

Numerical analysis of influence of selected elements on effectiveness of streamline rudder

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ABSTRACT

During designing steering gear for large fast transport ships (e.g. container carriers), shipowners usually put forward strong demands concerning ship manoeuvrability. It means that streamline rudders should be characterized by a high effectiveness, i.e. fast increasing values of lifting force in function of rudder angle and large values of lifting force related to rudder area. As gabarites of streamline rudder depend on a form and draught of stern part of ship's hull, an improvement of rudder effectiveness can be reached by an appropriate selection of rudder profile and application of additional elements to rudder blade.

This paper presents results of numerical investigations (by using CFD methods) of hydrodynamic forces acting on rudder blades of the same gabarites but based on different profiles. Such calculations were also performed for selected rudder blades fitted with additional elements intended for the improving of rudder effectiveness.

Keywords: streamline rudder; improvement of rudder effectiveness; computational fluid dynamics (CFD)

INTRODUCTION

During designing the streamline rudder its designer tends to make its effectiveness as large as possible. The effect can be reached by selecting an appropriate geometry of rudder, including its profile, as well as by applying additional elements which on the one hand are able e.g. to increase lifting force, and on the other hand e.g. to reduce tip losses.

In the subject-matter literature can be found dimensionless results of model tests of hydrodynamic characteristics of airfoils or other profiles used in designing a given rudder of determined dimensions. However similar results of model tests of the rudders fitted with additional elements can be not always recalculated to a designed rudder of determined dimensions. Determination of effectiveness of a designed rudder can be hence performed:

- either by conducting its model tests in a model basin,
- or by using computational fluid dynamics methods (CFD).

Model tests of rudders are much more expensive than numerical analyses which can be presently conducted both for models and full scale objects in view of rather easy access to high-performance computers, today.

SCOPE OF THE NUMERICAL INVESTIGATIONS

The numerical investigations were conducted in two phases:

- I. In the first phase hydrodynamic characteristics of the profiles (Fig. 1) applicable to designing the rudders, were calculated. Dimensions of the rudders and their blade area

were the same as of the final rudder installed on B573 ship [1], which served as the initial object in the analyses in question.

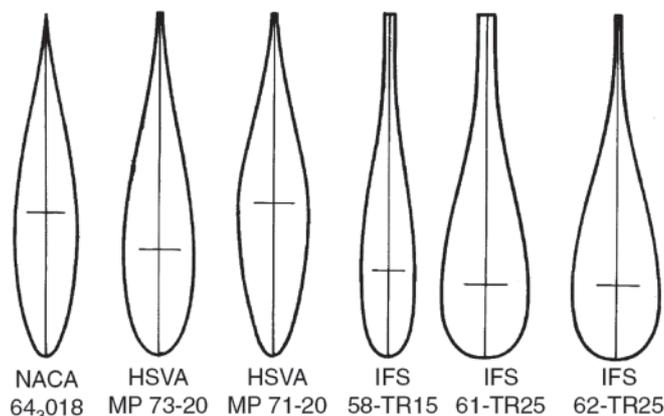


Fig. 1. The profiles used for the investigated rudders

- II. In the second phase certain modifications were introduced to the selected rudders of the above given profiles, and then successive calculations of their hydrodynamic characteristics were made, namely:

- for the rudder of NACA 0018 profile, fitted with a pivoting flap in the rear part of the profile, containing its trailing edge (Fig. 3a). In compliance with the subject-matter literature it was assumed that the deflection angle of the flap relative to rudder axis is equal to that of the main part of rudder blade (if the rudder angle was equal to 30° then the whole deflection angle of the flap was equal to 60°).

- for the rudder of IFS58-TR15 profile with an additional plate fixed at rudder top to reduce generation of tip vortices (Schilling rudder, Fig. 3b).

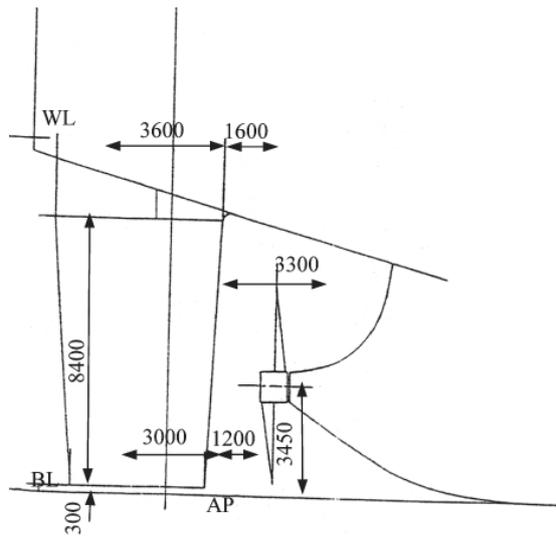


Fig. 2. The final rudder of B573 ship [1], of the area $A_r = 39.48 \text{ m}^2$ and the aspect ratio $\lambda = 1.79$

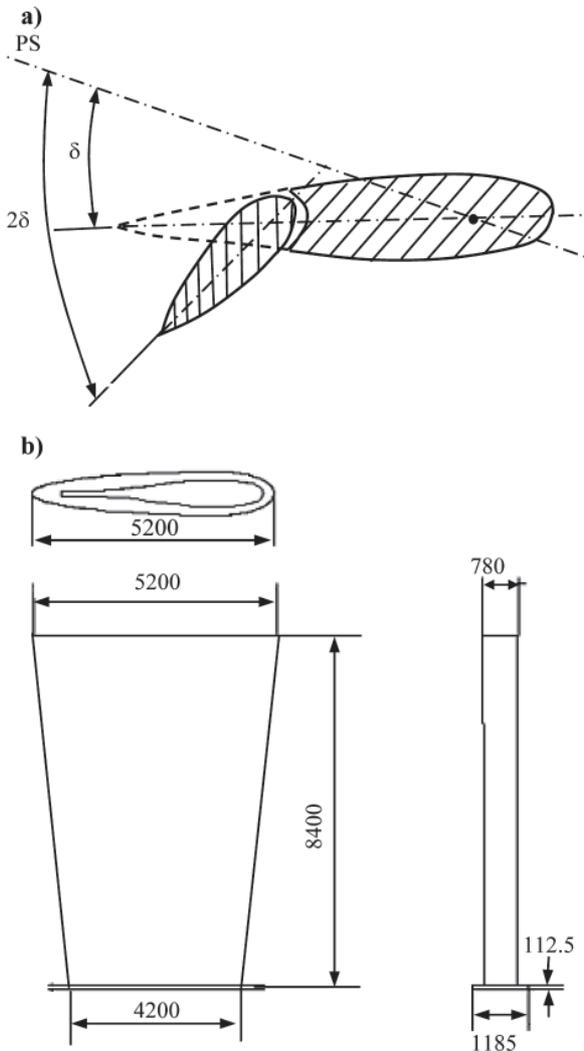


Fig. 3. Modification variants of the selected rudders:

- NACA 0018 rudder fitted with a pivoting flap.
- IFS 58-TR15 rudder fitted with an additional plate (Schilling's rudder)

The modified rudders maintained the same contour and dimensions as those of the B573 ship's rudder.

THE METHOD AND DOMAIN OF COMPUTATIONS

The computational model of the rudder prepared for numerical calculations is presented in Fig. 4.

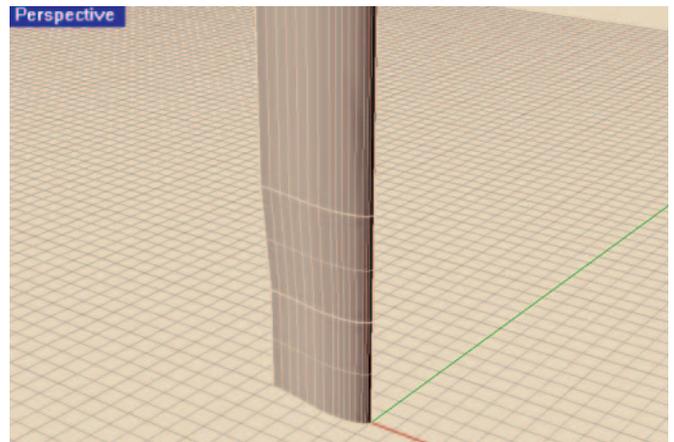


Fig. 4. The computational model of the rudder without any additional elements

The computational domain (Fig. 5) was so arranged as to make it possible to assume different inlet angles of waterflow velocity to the rudder. The upper and lower surface limiting the domain was defined to be the plane of symmetry. The rear surface was defined to be the pressure outlet and the front surface (a half of cylinder) and the side ones constituted the inlet for waterflow velocity to the domain.

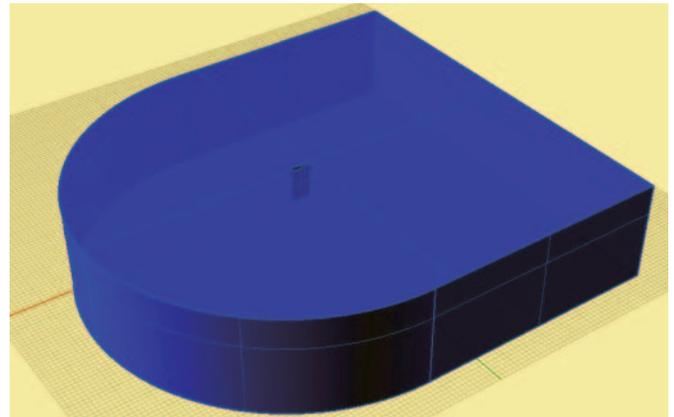


Fig. 5. The computational domain of rudders

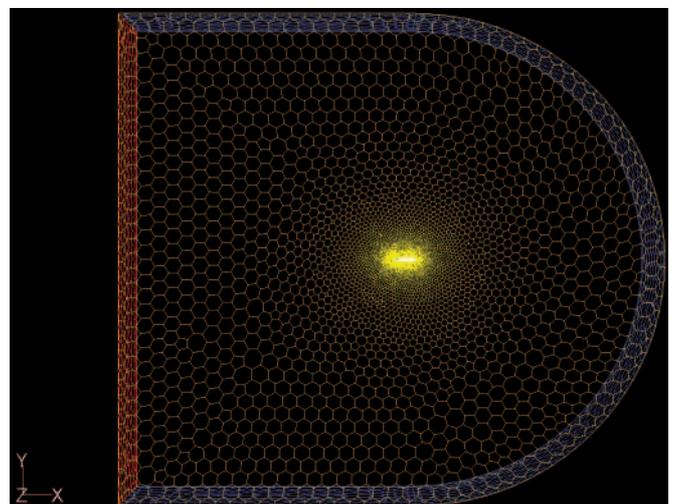


Fig. 6. The computational domain mesh. **Notation:** the blue area – velocity inlet, the yellow one – plane of symmetry, the red one – pressure outlet

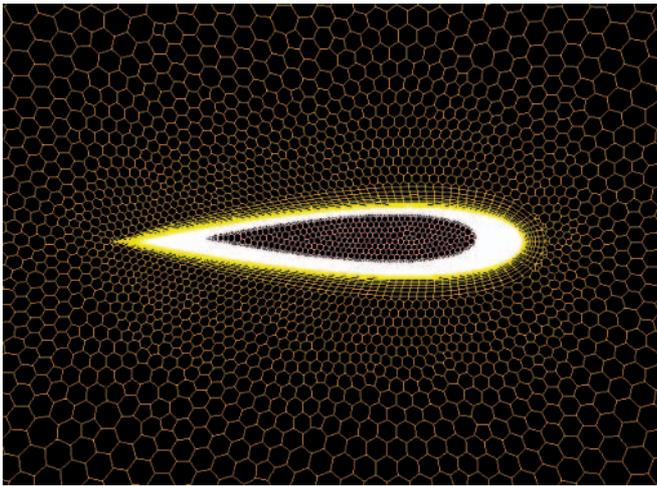


Fig. 7. The structural mesh in the boundary layer (view from the top of the rudder) Notation: the white area – the surfaces defining the rudder blade.

For the domain a polyhedral mesh (Fig. 6 and 7) refined in the vicinity of the rudder and fitted with structural boundary layer on surfaces modelling the rudder, was used.

CALCULATIONS FOR THE RUDDERS WITHOUT ANY ADDITIONAL ELEMENTS

The calculations in question were conducted with the use of Fluent system. The example pressure distributions and streamlines for the rudder of IFS58-TR15 profile are presented in Fig. 8, 9 and 10.

In Fig. 11 are presented results of the calculations in the form of the lifting force L and drag force D versus rudder angle for the rudders based on the profiles shown in Fig. 1.

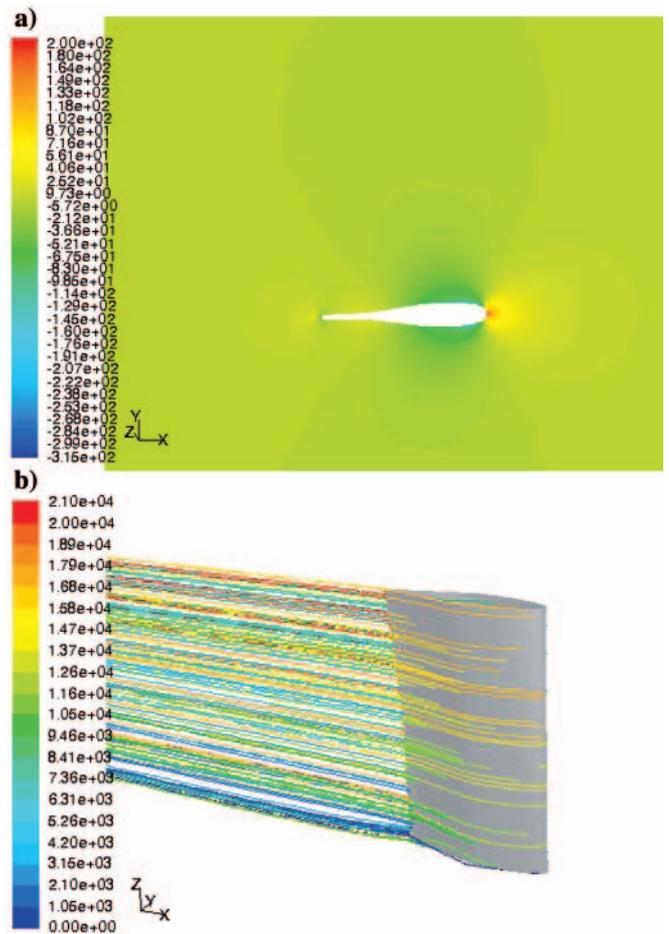


Fig. 8. The pressure distribution: a) and streamlines, b) for 0° angle of attack (the rudder of IFS58-TR15 profile)

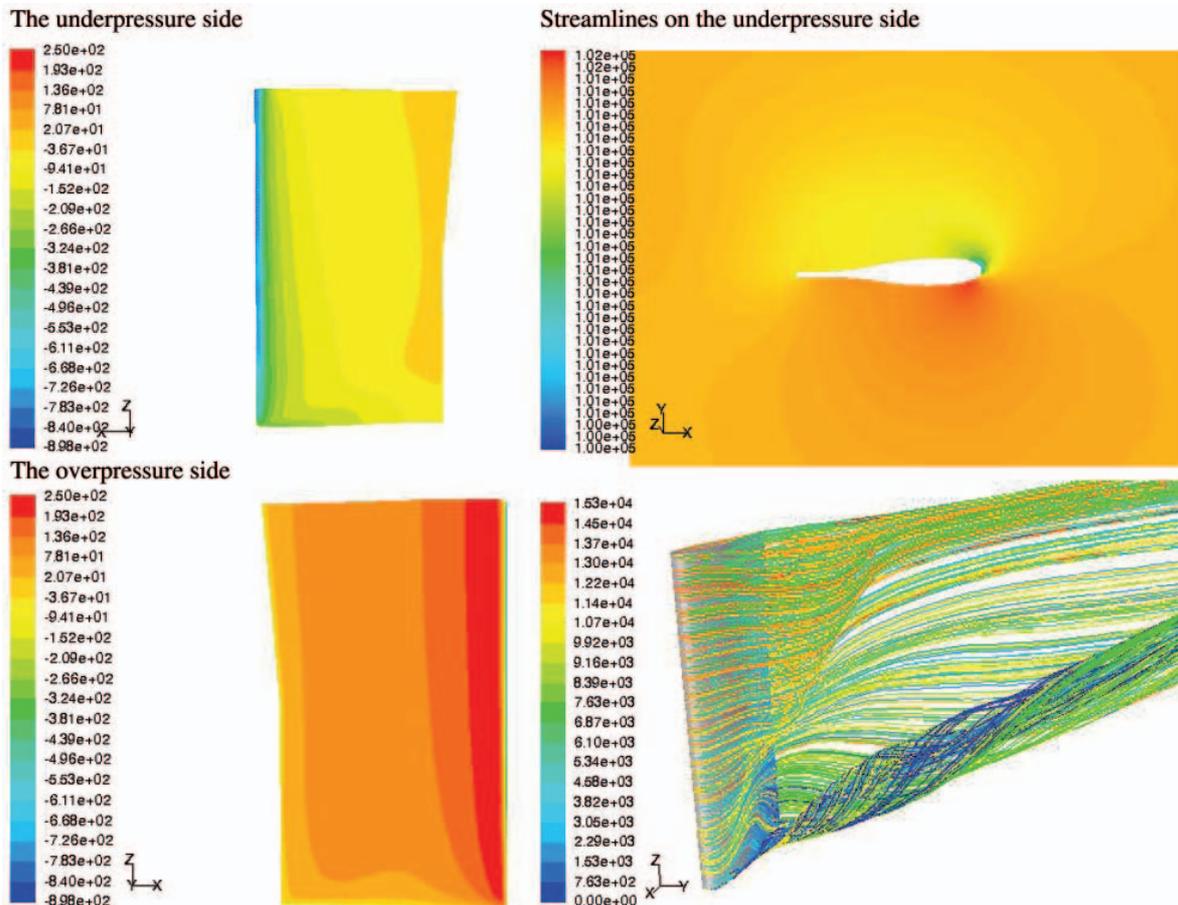


Fig. 9. The pressure distribution and streamlines for 40° angle of attack (the rudder of IFS58-TR15 profile)

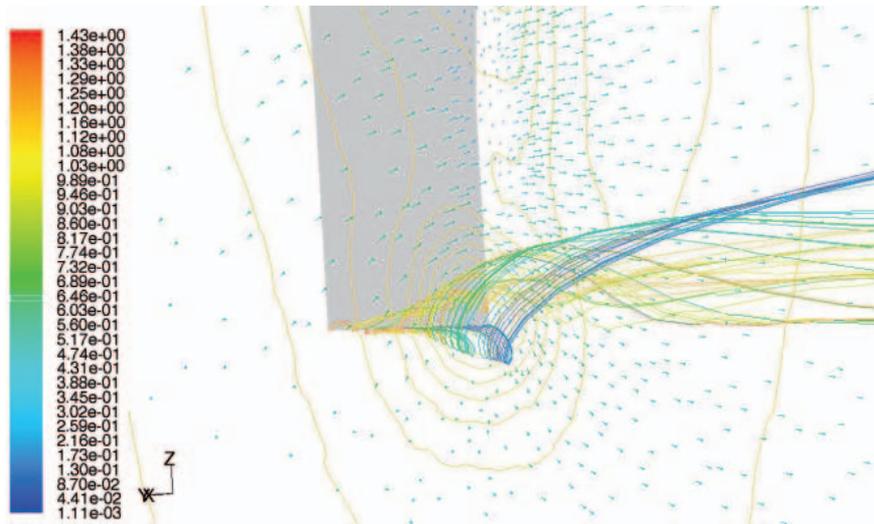


Fig. 10. The tip vortex generated on the rudder of IFS58-TR15 profile at 40° angle of attack. There are depicted streamlines, pressure profiles on iso-surface behind the rudder as well as velocity vectors on the surface

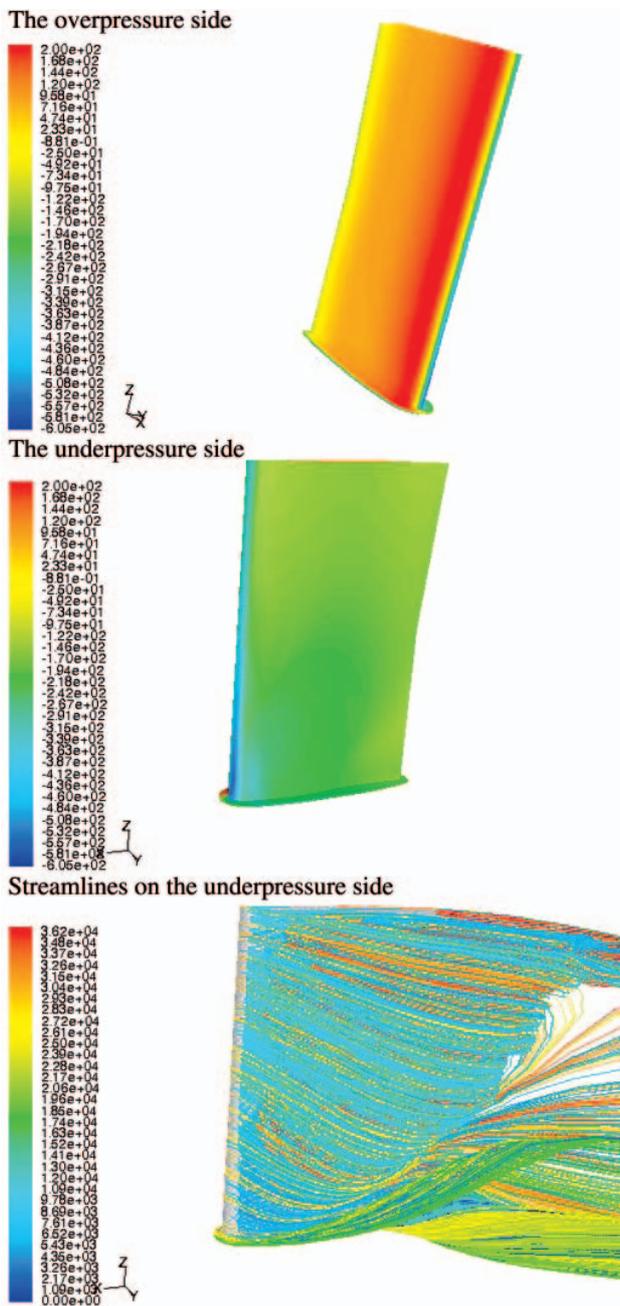


Fig. 12. The pressure distribution and streamlines for the IFS58-TR15 profile rudder at 40° angle of attack

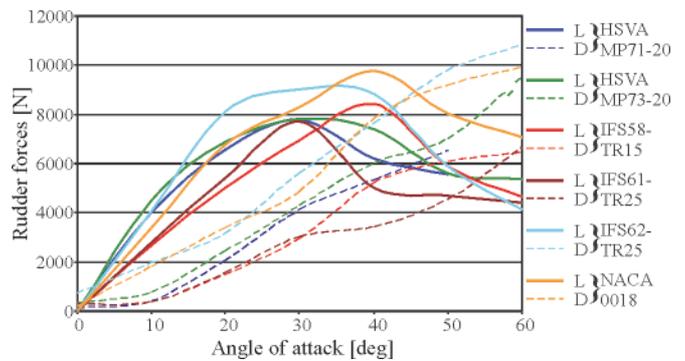


Fig. 11. Values of the lifting force L and drag force D versus rudder angle for the considered rudders

CALCULATIONS FOR THE RUDDERS FITTED WITH ADDITIONAL ELEMENTS

Dimensions of the rudders with additional elements were the same as for the rudders without them. The domain for computation of hydrodynamic forces acting on the modified rudders as well as the scope of the calculations was the same as in the case of the rudders without any modification. The pressure distributions and streamlines for the Schilling rudder of IFS58-TR15 profile are presented in Fig. 12.

The calculation results of the lifting force L and drag force D are presented in Fig. 13 for the NACA 0018 profile rudder fitted with the additional flap, and in Fig. 14 – for the Schilling rudder of IFS58-TR15 profile.

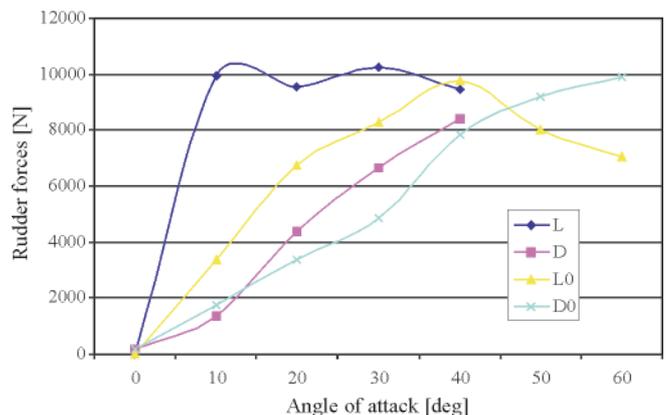


Fig. 13. The hydrodynamic characteristics of the rudder of NACA0018 profile. **Notation:** L , D – for rudder with flap; L_0 , D_0 – for standard rudder

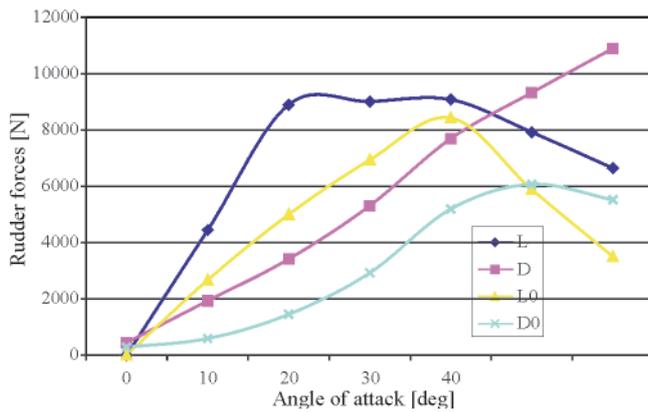


Fig. 14. The hydrodynamic characteristics of the rudder of IFS58-TR15 profile. Notation: L, D – for Schilling rudder; L0, D0 – for standard rudder

CONCLUSIONS

1. The performed numerical experiment was aimed at demonstration of high usefulness of CFD methods in investigating and designing the streamline rudders. The calculations performed for rudders of different profiles showed how far selection of a profile is important for a designed ship to which various requirements concerning its manoeuvrability or limitations imposed on its rudder, may be assigned. The achieved results can be assessed only qualitatively (by comparing hydrodynamic characteristics for particular profiles) because results of model tests of the rudder installed on B 573 ship were lacking. There are available results of model tests of foils of given profiles but having a very large aspect ratio. However in the case in question the rudders of strictly determined dimensions have been analyzed.
2. The two modified rudders analyzed in the second phase of the numerical experiment revealed much more favourable characteristics in contrast to the same rudders without any modification – however the obtained results should be considered rather qualitative, but not quantitative ones as additional investigations should be performed to obtain more exact results. In spite of that the quantitative changes have been found in line with expectations.

3. The performed analysis showed that the NACA0018 profile rudder fitted with the flap has much more favourable characteristics at small values of rudder angle. Probably, at smaller values of flow velocity in the whole domain and at its large values in the surrounding of the rudder behind the propeller, the rudder has curved the flow behind the propeller changing direction of thrust, in consequence. Such situation can happen during ship's manoeuvres at a very small (or even zero) speed of the ship.
4. The Schilling rudder, i.e. the modified rudder of IFS 58-TR15 profile, exhibits also more favourable characteristics mainly at small values of angle of attack. The difference can be also observed at the angle values close to separation of flow where run of the characteristics is more stable than in the case of the standard rudder. This results from a reduced tip vortex effect; however, as observed in Fig. 12, the tip vortex has not been fully removed.
5. In the drawings of this paper only certain examples of the performed computations of pressure distribution and streamlines, have been presented. The complete set of results of numerical analyzes in question can be found in the final report on the R&D project [2].

BIBLIOGRAPHY

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