The Propulsion Complex Design of the Cargo Ship of the Restricted Navigating Area on the Base of Modern Computation Fluid Dynamics Methods

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The constant grows of the motor fuel prices increases the requirements to the quality of ship propulsion study on the design stage. Some unusual approaches that applied during development of the "Volgo-Donmax" class ship project (MEB project name RSD19) are described in this article.

Class "Volgo-Donmax" consists of the largest ships designated for the operation on the Russian inland waterways. This class "is defined by the overall dimensions of the Unified Deep-Water System locks and has the maximum possible characteristic draft 3.60 m in the river, capacity 5000 tons, and the capacity at the maximum draft is above 7000 tons" ([1]). The significant part of this class new vessels at the domestic design market are being built by MEB projects. The projects of these ships as many other MEB projects of the new vessels have some similar features in the providing of necessary propulsion qualities. First of all, rudderpropeller is often used as the propulsion complex. Ships have high block coefficient (above 0.9) and higher specific power than the operated vessels of such assignment.

Question about advantages and disadvantages of the rudderpropeller as the main propulsor of the ship of restricted navigating area is difficult. It doesn't have the only answer without taking into account a number of concrete conditions that valid for only one considered ship. Rudderpropeller defines almost all conception of ship propulsion, but allot her some features in the cost and building adaptability. Notice, that the question about their applying and, in general, about the type of propulsion usually is decided by the customer at the early stage of the project development. The optimization of the ship propulsion taking into consideration the owner's opinion is the task for the naval architect.

The beginning of the RSD19 project development put to MEB the task of design of the ship with the conventional twin-screw propulsion system including the fixed pitch ducted propellers (FPP) and balanced rudders of spade type. It is necessary to complete this task in the oblate terms on the base of the solutions for the vessels of "Volgo-Donmax" class with rudderpropellers. The new ship customer is Volgograd Shipbuilding yard that is belonged to the group of companies "Marine and Oil-Gas Projects". MEB project 006RSD05 (type "Geidar Aliev") of the dry-cargo ship equipped with the "Shottel" rudderpropellers was the direct prototype. The increasing of the requirements to the navigating area (area I against II in the prototype) with the saving of the maximum possible deadweight and restricted dimensions together with the changing of the propulsion system caused the significant complication of the design process.

In this situation the project quality providing requires the realization of some advantages of the conventional propulsion with losing advantages of rudderpropeller. The technology simplifying and costs decreasing of hull construction, the improvement of the maneuverability and steering qualities are referred to the obvious rudderpropeller advantages. Besides, the rudderpropeller can be installed and removed afloat (for some rudderpropeller types) and it is possible its unit repair. The rudderpropellers disadvantage is the lower efficiency of the propellers, because their diameter is restricted on the ships with the small draught. In accordance with this, the natural architect's desire is to provide the more high efficiency of the propulsion system when he refuses the rudderpropeller applying. This is achieved, first of all, by the arranging of the propellers with the optimal diameters.

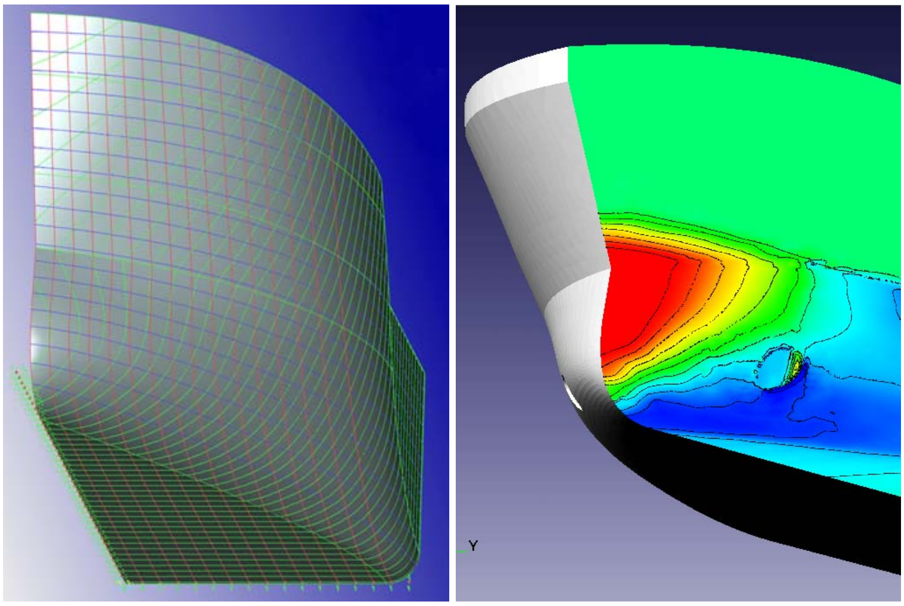
It is the difficult task for the ship with the principal dimensions conformed to the restrictions of the "Volgo-Donmax" class and with the high block coefficient.

The traditional solution of this task connected with the model tests in the towing tank. Their purpose is studying of the ship aft part form and interaction of the propulsion elements. But the most of the ship projects with the restricted navigating area that are being developed in our country nowadays, don't include the results of model tests although often need them more than the ocean liners projects, because the design terms are shot. It is well known, that in the soviet merchant fleet cargo ships with the restricted navigation area were built in the large series. Studying of their propulsion was carried out on base of the model experiment results analyzing. Hence the reasonableness of the hull form and elements of the ship propulsion (for example projects 507B, 1743 and some other) is still the good standard for the specialists.

Nowadays situation can be characterized in the such way: in the case of model tests realization their terms of readiness and program allow using their results only for checking achieving of the contract propulsion qualities. But very rare they can be used for taking the decision about optimization in coordination with the short terms of project development.

The possibility of the necessary studies realization on base of the nowadays Computational Fluid Dynamics (CFD) methods was offered by the Digital Marine Technology (DMT) specialists seems to be an exit from this situation. CFD methods, realizated in the complex of engineering analysis, allow to find the complete picture of the ship hull flow at the early stage of it's design. They permit solving the tasks of the ship hull form optimization and configuration of the appendages; studying of propulsor work conditions, steering gear and transverse thrusters. Besides, the trim and sinkage characteristics of the high speed crafts can be found and the main machinery power can be defined. It is possible to receive not only the value of resistance but the pictures of the physical variables distribution in the flow and at the hull surface. These contributed to the more fast research of the effective ways of the hydrodynamic qualities improvement of the studied objects.

During the project RSD19 development, the general measures of the hydrodynamic features optimization were connected with the developing of the aftship form. The fore part, designed earlier as well with the help of CFD methods for ship project 006RSD05, was saved without changes (fig.1)



a b

Fig. 1. Fore End:
a –hull form model ; b – pressure distribution.

The ducted propellers diameters and general arrangement of the propulsion complex were determined for ship proceed from optimal Taylor variable value. The increased propellers diameter required the appliance of stern tunnels in difference of ships with rudderpropellers (fig.2).

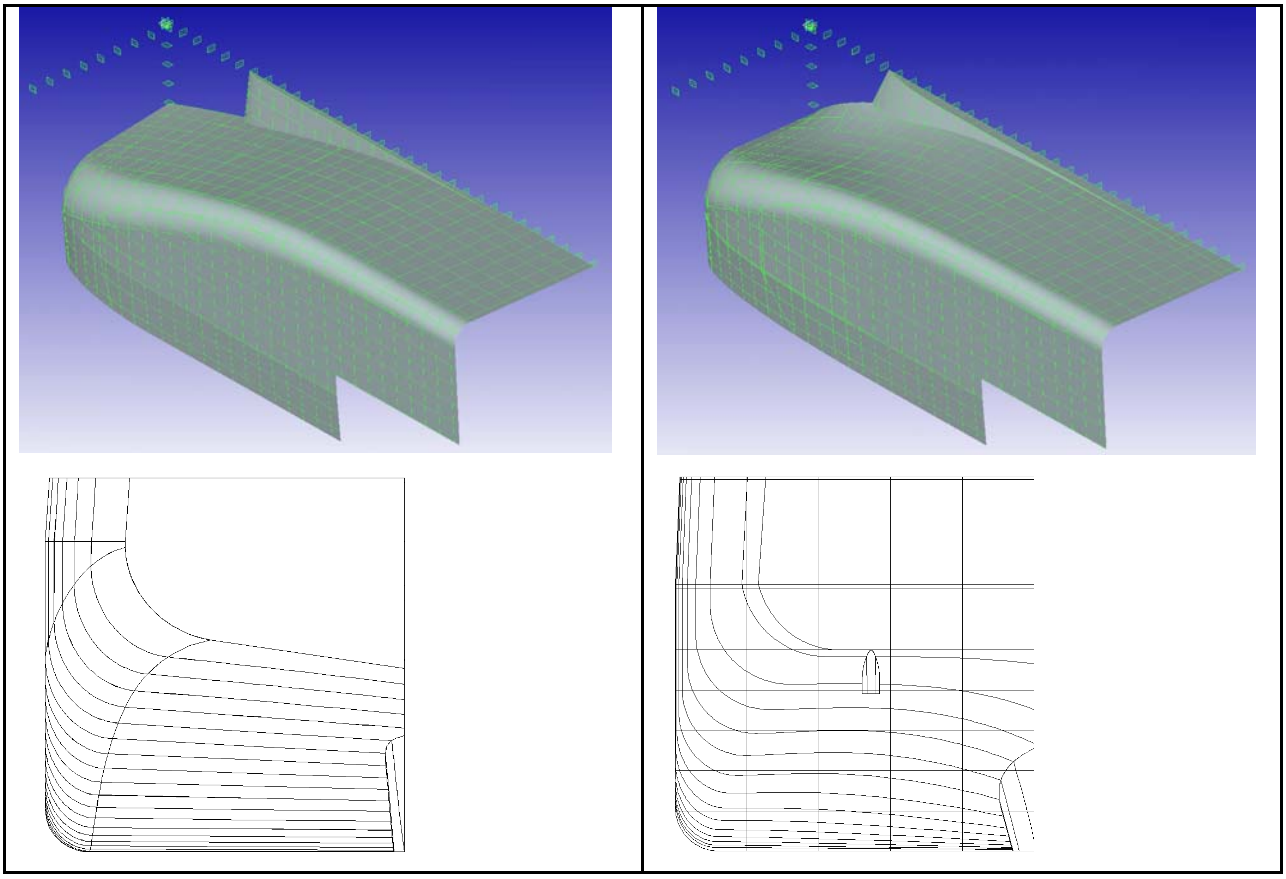


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Fig. 2. Aft End:
a – ship with the rudderpropellers (MEB project 006RSD05); b – ship with the tunnels.

The form of the aft end and tunnels was studied by consequent correction of the variants according results of calculations. Studying of the streamlines at the ship hull took the large part in the choice of the tunnels shape (fig.3). The streamlines also good illustrate two-dimensional character of ship flow at B/T = 3.59, the ‘buttocks’ scheme is looked out.

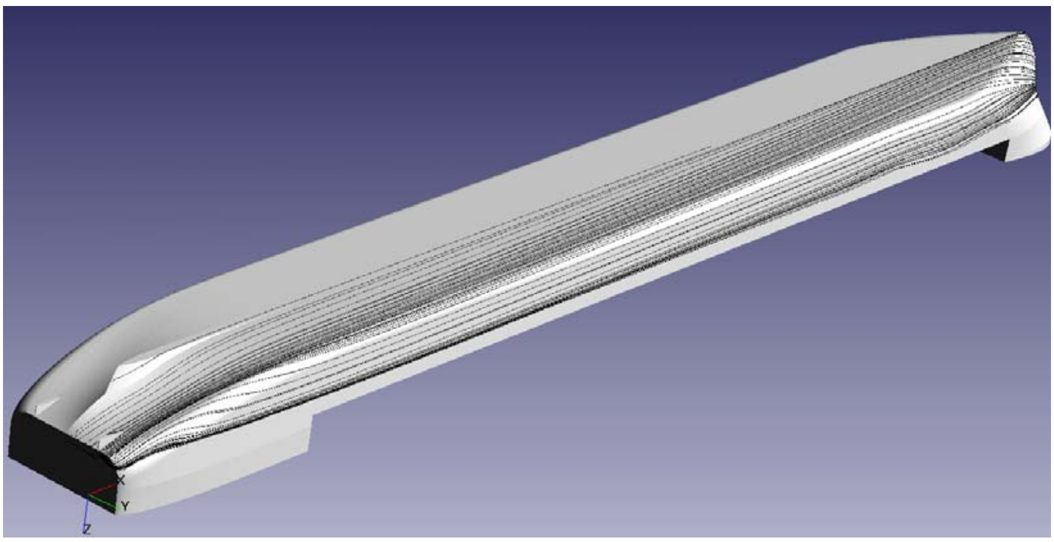

Fig. 3. Streamlines on Ship Hull. Speed 11.5 knots

The propulsion regime of the ship designed for operation at speed 10-11 knots (Fn = 0.14 – 0.16) differed from the regimes with the developed wave resistance that are inherent the most of seagoing vessels. The decomposition of total resistance components was received by means of numerical methods for the final variation of the ship hull form (project RSD19) at the towage speed 10.5 knots. It is represented at fig.4.

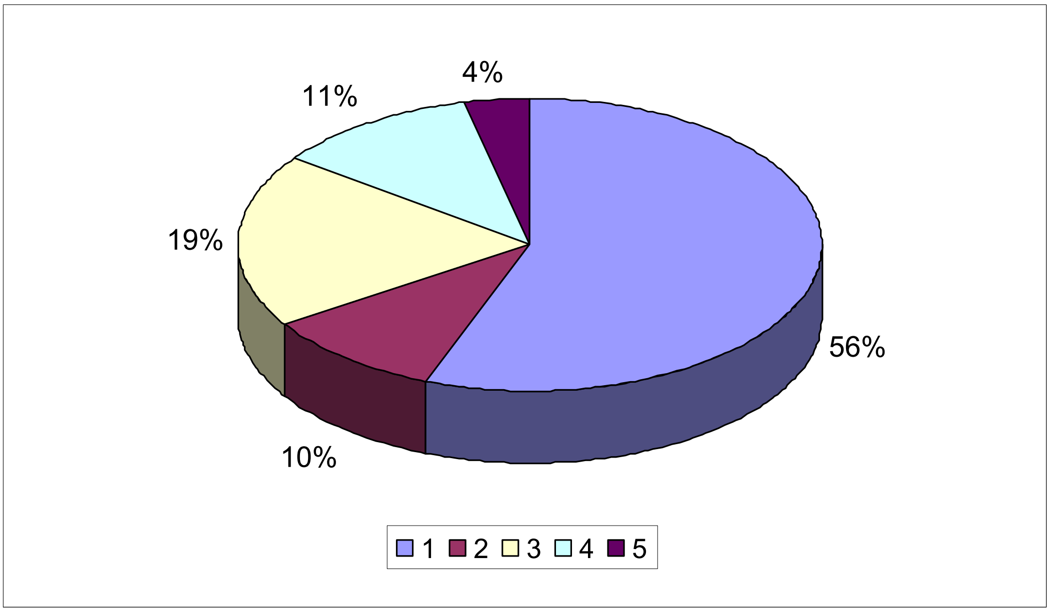

Fig. 4. The Total Resistance Decomposition
1 – frictional resistance; 2 – wave resistance; 3 – viscous pressure resistance; 4 – appendages resistance; 5 – air resistance of the upperworks.

By these reasons, the main components of the total resistance almost connected with viscosity.

Taking into account the high block coefficient and restricted draught, it is important to avoid the developed boundary layer separation in the aft end, especially in the propeller slipstream area, for providing good propulsion. The picture of the shear stress distribution on the ship surface allows understanding of boundary layer separation. It was considered while the aft end form studied. The distribution of the shear stress on the surface of the hull final version is represented at fig. 5, 6. The shear stress above zero witness about the boundary layer separation. It is in the transom area and on rudder foundations (the flowing of these elements is inevitable has the separation character), i.e. on the considerable distance astern of the propellers.

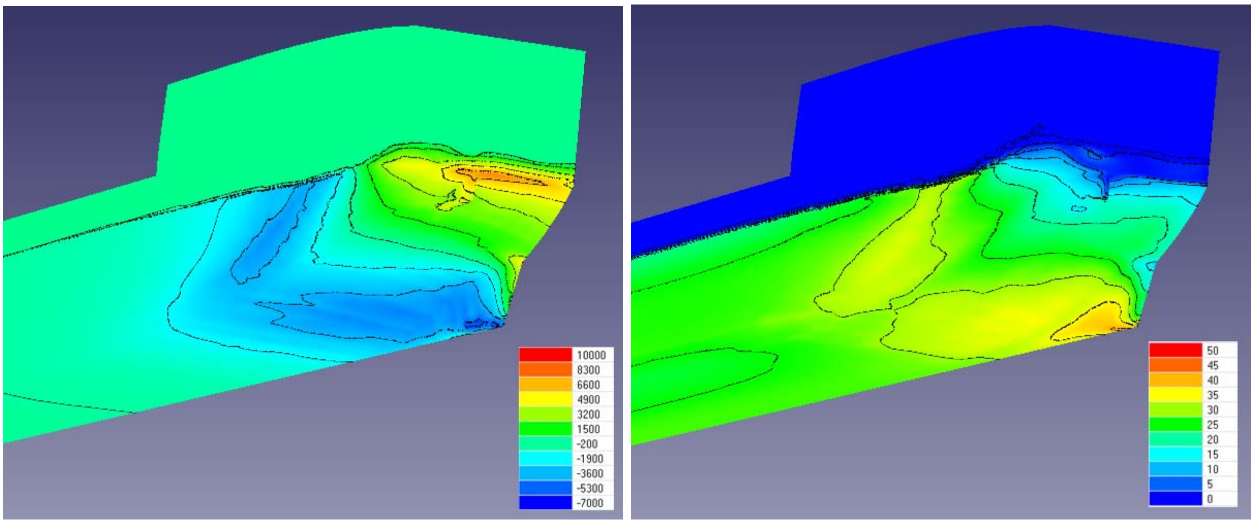

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Fig. 5. The Distribution of the Stress at the Ship Hull:
a – normal stress (pressure); b – shear stress

The aforesaid design methods in the conditions of close cooperation of MEB and DMT specialists allowed to reduce the time of developing of the lines plan to 20 days. Then the general designer received the hull form with results of it's hydrodynamical optimization, agreed configuration of the appendages and elements of the propulsion system (fig.6), necessary data about ship towing resistance in the interested speed range and prediction of the ship speed. This information was updated and used for the calculations of the ship propulsion qualities in ballast and full load condition.

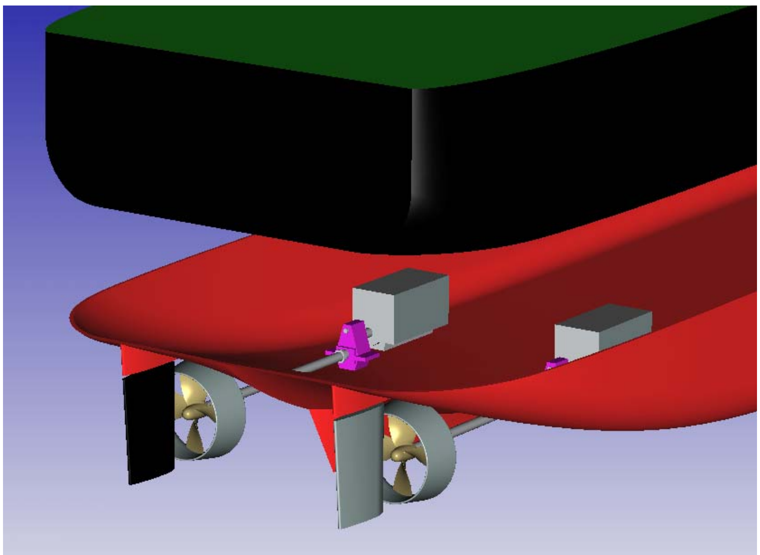

Fig 6. Three-dimensional Model of Propulsion System Arrangement

The towing and propulsion tests of the ship model were carried out in the big towing tank of Krylov Shipbuilding Research Institute under the leadership of prof. Gennady I. Kanevsky on the consequence stages of project development. Their objective was the project solutions checking and determination of the ship propulsion qualities. The photos of the model are shown on the figure 7 (according report [2]).

It is interesting to compare the results of the model tests and calculations after finishing the design of the ship propulsion system. For main hydrodynamic parameter of the ship hull –

the towing resistance – the comparison is given at the table 1. Ship speed in knots is submitted in the column 1 of the table. The total ship resistance according to the report data of Krylov Shipbuilding Research Institute is in column 2. The resistance according to the report data of DMT [3] is in column 3. The specialists of Krylov Shipbuilding Research Institute in recalculation of model test results took the value of the model-ship correlation coefficient for painting of the hull submerged part with the self-polishing cladding (SPC) and the fine weather at trial. The value of the surplus coefficient is $0.09e^{-3}$. The DMT specialists in their calculations took the surplus coefficient $0.30e^{-3}$ submitted in [4], that recommended to the average trial conditions. The results of calculations, that were carried out for the full-scale trial conditions, are represented in column 3 of the table 1.

After the comparison of the results, their insignificant differences are obvious. The level of difference doesn't exceed the errors of the experiment in modern hydrodynamic laboratories that equipped with the large ship model basins. The aforementioned scheme of the hull painting has small effect on the value of total resistance.

The appearances, that attended the ship propulsion, are significantly complex. That's why the comparison looks more favorable for the numerical method. The Froude numbers are low, but the high block coefficient and unusual ratio of the principal dimensions cause the powerful turbulence and boundary layer separations. The empirical methods don't account the physical features of the certain hull flowing. At this time the opinion among specialists about capability of the empirical methods to replace the model test for the ships of the restricted navigating area is obviously mistake. This is good illustrated with the comparison of the experiment and calculation results of the total ship resistance of the RSD19 vessel by means of Holtrop-Mennen power prediction method [5]. This method is well-known nowadays in the practice of design. The results of comparison are represented at figure 8. The calculation by empirical methods even with the carefully prepared data about geometric features of the hull, allowes to determinate the total resistance of the ship only with error 35-40%.

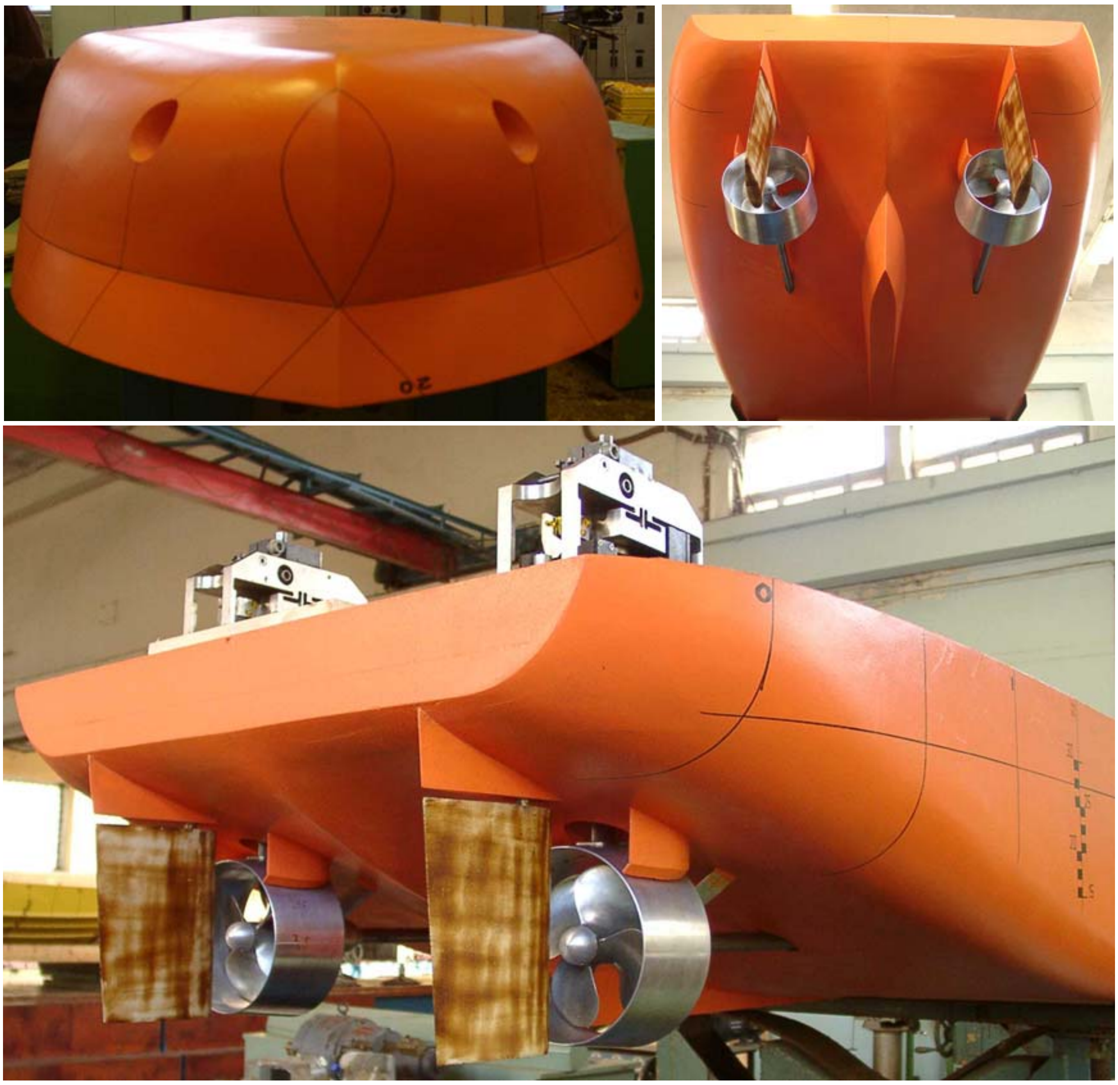

Fig. 7. Self-propelled Model Of The Ship (project RSD19) Made by Krylov Shipbuilding Research Institute.

To predict the propulsion qualities, it is necessary also to receive the coefficients of the interaction of the propellers and ship hull. The experimental solution of this problem consist of the self-propulsion tests realization. During the tests the requirement interaction coefficients are determinated with the help of the characteristics of the propeller model behind the hull model. This method is the most precise method nowadays. However, the CFD techniques permit simulation the interaction of the propeller and hull. At the first approximation the wake fraction can be determinated with the injuring of the wake distribution at the slipstream area of the propeller (fig.9), but the thrust deduction – on the base of empiric expression. Such scheme permits to carry out the prediction of the propulsion qualities of the studied ship types with the good accuracy. However, it is neglects the dependence of the interaction coefficients on the propeller load (effective interaction component). The other way of CFD computation allows to take into account these factors.

Table1

Vs, kn.	Total resistance Rt, кN		
	Krylov Shipbuilding Research Institute hull with SPC	DMT, New painted hull	DMT, Hull with SPC
1	2	3	4
8.0	75.3	74.56	72.74
9.5	107.5	111.04	108.19
10.5	137.2	138.94	137.08
11.5	179.2	177.03	176.54
12.5	234.3	234.84	229.11

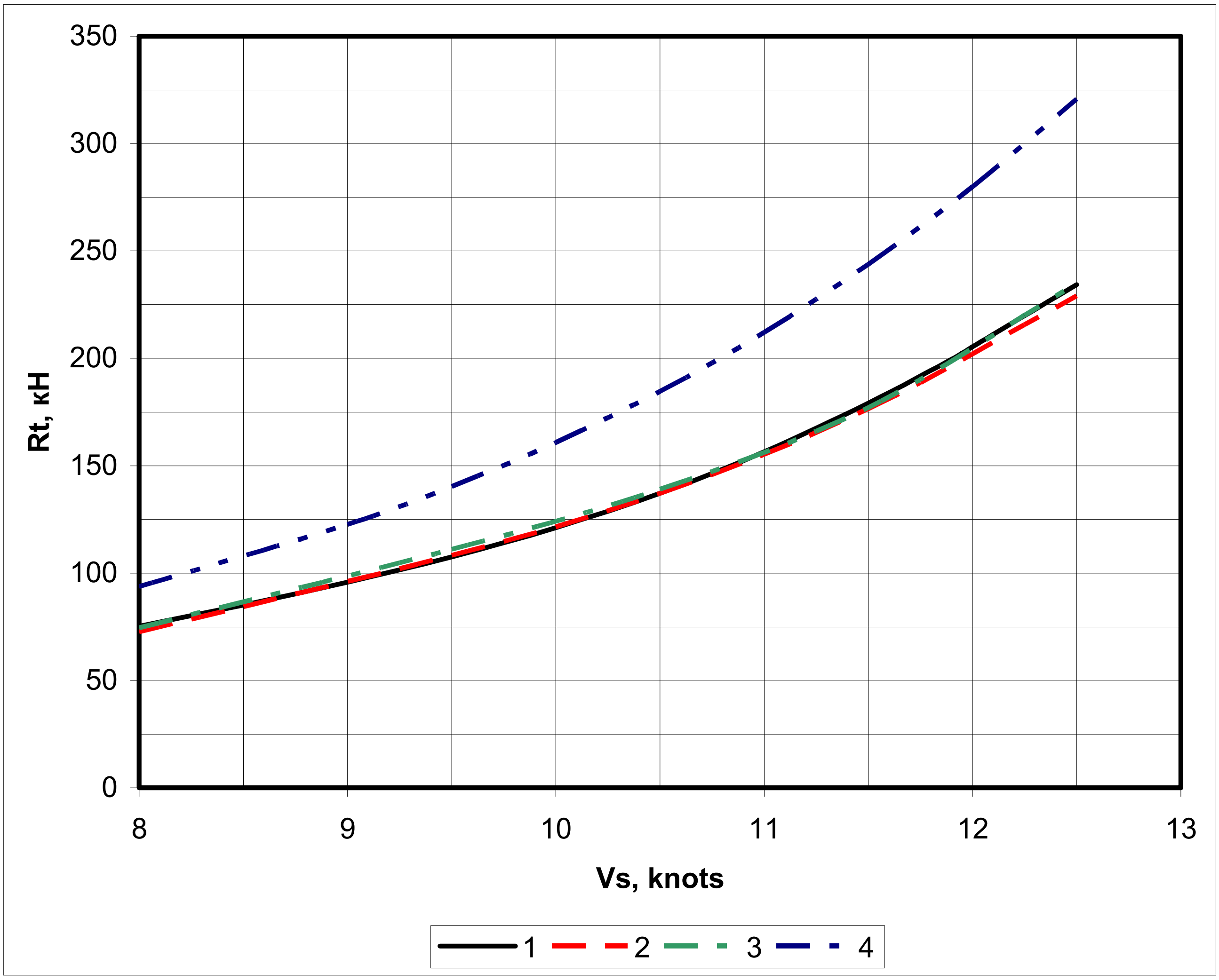

Fig. 8. Comparison Of The RSD19 Total Resistance With The Data of:
1 – model test; 2,3 – calculation with the CFD method; 4 – calculation by means of the Holtrop – Mennen method.

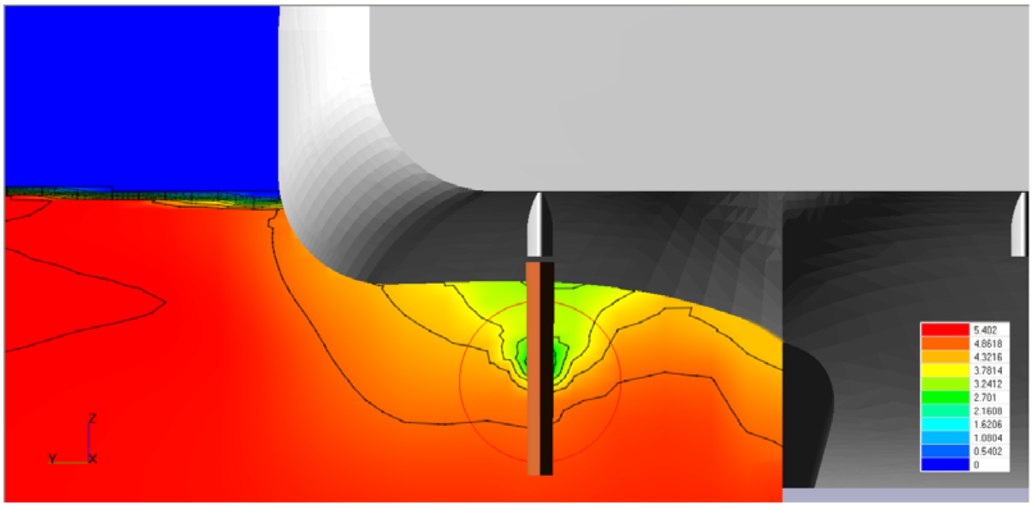

Fig. 9. The Wake Distribution

The account of the effective interaction components by the CFD methods is realizated by means of the combined calculation of the hull and propeller flowing. First flow caused by ship towing. Second flow caused by the work of propeller and created by means of simplified (fig.10,a) or exact (fig.10,b) model of the propeller. This technique is very close to the model self-propulsion tests technique. Suction force is determinated as the part of the ship resistance. The applying of the technique is accompanied with the significant complexity of the calculations, but also represents the detail information about physical features of the propulsion elements interrelation. This data is very useful for the optimization of the propulsion elements.

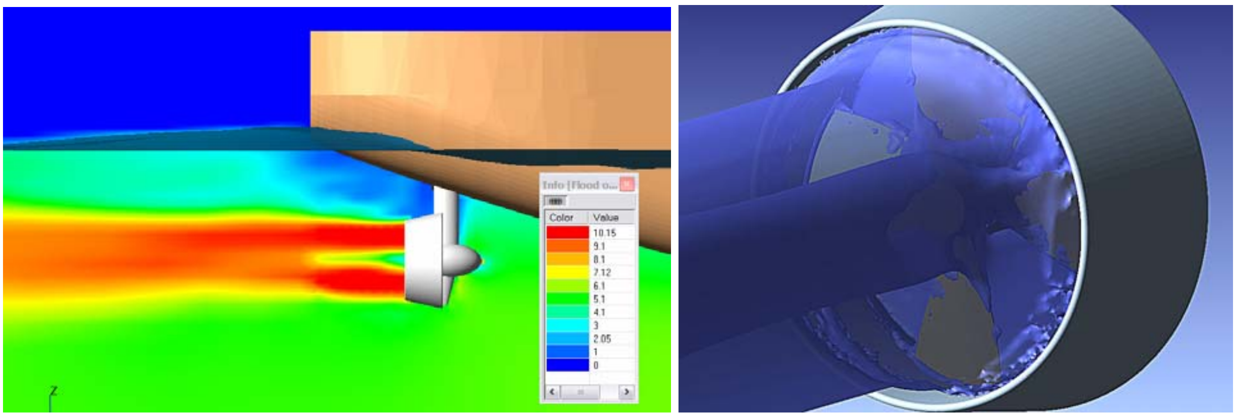

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Fig. 10. Simulation of the Propellers and the Ship Hull Interaction by means of CFD Methods: a – simplified model of ducted propellers; b – the exact model

The prognosis of speed during the trial in the equal conditions appeared identical by the model tests data and proximity calculations with using of the results of CFD towing resistance calculations in applying to RSD19 vessel. The ship speed is 11.9 knots at 85% of main engines power. The accepted reserve of main engine power is understood as the equal conditions. Pitch of the propellers is selected with the account of main engine power reserve. However, the norming of main engine power reserve for the considered ship type is the other complex problem.

The next situation is often looked out by the results of the ship operation. The ships designed with the hull strength for certain navigating area at sea with the account of set intensity of the sea roughness, can not efficiently maintain the required course and speed at these conditions in practice. This is caused by the insufficient project reserve of main engine power, because it is as a rule selected by means of the technique that accepted for the usual seagoing vessels (the “sea margin”). Such main engine power reserve might to be insufficient for the ship with restricted navigating area, the block coefficient above 0.9 and unusual ratio of the principal dimensions. This problem can not be resolved only by means of the increasing of main engine power reserve, because in good condition of operation the main engines will work on the partial regimes.

It is possibly, the applying of the controllable pitch propellers or variable pitch propeller [6], [7] is useful for the ship with the restricted navigating area.

Analyzing in general the results of hydrodynamic qualities optimization of the ship (project name RSD19) the following can be noted:

1. The combination of the propulsion elements and ship form that provided enough good ship propulsion qualities was found.
2. The applying of the “ducted propellers” permits to receive the value of the propulsion efficiency above 0.6 in full load at the full speed that is confirmed with the results of calculation and model experiments.
3. The techniques based on modern CFD methods showed the results that can be compared with the results of model tests.

It allows to consider that applying of the nowadays numerical techniques in design of the ships with restricted navigating area is very useful.

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References

1. Егоров Г.В. Выбор главных элементов сухогрузных и нефтеналивных судов смешанного «река-море» плавания // Судостроение. – 2004. - № 6. - С.10 - 16.
2. Исследование ходовых качеств сухогрузного судна проекта RSD19. – Научно-технический отчет, Выпуск № 43433. – СПб, ЦНИИ им акад. А.Н.Крылова, 2005. – 53 с.
3. Форма корпуса и ходкость судна. Проект RSD19. - Выпуск DMT – 05 – 005, 2005. – 47 с.
4. Справочник по теории корабля: В трех томах. - Том 1. Гидромеханика. Сопротивление движению судов. Судовые движители / Под ред. Я.И. Войткунского. – Л.: Судостроение, 1985. – 768 с.
5. Holtrop J., Mennen G.G.J. An Approximate Power Prediction Method // International Shipbuilding Progress. - 1982. - Vol. 29. – P.166 – 170.
6. Вишневский Л.И., Зубахин В.Ф., Сизов И.И. Особенности конструкции и перспективы применения винтов с подвижным креплением лопастей на транспортных судах // Труды международной конференции «Военно-морской флот и судостроение в современных условиях». - СПб, 1996. – С. 245 – 253.
7. Тогуняц А.Р., Печенюк А.Р., Вишневский Л.И. Совершенствование ходкости скоростных судов путем использования винтов с подвижным креплением лопастей на ступице // Труды международной конференции "FAST'2005". - СПб, 2005. – С. 521 – 526.