

# Numerical analysis of influence of streamline rudder on screw propeller efficiency

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## ABSTRACT

*During designing the ship its designer tends to obtain as high as possible efficiency of ship propulsion system. To this end on certain ships additional elements such as: nozzles, half-nozzles or suitably profiled fins attached to underwater part of ship's hull before screw propeller, are applied (sometimes they are intended for the mitigating of vibration resulting from operation of screw propeller). Another device which affects operation of screw propeller is streamline rudder capable of improving its efficiency (most of the transport ships is fitted with single screw propeller and streamline rudder placed behind it). In this paper the influence of streamline rudder on screw propeller efficiency has been examined with the use of numerical methods of fluid dynamics (CFD). The obtained results indicate a very favourable influence of the rudder on screw propeller efficiency. Research in this area is continued and its results concerning impact of particular geometrical parameters of rudder on screw propeller efficiency, will be presented in the future.*

**Keywords:** Streamline rudder, improvement of screw propeller efficiency, computational fluid dynamics (CFD)

## INTRODUCTION

During ship's design process one of the most important tasks is a design of its propulsion system which should ensure reaching the assumed service speed by the designed ship at its as high as possible propulsion efficiency. The crucial element of ship propulsion system is a screw propeller whose efficiency is decisive of overall propulsion efficiency. Geometry of screw propeller decides on its efficiency, hence it should be optimum one in assumed design conditions, i.e. screw propeller should develop demanded thrust at an assumed ship's service speed. Apart from the optimum design, screw propeller efficiency can be improved by using various additional devices such as: nozzles, half-nozzles, or suitably profiled fins attached to underwater part of ship's hull before screw propeller [5] (sometimes they are intended for the mitigating of hull plating vibration resulting from screw propeller operation). The additional devices are aimed at the improving of distribution (direction and velocity) of water stream flowing from around the hull towards the screw propeller. The devices produce a positive effect only in strictly defined conditions. As results from practice, they are applied very rarely.

Another device which influences screw propeller operation is a streamline rudder capable of improving its efficiency. Majority of transport ships is fitted with single screw propeller and streamline rudder placed behind it. Therefore it seems purposeful to examine which way and in which conditions streamline rudder affects screw propeller operation, and how much screw propeller efficiency can be increased.

## SCREW PROPELLER – STREAMLINE RUDDER SYSTEM

The screw propeller – streamline rudder system is exemplified in Fig. 1.

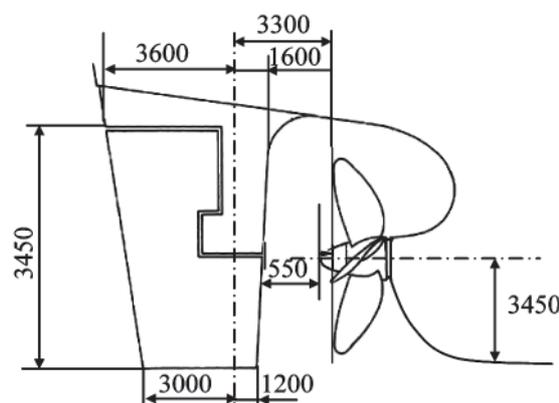


Fig. 1. The semi-spade rudder behind the screw propeller of B 573 ship [8].  
(All the dimensions given in mm)

A few dozen years ago already it has been observed that a blade rudder of airfoil profile not only improves ship's manoeuvrability but also increases screw propeller efficiency and – in consequence – overall propulsion efficiency of ship [6]. The improvement of screw propeller efficiency results from the following reasons:

- part straightening the flow behind the propeller (which leads to lowering the induced circumferential velocity)
- a more favourable distribution of water pressure behind the propeller and reduction of vortices flowing downstream from the propeller, mainly from its boss.

However apart from knowledge of the facts there is a lack of results of systematic investigations, e.g. model tests, and in the subject-matter literature only a general information can be found, that does not provide any basis to state which way geometrical features of streamline rudder affect screw propeller efficiency and how large increase of the efficiency would be possible. Yet the application of numerical methods of computational fluid dynamics (CFD) to modelling water flow around propeller and rudder has made it possible to assess quantitatively and qualitatively influence of rudder on screw propeller efficiency. Most publications in which results obtained by means of CFD methods have been presented, deal mainly with influence of screw propeller on rudder or with investigation of flow around the hull, propeller and rudder [1, 2, 3, 4 and 7]. In this paper preliminary results of numerical investigations concerning influence of rudder on screw propeller efficiency, are presented.

### SCOPE OF THE INVESTIGATIONS

Within the frame of the conducted research project a numerical analysis of flow around screw propeller was performed by using Fluent system to determine the thrust coefficient  $K_t$  and torque coefficient  $K_q$  as well as screw propeller efficiency  $\eta_0$  for:

- a free propeller
- a screw propeller accompanied with a rudder of HSVAMP73-20 profile in the position of no deflection
- for a screw propeller accompanied with a rudder of HSVAMP73-20 profile in the position of 15° deflection.

The investigations were performed for the hull of a B573 ship (built by Stocznia Szczecinska), its screw propeller and streamline rudder (Fig. 1).

As results of model tests on rudder / propeller interaction for the B 573 ship have been lacking, the obtained computational results were compared, only at the advance coefficient  $J = 0.70$ , with the values calculated on the basis of the propulsion prediction for free screw propeller [8].

*Geometrical parameters of the screw propeller of B 573 ship (Fig. 1) [9]:*

Diameter	D	5900 mm
Pitch ratio	P/D	0.739
Expanded area ratio	$A_E/A_0$	0.578
Number of blades	z	4

*Geometrical parameters of the rudder of B 573 ship (Fig. 1) [8]:*

The rudder was designed on the basis of HSVAMP73-20 profile. Its contour and size are in compliance with the rudder installed on B 573 ship.

The computational model of the rudder is shown in Fig. 2, and that of the screw propeller – in Fig. 3.

The computation domain consisted of three co-axial cylinders (Fig. 4). The screw propeller was placed inside the small cylinder put inside the fore large cylinder. Rear faces of both the cylinders were located in one common plane and adhered the fore face of the rear cylinder. Such arrangement makes it possible to apply the mesh for free-

propeller calculations by using the sliding mesh method (the small cylinder is a rotating element and the large cylinders are motionless). For the free-propeller calculations no physical element is placed in the rear cylinder. For the calculations of propeller and rudder together in the rear cylinder is placed the rudder model either with or without deflection, respective of a modeled case.

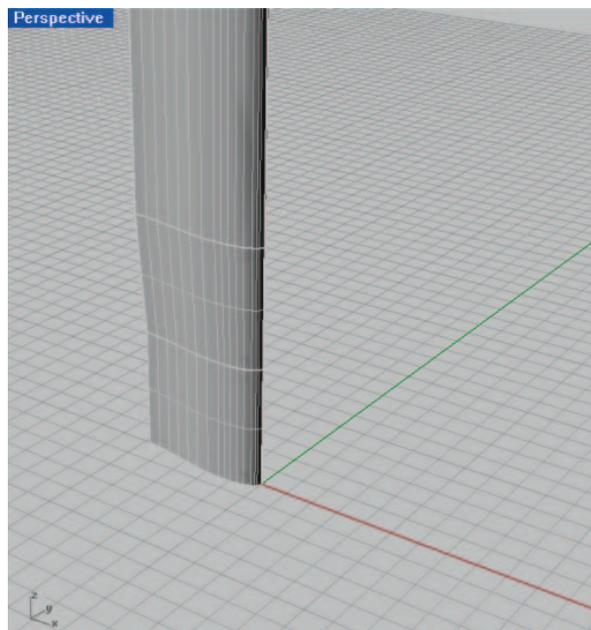


Fig. 2. Computational model of the rudder without any deflection

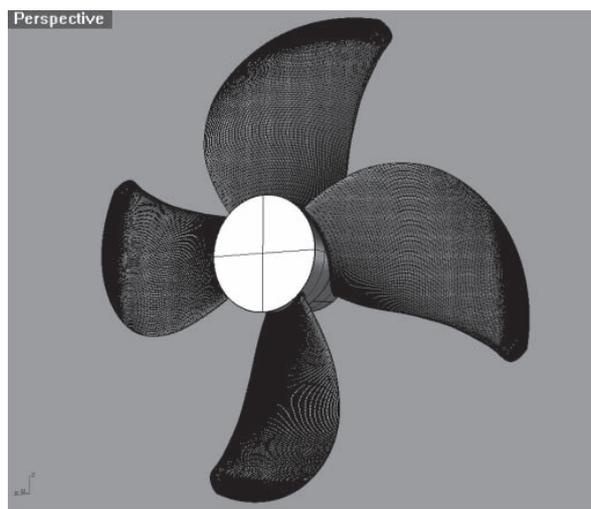


Fig. 3. Computational model of the screw propeller

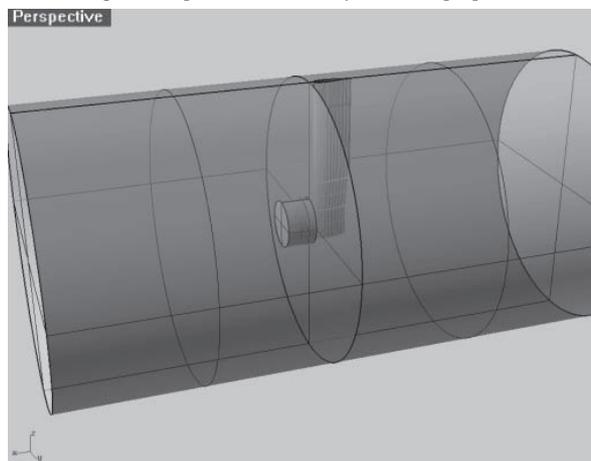


Fig. 4. Computation domain for the set of screw propeller and rudder

## RESULTS OF THE NUMERICAL CALCULATIONS

In advance of the actual calculations of rudder influence on screw propeller efficiency, the following has been calculated:

- Hydrodynamic characteristics of the screw propeller model, which were compared with results of experimental model tests. The propeller model geometry acc. P 355 storage propeller and results of its model tests are contained in the report [8].

Description of the numerical calculations of the hydrodynamic characteristics and their results are presented in [10].

- Hydrodynamic characteristics of the streamline rudder of B 573 ship, (Fig. 1). Results of numerical calculations of the characteristics are presented in [11].

The actual numerical calculations of screw propeller efficiency with accounting for impact of rudder, were then performed. They were carried out for the real dimensions of the propeller and rudder installed on B 573 ship, Fig.1.

In Fig. 5 an example pressure distribution and streamlines for both the propeller and rudder without any deflection is presented, and in Fig. 6 – for both the propeller and the rudder deflected by 15° (The complete set of pressure and velocity distributions as well as streamlines is given in [12]).

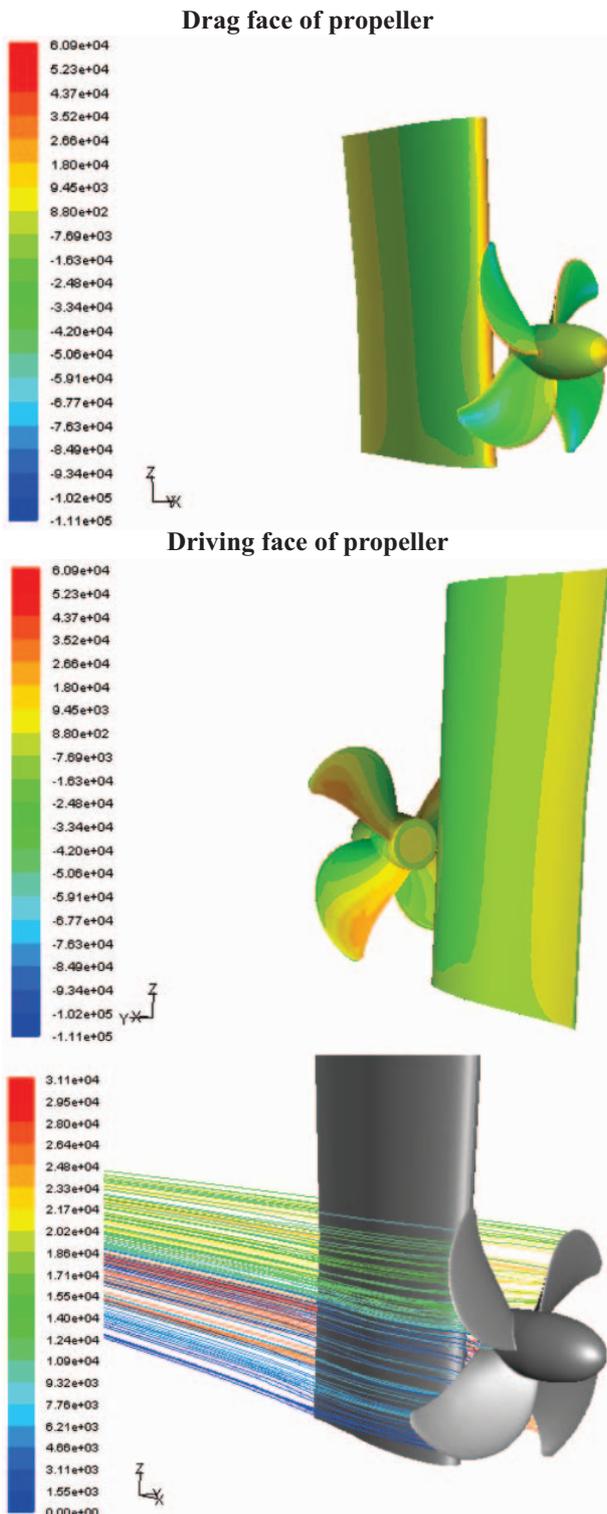


Fig. 5. Pressure distribution and streamlines for the set of propeller and rudder without any deflection, the advance ratio  $J = 0.7$

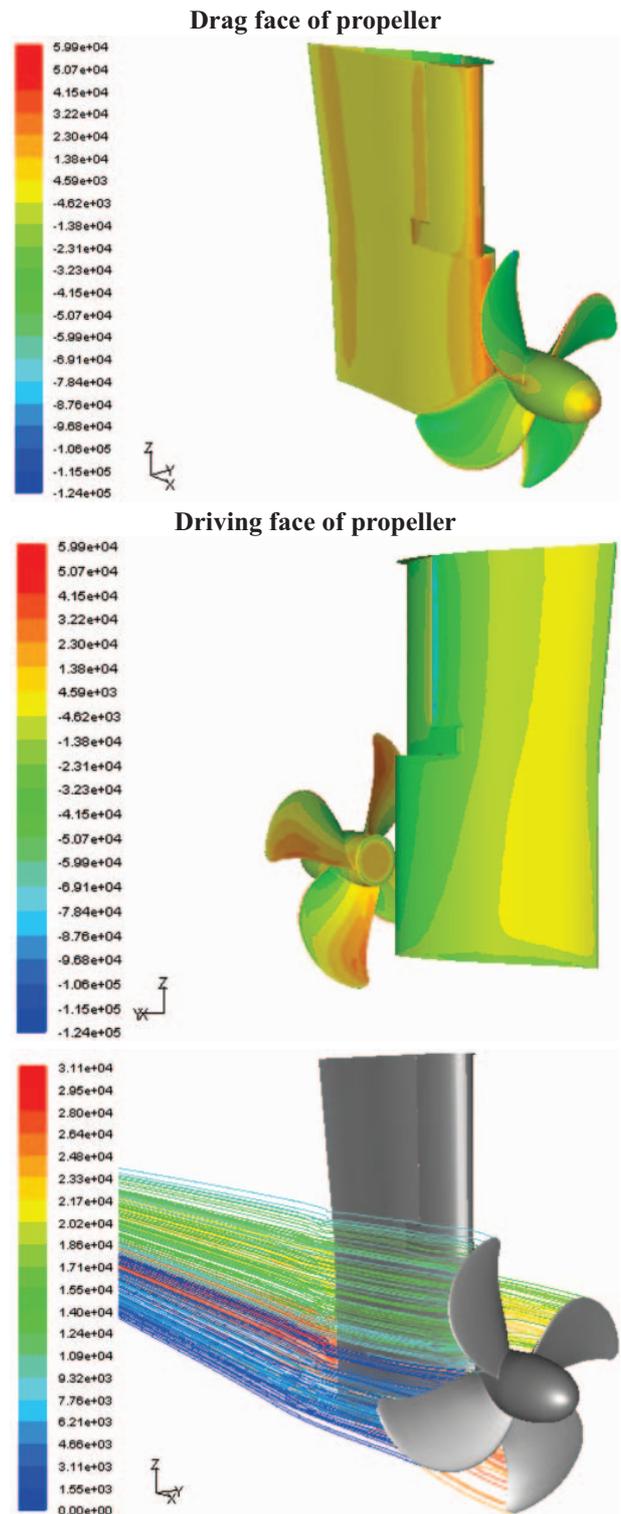


Fig. 6. Pressure distribution and streamlines for the set of propeller and rudder deflected by 15°, the advance ratio  $J = 0.7$

Tab. 1. Data and results of the analysis performed by using the Fluent system.

Screw propeller without rudder										
No.	J [-]	D [m]	n [1/s]	V [m/s]	T [N]	Kt [-]	Q [Nm]	10Kq [-]	$\rho$ [t/m <sup>3</sup> ]	$\eta_0$ [-]
1	0.1	5.9	1.5	0.885	1624159	0.596514	948528.9	0.59046	998.66	0.160868
2	0.2	5.9	1.5	1.77	1365931	0.501673	839757.7	0.52275	998.66	0.305631
3	0.3	5.9	1.5	2.655	1122907	0.412416	722395.3	0.449691	998.66	0.438109
4	0.4	5.9	1.5	3.54	924202.1	0.339437	623854.7	0.38835	998.66	0.556719
5	0.5	5.9	1.5	4.425	720384.5	0.264579	518421.4	0.322718	998.66	0.652745
6	0.6	5.9	1.5	5.31	517910.9	0.190216	405355.8	0.252334	998.66	0.720215
7	0.7	5.9	1.5	6.195	281523.2	0.103397	281425.6	0.175188	998.66	0.657871
8	0.8	5.9	1.5	7.08	51307.51	0.018844	146254.1	0.091043	998.66	0.263667
Screw propeller + rudder without deflection										
No.	J [-]	D [m]	n [1/s]	V [m/s]	T [N]	Kt [-]	Q [Nm]	10Kq [-]	$\rho$ [t/m <sup>3</sup> ]	$\eta_0$ [-]
1	0.1	5.9	1.5	0.885	1529143	0.561616	930528	0.579254	998.66	0.154387
2	0.2	5.9	1.5	1.77	1295804	0.475917	802417.5	0.499505	998.66	0.303432
3	0.7	5.9	1.5	6.195	354941.1	0.130361	298832.2	0.186023	998.66	0.781123
Screw propeller + deflected rudder										
No.	J [-]	D [m]	n [1/s]	V [m/s]	T [N]	Kt [-]	Q [Nm]	10Kq [-]	$\rho$ [t/m <sup>3</sup> ]	$\eta_0$ [-]
1	0.1	5.9	1.5	0.885	1618327	0.594372	950265.5	0.591541	998.66	0.159998
2	0.2	5.9	1.5	1.77	1388741	0.51005	839860.6	0.522814	998.66	0.310697
3	0.7	5.9	1.5	6.195	380906.1	0.139897	315136.1	0.196172	998.66	0.794896

Results of the calculations of thrust, torque and efficiency of the propeller with accounting for the rudder, are presented in Tab. 1, and its hydrodynamic characteristics – in Fig. 7 through 10.

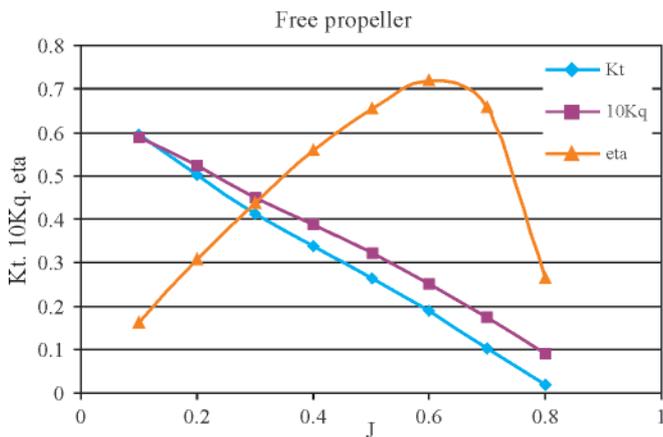


Fig. 7. Hydrodynamic characteristics of the free propeller without rudder

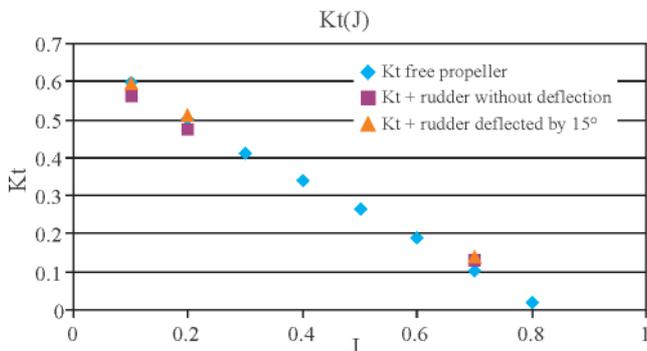


Fig. 8. The thrust coefficient  $K_t$  for the free propeller, the set of the free propeller and rudder without deflection and that of the free propeller and rudder deflected by 15°

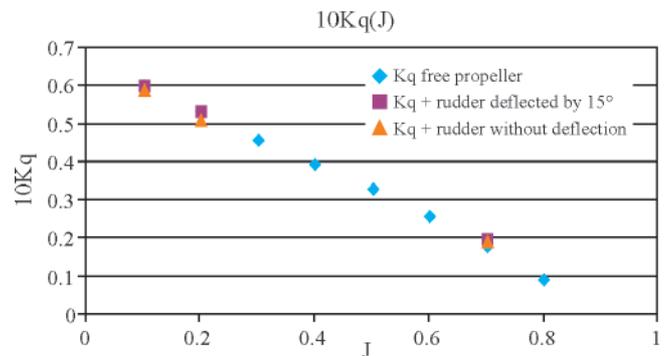


Fig. 9. The torque coefficient  $K_q$  for the free propeller, the set of the free propeller and rudder without deflection and that of the free propeller and rudder deflected by 15°

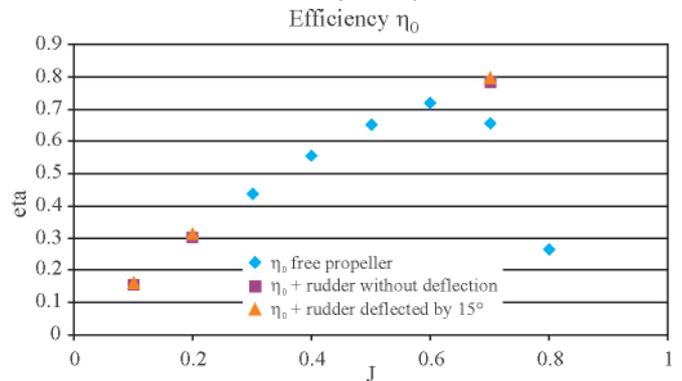


Fig. 10. The efficiency  $\eta_0$  for the free propeller, the set of the free propeller and rudder without deflection and that of the free propeller and rudder deflected by 15°

## CONCLUSIONS

As data concerning results of model tests are very scarce, to make comparison of the numerical analysis results with those of real model tests for free propeller is possible only for values corresponding with the advance ratio  $J = 0.70$ ; relevant results of numerical calculations and model tests are compared in Tab. 2.

Tab. 2.

	model tests	numerical analysis	model / analysis
T	314800	281523.2	1.11820269
Q	228800	281425.59	0.81300354
$\eta$	0.564	0.65787141	0.8573104

The comparison of results for only one value of the advance ratio  $J$  does not allow to assess if the remaining results are correct or not, and does not provide information on correctness of run of the characteristics. However this is the only way of assessing the performed analysis in view of the lack of data.

Comparison of the efficiency, thrust and torque coefficients for free propeller, the set of propeller and rudder without deflection and that of propeller and rudder deflected by  $15^\circ$ , is performed in Tab. 3, 4 and 5.

Tab. 3.

Efficiency $\eta_0$				
No.	J	Free propeller	Propeller + rudder without deflection	Propeller + rudder deflected by $15^\circ$
1	0.1	0.160868285	0.154387068	0.159997698
2	0.2	0.305630894	0.303431839	0.310696571
3	0.7	0.65787141	0.781122746	0.794895671

Tab. 4.

Thrust coefficient $K_T$				
No.	J	Free propeller	Propeller + rudder without deflection	Propeller + rudder deflected by $15^\circ$
1	0.1	0.596513711	0.561616382	0.594371651
2	0.2	0.501672932	0.47591672	0.510050409
3	0.7	0.103396532	0.130361105	0.13989741

Tab.5.

Torque coefficient $K_q$				
No.	J	Free propeller	Propeller + rudder without deflection	Propeller + rudder deflected by $15^\circ$
1	0.1	0.059045983	0.057925422	0.05915408
2	0.2	0.052274967	0.049950537	0.052281374
3	0.7	0.01751876	0.018602322	0.019617241

In numerical calculations an applied computational model, type and size of mesh, and quality of geometrical model of analysed propeller play a very important role. The applied computational model could differ from the real propeller because of very scarce data on propeller geometry, hence to assess a degree of similarity between model and real propeller is not possible. The qualitative analysis performed by means of CFD methods demonstrated that the working screw propeller accompanied with streamline rudder located behind it, is capable of developing a greater efficiency than the free propeller without rudder.

As a result of presently conducted investigations an impact of geometrical parameters of rudder on propeller efficiency will be determined.

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