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# Optimisation of ship hydrodynamic design

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*Abstract*

The paper deals with applications of modern computer-aided hull design methods that are improving the hydrodynamic qualities at the initial stages of ship design.

The CAE/CAD system was developed for the purpose of integrating the general design models, models for physical studies and ship model data on the basis of unified dialogue computer techniques of solving optimisation problems.

A priori it is supposed that the selection of the ship main particulars is fulfilled.

Hydrodynamic hull-form fairing is based on a mathematical model, which suggests the description of a ship hull lines by using the frame- construction representation.

The studies of the hull form obtained in the multicriteria's formulation are made from computations of wave, residual and total resistance, seakeeping parameters, statics, hydrodynamic characteristics of flow and economic justification results of design.

The mathematical optimisation method is based on the original "Base point method " intended for solving the non-linear programming task. This method allows to reduce considerably the number of calculations of the objective functions during the solving process in comparison with other methods.

Applications presented gives insight into hydrodynamics parameters that are validated against recent experimental data for high-speed vessels.

The program– methodology complex is used to compare different variants of hull shapes, for improving hull form of prototype, and also for solving the hydrodynamic optimisation problem of theoretical fairing of ship hull.

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## *Formulation of the design problem model*

Here the results of using the dialogue optimisation methods proposed in the work [6], [7] are presented which are comformed to the ship surface form on the stage of design decisions that reckon on realisation of multicriteria's problems.

Let us formulate the task of searching the design solution that would be optimal by several criteria. Let it is required to achieve an optimum of some F convolution of f function on criterion's multitude v = 1,...,M. Now decision depends on three vectors X ,B .

$X = \{x_j\}, \quad j = 1, \ldots, J$ – vector of independent controlled variables (parameters); in the case of hull form optimisation such variables are the parameters, which describe the ship surface in accordance with its mathematical model and allow uniquely to obtain ordinates of the ship surface.

$B = \{b_q\}, \quad q = 1, \ldots, Q$ is a vector of initial data or, in another terminology, a vector of external environment ( uncontrolled variables (parameters); in our case - operation conditions (speed of ship, water salinity, ...).

With account of above mentioned the formalised statement of the design problem may appear as follows:

$F = \{f_v(X, B), \quad v = 1, \ldots, M\} \rightarrow extr(min)$

$G = \{g_s(X, B) - b_s; \quad s = 1, \ldots, S\} \geq 0;$

where

M – the number of indexes-criteria under consideration in this design problem;

S – number of limit indexes;

G – limitations for the area of design solutions that is described in Q-dimensional space. This vector sets up a numerical limitation in normalised form ( for example, the ship obtained as a result of problem solution must possess enough stability - the co-ordinate of metacenter $Z_m^{(X)} - Z_m^g \geq 0$; the requirements for allocation of propulsion plant and transported cargo must be fulfilled: $Y^{o(X)} - Y^g \geq 0, \ldots$; etc.

In this problem one of criteria $f_v$ may be a ship resistance.

The method of investigating the solution of multicriteria's design problem is based on scanning of independent variable's quantity space [6].

Principal feature of proposed method lies in the fact that a designer is presented with a possibility of systematic viewing of multidimensional areas of changing the parameters he is interested in.

As a result of scanning the task variable's area, a relational data base is formed. It has the following columns: $r = 1, \ldots, R$;

$R, X^{(r)}, F^{(r)}, G^{(r)}$;

At the first stage not permitted solutions are excluded from the total set of solutions obtained as a result of multicriteria's optimisation. ( For example, from the general point of view, removing the abscissa buoyancy centre

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to bow is unfavourable for allocation of engine room, essential reduction of z-co-ordinate of metacenter is not permitted according to the stability criterion). Then exclusion of the solutions that are losing along the multitude of criteria is provided.

Thereby, the optimal Pareto set is extracted from the whole solution sets, and designer selects the most suitable solution.

## *CAE/CAD system program units*

*Input* unit checks the geometric features of the hull form and stability and has some freedom to change the design to eliminate any problems found. The resulting design and intermediate steps are still constrained to lie within the limits originally specified by the user.

Corresponding mathematical model of ship lines generation allows to generate and manipulate by lines of any ship types, including hydrofoils . *Hull geometry* unit gives each minimum is associated with a set of parameters that represent a potentially optimum hull design.

There were developed the algorithms ensuring the prohibition of Y(x,z) variations. As a result of task solution, there is formed a mathematical model of ship lines ( theoretical ship lines, table of ordinate's model ) of optimal form.

The designer is obtained not only in sought for solution itself, but the neighbourhood ( selection from a few best designs for the further consideration in order of merit ) of the parameters under variation due to initial data or task conditions . The system allows the user to choose a near optimum design for reasons of personal preference ( such as resistance characteristics, static's parameters, parameters of flow around body, economic and other criteria).

The basis of *optimisation* unit is formed by special "Base Point" method [5], which is intended for solution of non-linear programming problems. This method allows to reduce considerably the number of calculations of goal-functions during the solution of problem compared with other methods. The last reason gives an opportunity of solving optimisation problem of hydrodynamically flow parameters and ship geometry for investigation and practical design.

*Criterion's* unit performs database of calculation techniques [8] including:

**a). Resistance criteria**

The package is equally applicable to conventional and high-speed displacement vessels. The package has been extensively developed last decade.

At present there are several methods allows the ship designer to achieve a specified set of resistance for targets' ships, to predict wave resistance or residual resistance for given ship forms and ship speeds, which may be classified as follows:

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- the methods of estimation on the basis of comparison of the resistance characteristics of type ships;
- the methods of estimation by charts derived from systematic series test results for wide range of conventional and high-speed planing ships;
- the methods of estimation by regression formulae based on tank test results of various ship forms ;
- the methods of estimation based on theoretical calculation of resistance.

The actual resistance of each design is computed using the programs for conventional and high-speed vessels. The wave resistance is the most cumbersome in calculations. Due to interactive character of optimisation method such calculations would be carried out repeatedly. The calculation Rw for conventional ships is based on introduction of correction factors into integrals of linear theory, which are not connected with some concrete ship hull form. They are based on calculation results of two-dimensional non- linear wave deformations, and method of "limitation of amplitudes". Calculation method for Rw is described in [1], [3].

**b). Flow criteria**

Principal difficulty of optimisation of hull forms is in the opportunity of sharp increase of viscous resistance while ship surface variations are relatively small and inessential for wave resistance [4].

Such changings may lead to separation of boundary layer on the hull. A number of criteria that characterise a flow along ship board have been gained:

- minimum and maximum values of pressure coefficient in bow and stern ends of ship;
- values of transverse ( longitudinal ) pressure gradients at the level of the screw propeller axis in the stern end of ship.

Designer calculates the potential flow and boundary layer development around a ship, including the free surface, using a panel method and integral boundary layer scheme to perform the hydrodynamic analysis to optimise its hydrodynamic performance with regard to viscous resistance.

Results are listed in a temporary database file in report form by the program, may be transfer by **interface** unit to AUTOCAD system.

## *Numeric simulation and resistance test results*

As a demonstration, the design of ferry ship has been examined. Figures 1 and 2 show approximate body plans generated for this ship ( initial I and optimised II variant ) and tables show the main particulars and hull form parameters used. The investigation will be carried out at the condition that the main dimensions were selected and now have the following values: length between perpendiculars Lpp =127.4 m, design width B=21.5 m, design draught T = 7.5 m, coefficient of displacement Cb= 0.71. The principal ship dimensions have not been changed. The significant changes are the forward shift of the centre of gravity the increases in the forward waterplane area coefficient, see Table 1. The investigated range of Fr number is 0.20 - 0.23. Obtained numerical and graphical results demonstrate the advisability of the following changes of the ship hull that positively effect on the ship resistance, see Table 2. In Table 3 there are represented an extreme value of pressure coefficient on the ship surface of investigated ship.

The resistance tests were performed at Krylov Research Shipbuilding Institute, the lengths of models are Lpp = 4.9 m. The three tests of initial and optimised variant at the full, ballast ( trimming aft), overload ( trimming aft ) draughts were performed. Diagrams of residual coefficient at first test are shown in figure 3, second and third tests on figure 4.

From these tests clearly the resistance was be decreased at all load condition. All have a better resistance than the original initial ship. That result demonstrates considerable effect may be reached by co-ordinated decision of multicriteria's problem.

## *Conclusion*

This report is devoted to the brief description of setting up and solving the hydrodynamic optimisation problem of theoretical fairing of the ship hull form based on the program-methodology complex. The structure and software of this complex are the result of long-standing research activity in CAD sphere [1], [2], [3].

Hydrodynamic criteria were tested during last 10 years in more than 30 perspective ship design. In most cases optimisation process resulted in improvement of ship hydrodynamic ( propulsive ) characteristics.

Authors' experience with a number of projects showed that the ship hull optimisation according to the ship resistance may lead to considerable improvement of design and hydrodynamics characteristics. As the experiments of a number of optimised variants showed, the speed under constant power is increased as 0.3-0.5 knots.

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**Table 1. Characteristics of variants.**

| | Variant of ship | | I | II |
|---|---|---|---|---|
| 1. | Ship displacement, $m^3$ | V | 14637. | 14546. |
| 2. | Abscissa CB, m | Lcb | -0.05 | 0.07 |
| 3. | Block coefficient | Cb | 0.7125 | 0.7081 |
| 4. | Waterplane area coefficient | Cwl | 0.7698 | 0.8098 |
| 5. | Wetted surface, $m^2$ | S | 3632. | 3620. |
| 6. | Applicate of metacenter, m | Zm | 8.93 | 8.91 |

**Table 2. Theoretical coefficient of residual resistance** $[Cr + Ca]10^3$

| | Fr | Vs,knots | I | II |
|---|---|---|---|---|
| 1. | 0.15 | 10.32 | 1.11 | 1.11 |
| 2. | 0.17 | 11.69 | 1.17 | 1.14 |
| 3. | 0.19 | 13.07 | 1.26 | 1.19 |
| 4. | 0.21 | 14.44 | 1.45 | 1.28 |
| 5. | 0.23 | 15.82 | 1.71 | 1.54 |
| 6. | 0.25 | 17.19 | 2.17 | 1.93 |

Correlation allowance $Ca = 0.45 * 10^3$

**Table 3. Minimum calculated values of pressure coefficient in stern and bow**

| Variant | Stern | Bow |
|---|---|---|
| I | -0.1951 | -0.1619 |
| II | -0.1779 | -0.1416 |

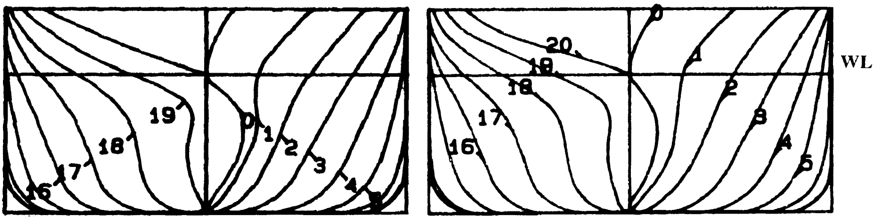


**Figure 1, 2: Hull form of initial and optimised variant.**

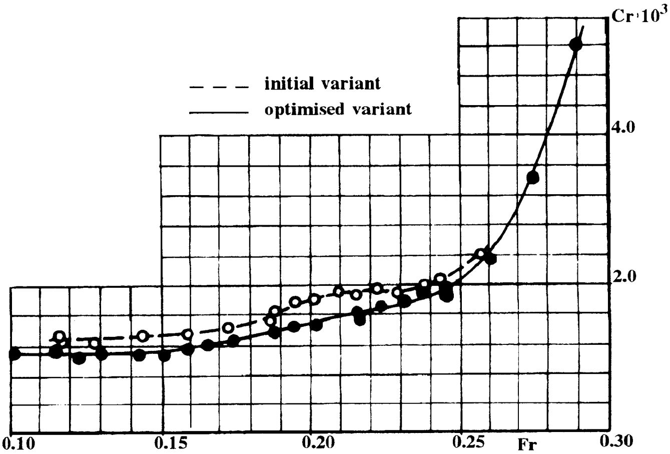


**Figure 3: Coefficient of residual resistance at full load draught.**

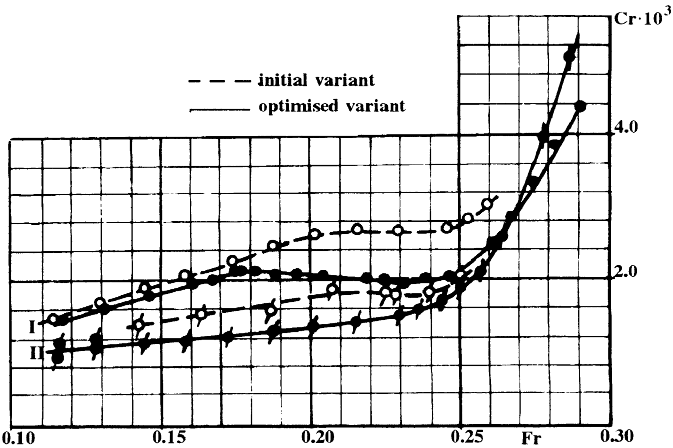


**Figure 4: Coefficient of residual resistance at ballast (I) and overload(II).**