**Computation of perspective KRISO containership towing tests with the help of the complex of hydrodynamical analysis “Flow Vision”**

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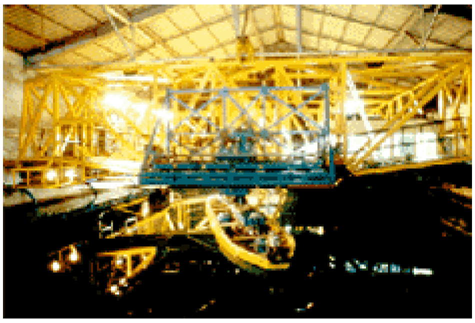
Computation of the ship hull flow with the help of complexes of hydrodynamical analysis now gets the increasing practical value in the domestic and foreign design organizations. Definition of the stream flowing near the hull of a vessel, at early stages of its designing allows solving qualitatively tasks of optimization of the hull form and configuration of the appendages; studying of operating conditions of thrusters, steering devices and bow thrusters; definition of trim of high-speed crafts; definition of engine plant power of the vessel. However, it is clear, that all aforementioned advantages of the computational fluid dynamics methods can be fully implemented only under condition of a good coordination of received results with the most reliable experimental and theoretical data.

The report is devoted to a series of calculations of perspective containership towing resistance, executed in a program complex “Flow Vision”. The ship developed in the Korea Research Institute for Ships and Ocean Engineering (KRISO). The object of studying represents the modern large cargo ship intended for transportation of containers of the international standard (TEU) on ocean lines with high operational speed. Example of existing ships of such type is m/v “Susan Maersk” (see fig. 1).


Fig. 1. Containership “Susan Maersk”

During development of the project of a vessel experimental researches in KRISO towing tank have been executed, materials of researches and three-dimensional analytical model of ship's hull have been published on a site [1] devoted to the international conference on questions of ship hydrodynamics "Gothenburg 2000", and recommended for testing program complexes of the hydrodynamical analysis in tasks of definition of towing characteristics of seagoing vessels. Indeed, the sizes and equipment of KRISO towing tank allow testing models of such sizes, which reduce influence of scale effects to a minimum, and the chosen hull form concern to the most investigated, classical type, typical for modern high-speed cargo ships. The main characteristics of the ship in full and model scale the following.



| | Full scale | Model scale |
|---|---|---|
| Length between perpendiculars $L_{bp}$ (m) | 230.0 | 7.2786 |
| Breadth B (m) | 32.2 | 1.0190 |
| Depth D (m) | 19.0 | 0.6013 |
| Draught T (m) | 10.8 | 0.3418 |
| Volume V ($m^3$) | 52030.0 | 1.6490 |
| Wetted surface area Ω ($m^2$) | 9424.0 | 9.4379 |
| Block coefficient Cb | 0.6505 | |
| Middle-frame coefficient Cm | 0.9849 | |
| Longitudinal centre of buoyancy LCB (%), afore «+» | -1.48 | |
| Scale factor | 31.5994 : 1.0000 | |

According to the technique of carrying out of model tests accepted now, in towing tank dimensionless dependence of residual resistance coefficient of model on its relative speed – Froude number (see fig. 2) is determined. Such dependence can be received as follows. From the value of total resistance measured during model tests for every speed, subtract frictional resistance of equivalent technically smooth flat plate which area of a surface is equal to the area of wetted surface of model. The result - residual resistance - then will be transformed to dimensionless coefficient of residual resistance under the formula:

$$C_r = \frac{R_o}{0.5 \cdot \rho \cdot v^2 \cdot \Omega},$$

where: $R_o$ - residual resistance, N;

$\rho$ - density of water in towing tank, kg/m$^3$;

$v$ - speed of the model, m/s;

$\Omega$ - wetted surface area of the model, m$^2$.

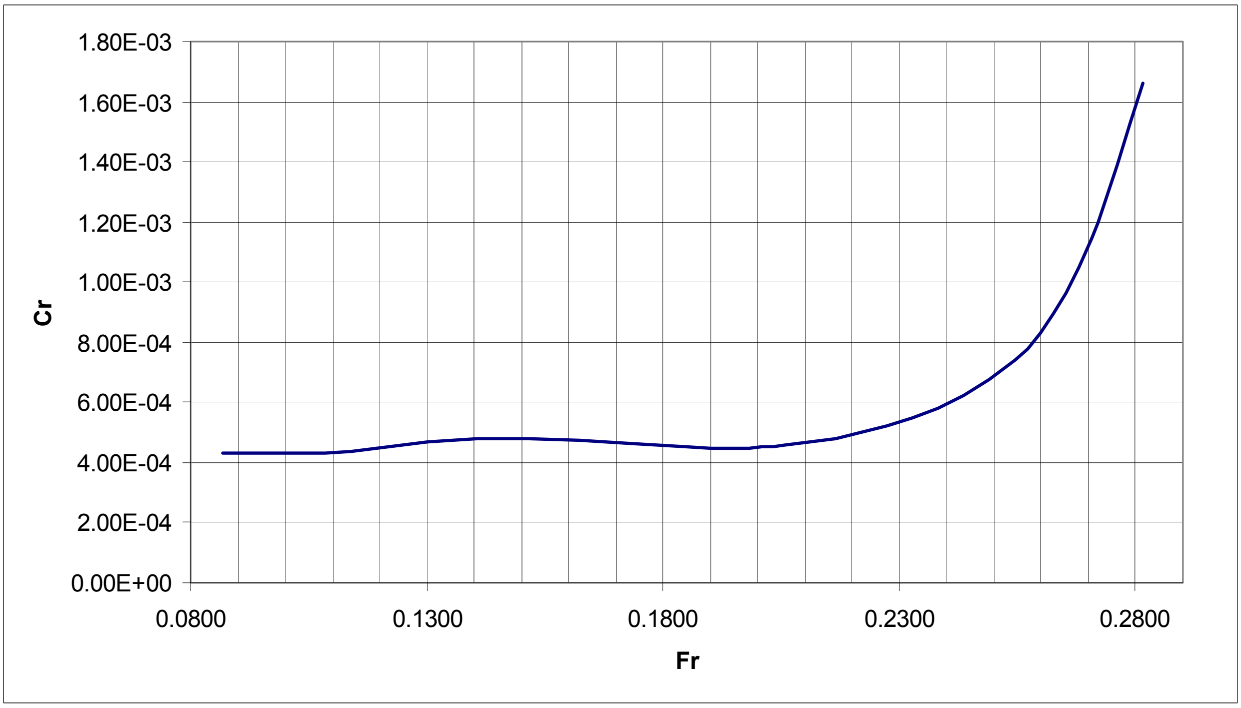



Fig. 2. Experimental dependence of residual resistance coefficient on Froude number

Let's notice, that experimental dependence of residual resistance coefficient on Froude number is considered equal for model scale and full scale and represents itself dependence of the resistance forces which are not connected with any scale effects, on speed of movement of a vessel. For definition of dependence of total resistance in full scale from speed, it is necessary to execute recalculation in view of frictional resistance, calculated according to Reynolds numbers describing a regime of flow in a boundary layer of the vessel, by the following method.

Total resistance force can be calculated under the formula: $R = C_t \dfrac{\rho \cdot v^2}{2} \cdot \Omega$.

Total resistance coefficient represents the sum: $C_t = C_r + C_f + \varsigma$,

where: $C_r$ - residual resistance coefficient;

$C_f$ - coefficient of frictional resistance of equivalent plate;

$\varsigma$ - correlation coefficient, according to recommendations [3] $\varsigma = 0.1 \cdot 10^{-3}$.

The frictional resistance coefficient of an equivalent plate is recommended to calculate under well-known Prandtl – Schlichting formula: $C_f = \dfrac{0.455}{(\lg \mathrm{Re})^{2.58}}$.

Further, at comparison of the experimental and computational data, "dimensional" dependences of hull resistance on speed - direct full scale results of “Flow Vision” calculations and results of recalculation of model experiment, and also "dimensionless" - direct results of model experiment (fig. 2) and results of inverse recalculation of “Flow Vision” calculation results are compared.

During the preparation of numerical “Flow Vision” calculations, the primary purpose was observance of the conditions, allowing executing adequate comparison of results of calculation and experiment. Taking into account problems of preparation of calculations in model scale connected with scale effects and assignment of initial turbulence parameters of a stream, more simple and reliable way to calculate resistance of a vessel in complex “Flow Vision” is executing calculation in full scale.

Calculations are executed in hexahedral computational domain for the half of the vessel symmetric to its centre line; a method of the inversion of a stream is applied. The sizes of computational domain are chosen in view of recommendations on test of ship models in the towing tanks establishing allowable relations of the cross-section sizes of model and a pit of towing tank at which absence of essential influence of walls on results of tests is guaranteed. The general view of computational domain with model of the vessel and the notation of boundary conditions types on its walls is represented in figure 3 (the top side with a symmetry condition is not shown). On the model of the vessel the boundary condition of a wall with the logarithmic law for speed is established.

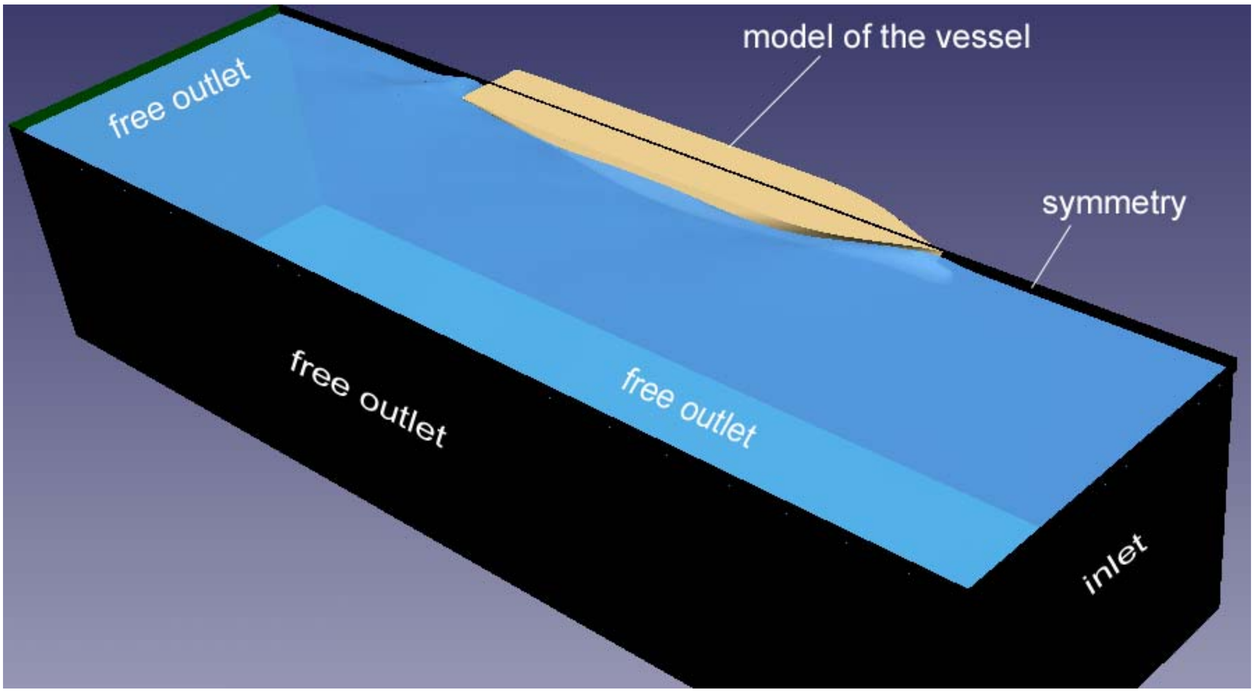



Fig. 3. A general view of computational domain with model of the vessel

In the computational domain the model of flow with a free surface is established, undisturbed level of liquid, inlet velocity of liquid both other physical values and constants necessary for correct functioning of computational model is set. Thus, as well as in conditions of experiment, as a liquid, flowing round a vessel, fresh pure water is accepted. The model of flow with a free surface is realized in the complex “Flow Vision” based on model of an incompressible fluid and includes the following hydrodynamical equations (according to [4]).

Navier-Stokes equation in view of turbulent viscosity in the form suggested by Reynolds:

$$\frac{\partial V}{\partial t} + \nabla(V \otimes V) = -\frac{\nabla P}{\rho} + \frac{1}{\rho}\nabla\left((\mu + \mu_t)\left(\nabla V + (\nabla V)^T\right)\right)$$

The equation of continuity:

$$\nabla V = 0$$

Expression for turbulent viscosity in κ - ε model of turbulence:

$$\mu_t = C_\mu \rho \frac{\kappa^2}{\varepsilon} f_\mu$$

Expressions for turbulent energy κ and its dissipation parameter ε:

$$\frac{\partial \kappa}{\partial t} + \nabla(V\kappa) = \frac{1}{\rho}\nabla\left(\left(\mu + \frac{\mu_t}{\sigma_\kappa}\right)\nabla k\right) + \frac{G}{\rho} - (\varepsilon - \varepsilon_{ini}) - F$$

$$\frac{\partial \varepsilon}{\partial t} + \nabla(V\varepsilon) = \frac{1}{\rho}\nabla\left(\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\nabla \varepsilon\right) + \frac{\varepsilon}{\kappa}\left(C_1\frac{G}{\rho} - C_2 f_1(\varepsilon - \varepsilon_{ini})\right), \text{ where:}$$

$\varepsilon_{ini}$ - Initial value of parameter (speed) of turbulent energy dissipation;

$G = \mu_{eff} \frac{\partial V_i}{\partial x_j}\left(\frac{\partial V_i}{\partial x_j} + \frac{\partial V_j}{\partial x_i}\right)$;

$\sigma_\kappa = 1$, $\sigma_\varepsilon = 1$, $C_\mu = 0.09$, $C_1 = 1.44$, $C_2 = 1.92$ - empirical parameters of model.

Recognizing that at a flow of the full-scale vessel Reynolds numbers reach great values, in computational domain the standard model of turbulence, according to which has been accepted:

$$\mu_{eff} = \mu + \mu_t,\ f_1 = 1,\ f_\mu = 1,\ F = 0.$$

In the accepted model the fluctuations of a free surface are traced with the help of variable VoF (Volume of Fluid) which in the equations is designated by letter F. In the areas completely occupied with a liquid, value of this variable is equal to “one”, in the areas completely occupied with gas, - to “zero”. On boundary of separation of two phases in each calculated cell the fraction of the volume occupied with a liquid and gas is defined. The free surface in this case corresponds to value of variable F = 0.5. Convection equation for function F:

$$\frac{\partial F}{\partial t} + V\nabla F = 0$$

The computational grid was formed on the basis of initial rough partition of computational domain with the subsequent automatic adaptive refinement of the first level on a surface of the hull. The complex “Flow Vision” allows to create a hexahedral computational grid, high quality resolution of geometry is reached with the help of sub-grid resolution technology and adaptive local refinement on boundary conditions. The initial grid is generated in view of the form of model of the hull, necessity to provide high density of a grid in area of a free surface, conditions of ship waves damping at distant borders of computational domain and many other factors (fig. 4).

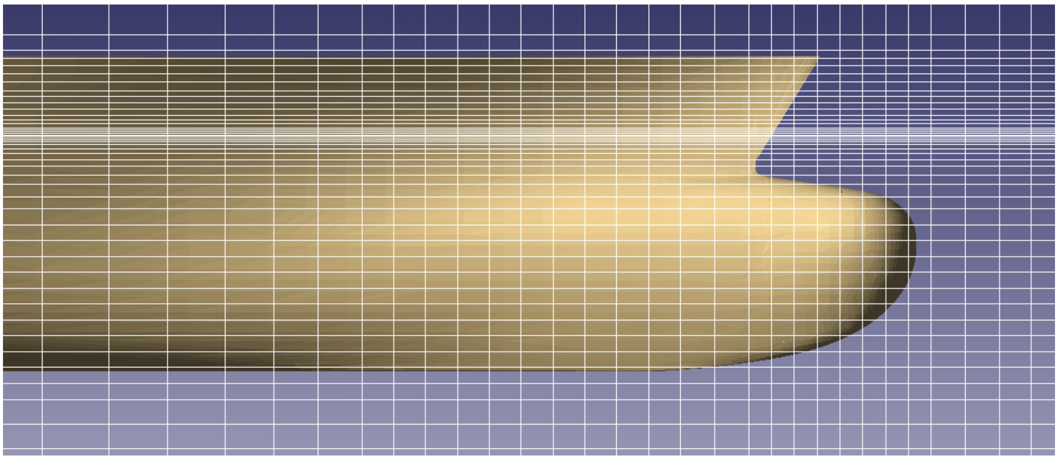


Fig. 4. Initial computational grid

Important point by preparation of calculations also appeared a choice of the fixed or free model of the vessel. When the moving model is fixed changes of trim due to action of hydrodynamical forces are not taken into account, the vessel is flowed round as an immoveable body. At assignment of displacement of the vessel, its moment of inertia around a transverse horizontal axis, and also degrees of freedom along a vertical axis and rotation around of a transverse horizontal axis the model becomes "free", that is can change the trim under action of hydrodynamical forces that is reflected in force of resistance if movement is realized with enough high relative speed. As tests of ship models in towing tanks carry out in a "free" mode, this mode is more preferable for using in calculations. However, in practice taking into account of degrees of freedom essentially complicates a computational variant and demands high charges of computer resources. For check of influence of changes of trim on force of resistance, some calculations for a designed speed of the vessel of 24 knots have been executed, particularly: calculation with the fixed model with zero immersion and trim; calculation with the fixed model with values of immersing and trim, measured during model tests; calculation with the appointed degrees of freedom. Results of all three calculations have not shown essential distinctions of resistance force of the vessel, obviously, in view of small changes of trim in the considered speed regime.

Let's consider results of calculations in comparison to the data of experiment in the dimensionless form, as dependence of residual resistance coefficient on Froude number (fig. 5).

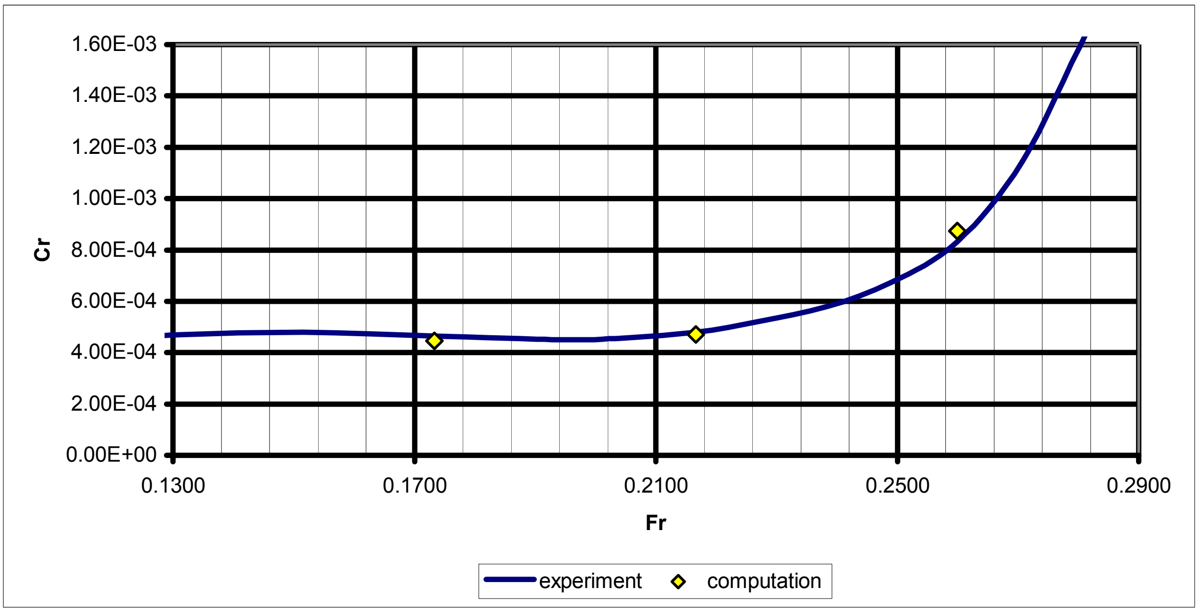



Fig. 5

In figure 6 results of numerical calculations and experiment in the dimensional form, as dependence of total resistance of the vessel on its speed are submitted. For comparison in figure results of resistance calculation with the help of empirical Holtrop – Mennen method [7] which frequently apply to an estimation of resistance of cargo ships on early design stages also are submitted.


Fig. 6

Let's consider comparison of some physical pictures of a flow of the ship hull, received experimentally and as a result of computation.

Wave profile at speed 24 knots (Fr = 0.26) - fig. 7

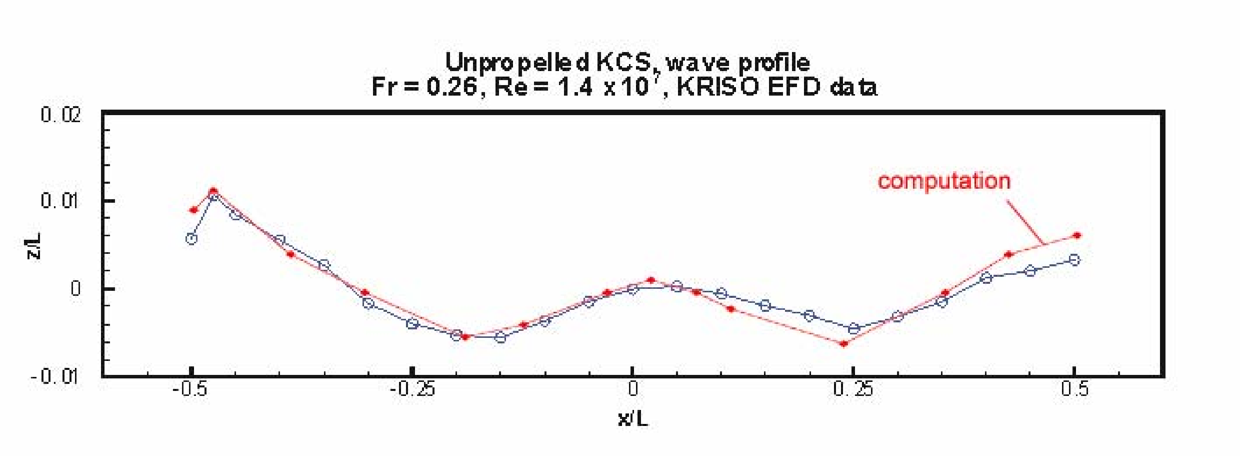



Fig. 7

General wave pattern of the vessel at speed 24 knots (Fr = 0.26) - fig. 8

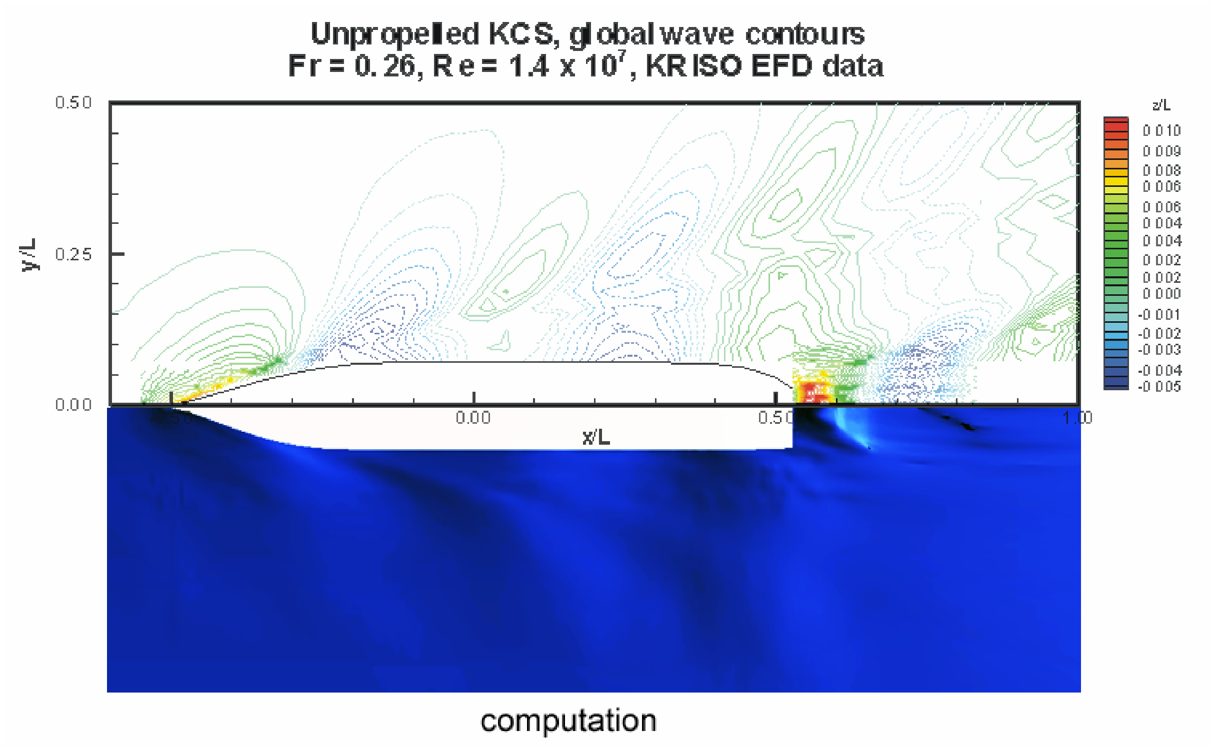



Fig. 8

It is necessary to note, that computation of ship hull flow allows to receive much more full visual information on characteristics of a stream, than experiment even in the most modern and well equipped research centers. Therefore besides those pictures of a flow which above mentioned for comparison to experiment, we should consider as examples some other concerning which experimental data are absent.

Distribution of dynamic pressure (minus hydrostatic) on the hull surface at speed 24 knots (Fr = 0.26) - fig. 9.

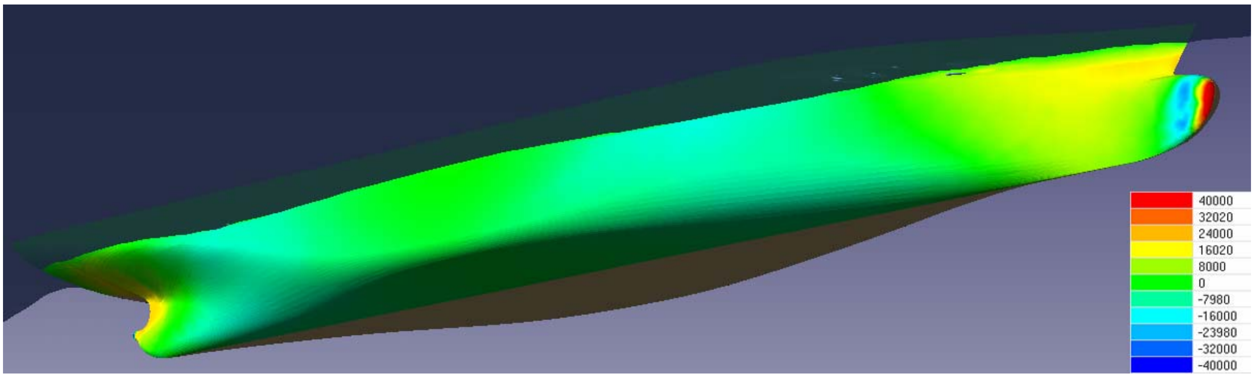



Fig. 9

Streamlines on a hull surface at speed 24 knots (Fr = 0.26) - fig. 10.

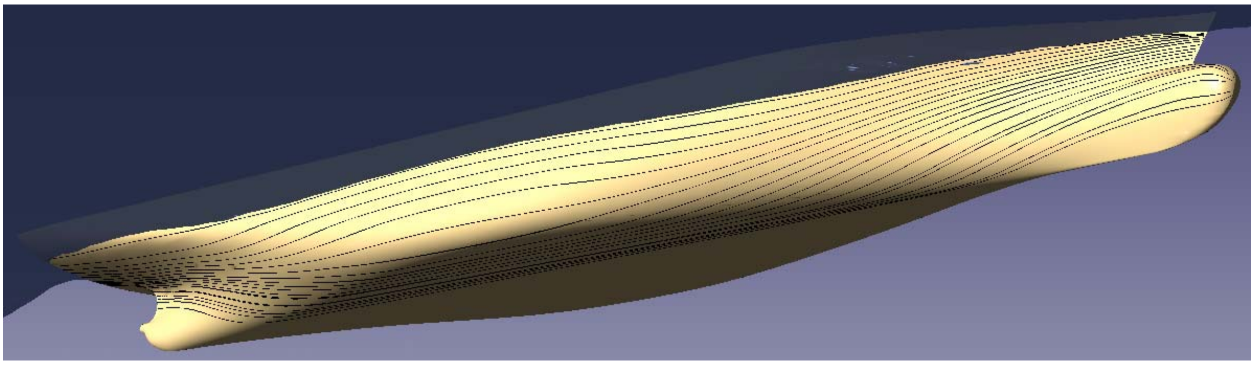


Fig. 10

The perspective view of free surface from aft viewpoint at speed 24 knots (Fr = 0.26) - fig. 11.

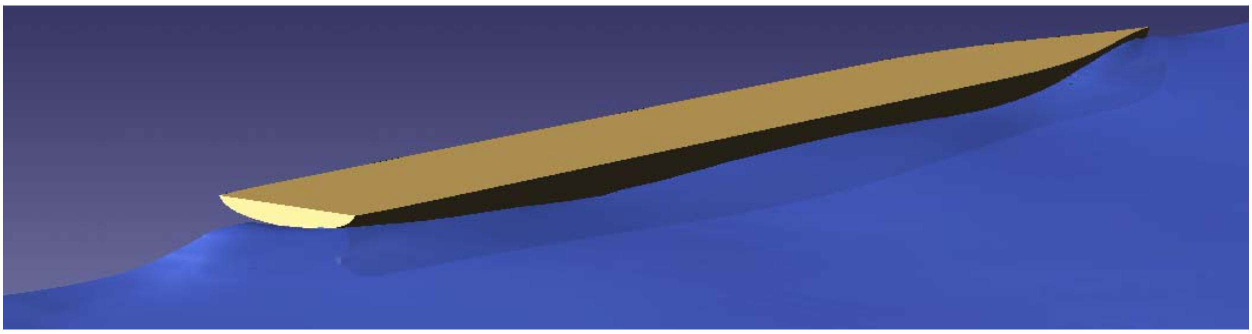


Fig. 11

The perspective view of free surface from fore viewpoint at speed 24 knots (Fr = 0.26) - fig. 12.

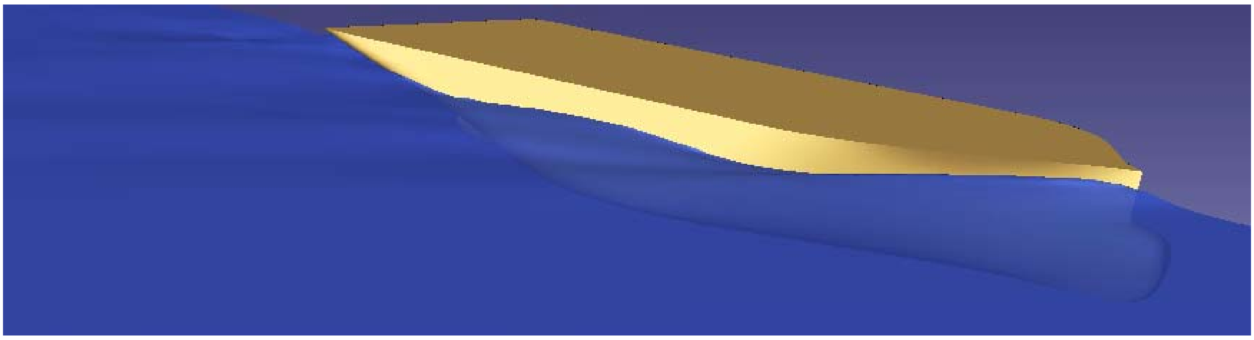


Fig. 12

**References**


1. http://www.nmri.go.jp/cfd/cfdws05/gothenburg2000/KCS/container.html
2. А.М. Басин, В.Н. Анфимов. Гидродинамика судна. Л.: Речной транспорт, 1961.
3. Справочник по теории корабля: В трех томах. Том 1. Гидромеханика. Сопротивление движению судов. Судовые движители/ Под ред. Я.И. Войткунского. Л.: Судостроение, 1985.
4. Система моделирования движения жидкости и газа FlowVision. Руководство пользователя. Москва, ООО «ТЕСИС», 2001.
5. П.А. Апухтин, Я.И. Войткунский. Сопротивление воды движению судов. Л.: МАШГИЗ, 1953.
6. H. Schneekluth and V. Bertram. Ship Design for Efficiency and Economy. Butterworth und Heinemann. Second Edition. 1998.
7. Holtrop J., Mennen G.G.J. An Approximate Power Prediction Method. ISP, Vol. 29, No. 335, 1982.
8. А.А. Костюков. Сопротивление воды движению судов. Л.: Судостроение, 1966.