.

Resistance tests have been done in the Froude number range 0.225 - 0.249, corresponding to towing speed 1.87 - 2.07 m/s.

Self-propulsion tests were the main part of the experiment program. A systematic series of self-propulsion model tests was carried out for rudders described in the item 3.1. For all rudders, experiments have been carried out for three rudderstock positions and for the same Froude number range as in resistance tests. During the tests, the model was running with a driven propeller at speed of the towing carriage. In order to achieve demanded load of the propeller, an additional towing force, taking into account differences between Reynolds numbers of ship and model and assumed resistance increase in service conditions was applied according to the formula:

$$F_D = 0.5 \rho_M V_M^2 S_M (C_{TM} - C_{TS}) \quad (6)$$

Where ρ_M = water density, V_M = model speed, S_M = wetted surface, C_{TM} , C_{TS} = total resistance coefficient for model and ship respectively.

During these tests the propeller revolutions (n), torque (Q) and thrust (T) have been measured.

4 TEST RESULTS

4.1 Open Water Rudder Tests

Hydrodynamic characteristics of all rudders were determined from open water tests. Results of the open water tests are shown in the Figure 5 in standard non-dimensional form:

$$C_D = \frac{D}{0.5 \rho V^2 A_{RT}} \quad (7)$$

Where D = drag force, V = water inflow velocity, A_{RT} = total area of rudder.

It can be seen that for very small angles of attack almost all rudders have the same value of drag coefficient. Only SCH rudder has significantly, approximately four-times, higher drag. At larger rudder angles the drag coefficient for BEC, BEC_E and SCH rudders is higher than for SPA, HOR and HOR_E, but this angle range is not in the interest area of current analysis.

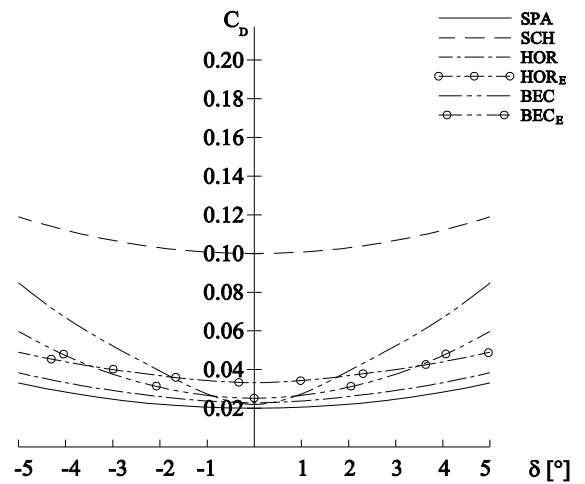


Figure 5. Drag force coefficients for rudders in open water conditions

4.2 Resistance Tests

Resistance tests have been carried out only for bare hull because of two reasons:

- it is purposeless to measure resistance with rudders because of different wake field in the rudder location in and out of behind-propeller conditions,
- small difference between total resistance coefficients of the hull equipped with different rudders was assumed (Nagarajan et al., 2008)

The resistance test results are shown in the Figure 6.

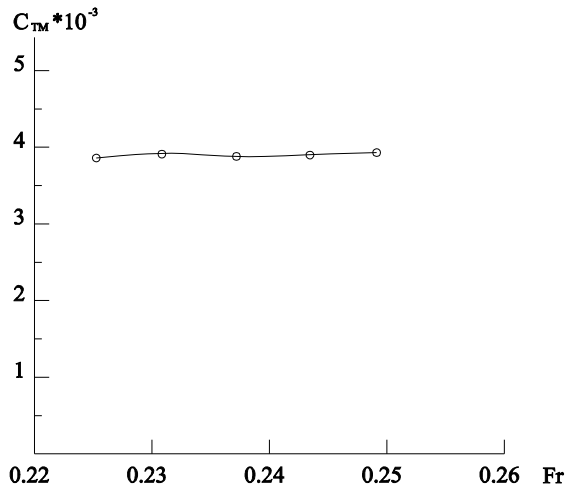


Figure 6. Resistance test results

4.3 Self-propulsion Tests

The self-propulsion tests were carried out according to standard ITTC procedures. On the basis of the tests thrust deduction fraction (t), wake fraction (w), hull- (η_H), rotative- (η_R) and propulsive (η_D) efficiency have been determined.

All the characteristics are presented in the function of distance to propeller disk, which is defined in percents of propeller diameter. All the results are shown in model scale values.

In all the figures a reference level, which defines the current characteristic in without rudder condition is presented.

Because of similarity of analysed propulsive characteristics behaviour for different ship velocities in the tested range, only one speed equal to $Fr = 0.249$ has been chosen for the results presentation. However in the Figures 11 - 15 the propulsive efficiency is shown for all tested ship speeds.

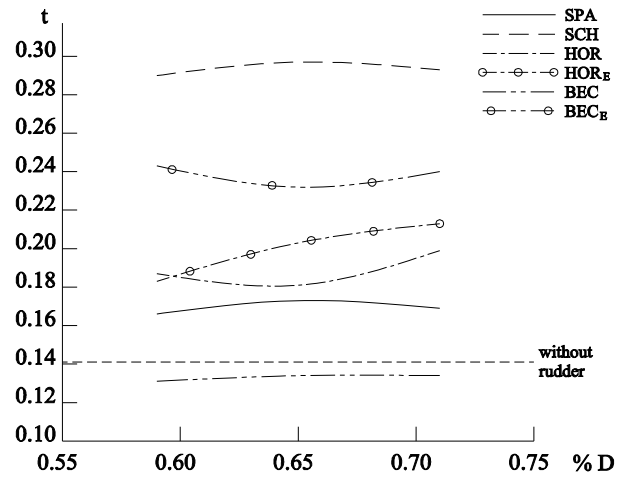


Figure 7. Thrust deduction fraction for $Fr = 0.249$

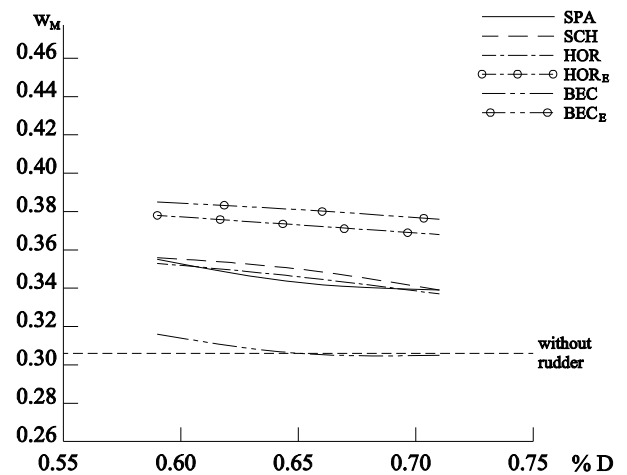


Figure 8. Wake fraction for $Fr = 0.249$

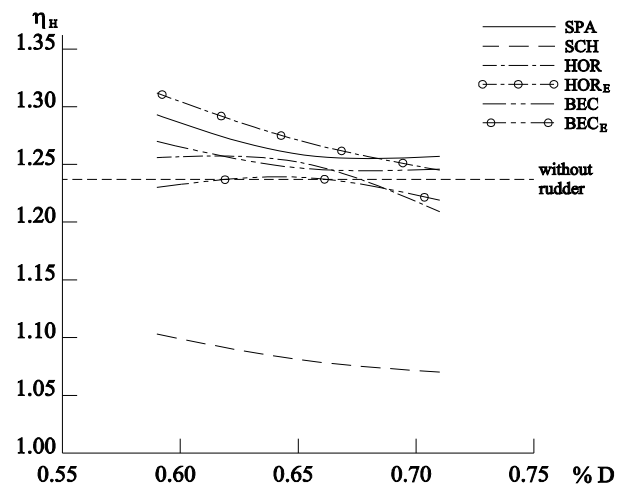


Figure 9. Hull efficiency for $Fr = 0.249$

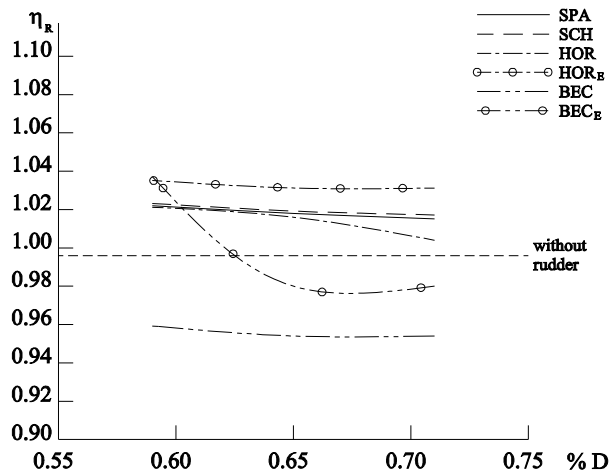


Figure 10. Rotative efficiency for $Fr = 0.249$

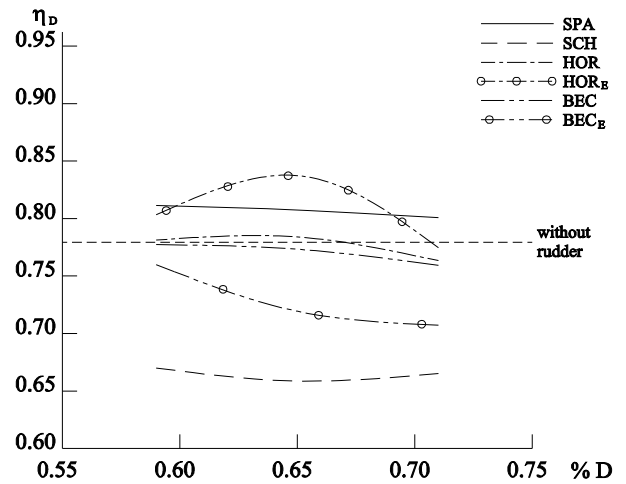


Figure 13. Propulsive efficiency for $Fr = 0.237$

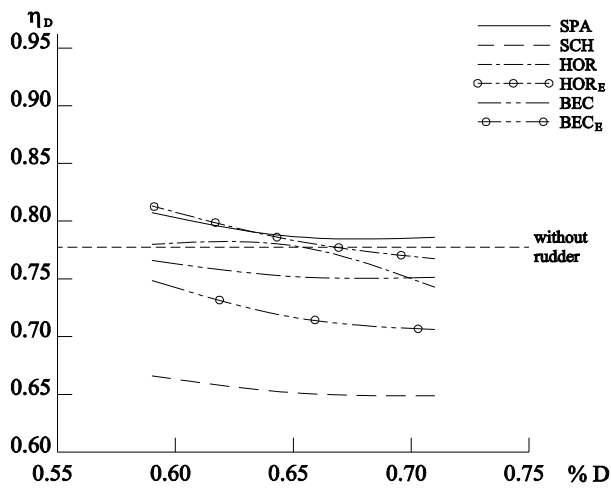


Figure 11. Propulsive efficiency for $Fr = 0.249$

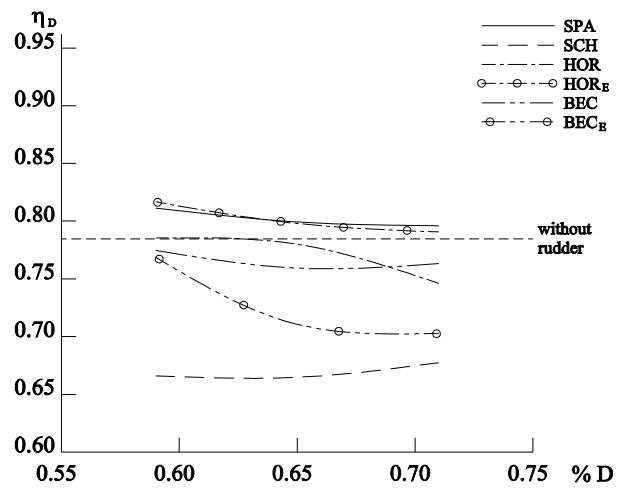


Figure 14. Propulsive efficiency for $Fr = 0.231$

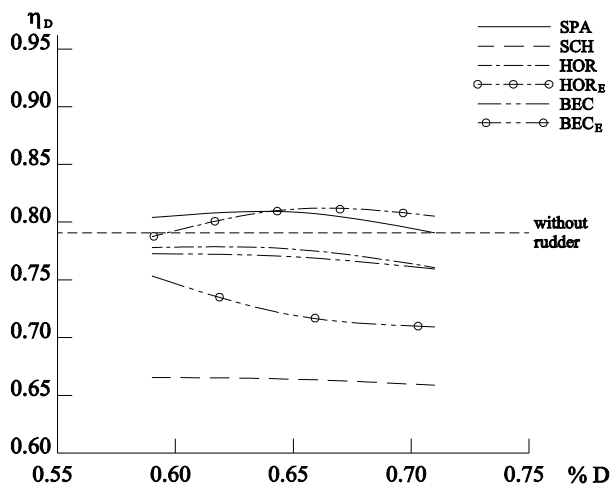


Figure 12. Propulsive efficiency for $Fr = 0.243$

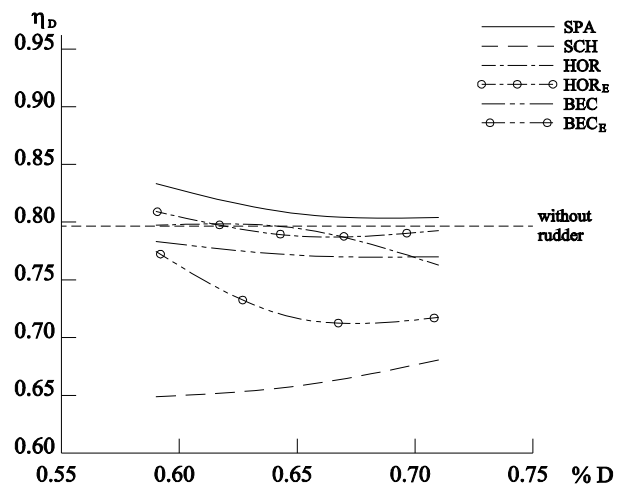


Figure 15. Propulsive efficiency for $Fr = 0.225$

4.4 Cavitation Tests

For all rudder types and rudderstock position, cavitation model tests have been carried out. The possible cavitation patterns have been observed on the rudder and on the propeller as well. The experiments were done for the cavitation number $\sigma = 2.003$.

In all positions, both rudders and propeller were free of cavitation.

5 CONCLUSIONS

This paper presents model tests of a single-screw, single rudder containership. Particularly the influence of rudder location on some propulsive characteristics has been studied.

Six types of rudders were used for the experiments. The rudders had the same lateral area, but different profile and construction. Two of these rudders were equipped with an efficiency bulb.

During the tests the rudderstock was located in three different positions along the hull centreline in the distance to propeller equal to 59, 65, 71 percent of propeller diameter. The self-propulsion model tests have been done for a Froude number range 0.225 - 0.249.

A big difference between total values of thrust deduction fraction for different rudder profiles can be observed. However for the tested ship speed range, for all rudder profiles and all rudderstock locations no tendency in thrust deduction fraction can be seen.

Wake fraction for all tested configurations was in the range from 0.3 to 0.4 and had a tendency to increase with approaching to the propeller.

The character of hull efficiency characteristics is mostly an effect of wake fraction and in most cases increase with approaching to propeller. It has a direct influence on the total propulsive efficiency.

In almost all configurations a small difference in rotative efficiency can be seen in the function of propeller - rudder distance. A slight tendency to increase with approaching to propeller is observed.

It can be seen that for almost all rudder types, for all tested ship velocities the best rudder location from the propulsive efficiency point of view is the closest to the propeller. For the sake of nearly the same rotative and small differences in free stream propeller efficiency it is mainly caused by increase of hull efficiency.

ACKNOWLEDGMENTS

Experiments described in this paper were a part of the research project No. R10 013 01 entitled "Optimisation of rudder profile geometry and the location of the rudder towards hull and propeller from the viewpoint of cavitation of propulsion system and the propulsive and manoeuvring characteristics of ships" funded by Polish Ministry of Science and Higher Education.

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