CREATION OF A COMPOSITE SUPERSTRUCTURE FOR A PASSENGER HYDROFOIL VESSEL

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ABSTRACT

The report considers the principles of creating a composite superstructure for a passenger hydrofoil vessel. To ensure the required efficiency characteristics, a passenger hydrofoil vessel must have the highest ratio between its payload and gross vehicle weight (GVW). Designing the superstructure is inextricably related to the vessel design as a whole. We consider the characteristic features of the mass load development of a passenger hydrofoil vessel using a single hydrodynamic model. We examine the design model for ensuring the strength of the composite superstructure of a passenger hydrofoil. Moreover, we look at the principles of preparing a finite element model of the composite superstructure.

INTRODUCTION

The report was prepared according to the results of applied research carried out by Bauman Moscow State Technical University under the subsidy-granted agreement no. 14.577.21.0103 with the Ministry of Education and Science of the Russian Federation. (Unique identifier of applied research (project) RFMEFI57714X0103) within the Federal Target Program "Research and development on priority directions of the Russian scientific and technological complex for the period of 2014 - 2020".
The report examines the design rationale of the composite superstructure for a passenger hydrofoil vessel (HFV).

PROBLEM STATEMENT

To expand the capabilities of creating the domestic passenger HFV with superstructures made of composites (Fig. 1, right), it is now necessary to solve a number of problems, in terms of improving the design characteristics of ships of this type and their optimization, as well as improving the structure of the entire process design.
It is necessary to develop methods of design rationale of superstructures in passenger HFV, taking into account the various aspects of their further exploitation and ensuring the competitiveness of ships of this type.

Efficiency criteria of the high-speed passenger vessel are associated with the production model of its application. The basis of selection criteria are economic indicators that determine the revenue and expenditure of the operational characteristics of the vessel. It is known that the operating return of a high-speed vessel greatly depends on its power, payload and capacity. The operating return (OR) of the ship can be represented as:

$$OR = f(W, DW) + \varphi(N) \qquad (1)$$

As a rule, the value of the operating return in a competitive market is bounded from above. Therefore, improving the operational efficiency of the high-speed vessel, primarily is due to the decrease in its operating costs.
Economic parameters determining the operating costs, can be considered as the total operating costs and deductions established by law paid by the shipowner:

- fuel costs;
- the crew costs;
- taxes and fees, depending on the characteristics (capacity, power, length) of the vessel;
- deductions, depending on the construction cost of the vessel.

The main ship operation expense items depend on its main dimensions and power. Expendable components of the ship operation can be represented as:

$$P = \sum_{i=1}^{n} p, \; f(\delta, L, B, T, H) + p_j N \to \min \qquad (2)$$

Construction cost of the vessel, in its turn, also depends on its main dimensions and capacity:

$$C=\sum_{i=1}^{m} q,\ f(\delta, L, B, T, H)+q_j N \rightarrow \min \qquad (3)$$

The criteria for determining the efficiency of high-speed vessels, which use their integrated expendable characteristics, including specific fuel consumption of the primary motors, their power, the total weight, speed, as well as characteristics of the payload are shown in [8]. These criteria can be fully applied to the passenger HFV.

The condition of high-speed passenger vessel optimization, including the passenger HFV, is reduced to minimization of its expendable characteristics under given constraints. Principles for enhancing the performance characteristics of a high-speed passenger vessel by increasing its payload, implemented at the design stage, which can be also fully applied to the passenger HFV, are given in [8, 9].

To ensure the required efficiency characteristics, the passenger HFV should have the highest ratio between its payload and GVW
:

$$\eta=\frac{DW}{D} \rightarrow \max \qquad (4)$$

The passenger HFV deadweight can be represented as the difference between the total weight of the ship and light-ship displacement (the empty weight of the vessel):

$$\eta=\frac{D-D_{nop}}{D} \rightarrow \max \qquad (5)$$

$$\eta=1-\frac{D_{nop}}{D} \rightarrow \max \qquad (6)$$

$$\frac{D_{nop}}{D} \rightarrow \min \qquad (7)$$

A number of restrictions relating to the passenger HFV operating conditions and its performance are imposed on the condition of minimizing such a criterion as the total fuel consumption of passenger HFV [8].

The main components of light-ship displacement for the passenger HFV will be the following:

$$D_{lsd}=P_{hull}+P_{\text{eq.}}+P_{pp}+P_{hu}+P_{psu}+P_{el.eq.}+\sum_{j=1}^{m} P_j \qquad (8)$$

where P_{hull} - hull mass;
$P_{об}$ - equipment mass ;
P_{pp} - power plant mass;
P_{hu} –hydrofoil unit mass ;
P_{psu} - propulsion/steering unit mass;
$P_{el.eq.}$ - electrical equipment mass;
ΣP_j - sum of masses of all the other light-ship displacement items, as a rule not exceeding 3-5% out of the total sum.

The main deadweight (payload) components for the passenger HFV will be the crew and passengers mass, as well as the fuel supply, which to a large extent, determines consumer qualities of the vessel of such type. Then:

$$DW=P_{pass}+P_{fuel}+\sum_{g=1}^{k} P_g \qquad (9)$$

where P_{pass} – crew and passengers mass;
P_{fuel} – fuel mass;
ΣP_g – mass of all the other items of the deadweight, as a rule not exceeding 3-5% out of the total sum. [2, 6].

It is known that the passenger hydrofoil vessel, like any other ship, is a system consisting of subsystems. On the first level of decomposition HFV is considered as a set of subsystems indicated by their function, such as "Hull", "Hydrodynamic unit" and others. The "HFV hull" subsystem is dominant in relation to all other vessel subsystems. The properties of the "HFV hull" subsystem are defined at the vessel decomposition stage as systems. It should be noted that since the "HFV hull" subsystem is, as mentioned above, the dominant one in the "Hydrofoil Vessel" system, its properties, to the greatest extent, determine the vessel qualities.

The composite superstructure is included into the "HFV hull" subsystem as a subsystem of the second level and as such should be considered in the optimization process. Therefore, to detail the properties of the superstructure, the "HFV hull" subsystem should be decomposed into separate subsystems, one of which is the "Superstructure" subsystem. At the same time, at the decomposition stage the boundary conditions of the "Superstructure" subsystem are determined, and the connections by which this subsystem interacts with the "HFV hull" subsystem are determined as well. Thus, the composite superstructure design optimization is directly related to the optimization of the passenger HFV [9].

In the analysis of the equations (5-9) with the fixed size of the passenger HFV (L, B, H = const) the condition for the minimum light-ship displacement (the empty weight of the vessel) is determined. It is provided by minimizing the hull and composite superstructure mass if other mass loading items are equal. This condition is imposed by the necessity of ensuring the vessel and superstructure strength and durability characteristics.

$$P_\kappa \rightarrow \min \tag{10}$$

This report considers the principles of increasing high-speed passenger vessel payload by using large composite elements in its construction. This is implemented at the design stage and can be fully applied to the passenger HFV [9].

SOLUTION

The main design features of the passenger HFV are identified by the structural and parametric design using a standard sized set. This work considers the principles of high-speed vessel parametric design of [7].

Designing the composite superstructure for a passenger HFV, as an element of the vessel, is closely connected with designing the vessel itself. Thus, passenger HFV optimization is made according to the criteria of economic efficiency.

The physical model of the method for the passenger HFV structural and parametric designing is a semblance of aerodynamic and hydrodynamic processes on the movement design in a single construction of the entire vessel. For the HFV is in the first place, the similarity of hydrodynamic systems and schemes of aerodynamic flow of superstructures. The similarity is due to the relatively small difference in the geometric dimensions of the largest and smallest ships [7].

Immediate structural and parametric synthesis of the characteristics of the projected ship is preceded by database development and construction of standard sized set of the passenger HFV. The serial transport vessel manual (vol. 1-10) [6] was chosen as an information basis for the database. It contains enough information about all domestic passenger HFVs. Thus, the vessel design characteristics are analyzed by various methods, including regression analysis.

The parametric HFV series is an ordered set of numerical values of its design characteristics. In the parametric HFV series, along with the vessels size, their mass and power characteristics, an important role is played by the individual elements of the mass load, discharge characteristics of the ship power installation, especially their hydrofoil units, propulsion systems, and so forth.

At the stage of determining the performance of the projected passenger HFV that leads to adopting the basic design decisions on the definition of the vessel principal dimensions and other project characteristics, we perform the project analysis of these characteristics using their standard series. Passenger HFV grouping in parametric series was made according to two key features, namely: using the aircraft layout of the vessel and using slightly submerged hydrofoils in a plane scheme. Passenger hydrofoil vessels considered as contenders have very specific architecture and layout drawing that combines the shape and hull structure in which the superstructure, hydrofoil construction, the elements of the propulsion steering unit are integrated. Thus, there has been formed a one-dimensional parametric dimension-type series of passenger HFV developed in various years by Alexeev's hydrofoil design bureau [1, 2].

From the mathematical point of view, the definition of the main dimensions and design characteristics of the passenger HFV is reduced to formulating and solving the system of design equations relating the unknown quantities with the requirements of the project. Balanced design features for the passenger HFV are determined by the system of design equations: buoyancy, mass load and power - propulsion. Thus, for each design embodiment the balance is represented in the form:

$$\begin{aligned}
&D = f_5(L^*) = \gamma\delta LBT = \gamma f_1(L^*) f_2(L^*) f_3(L^*) f_4(L^*) \\
&D = D_{nop} + DW = f_6(L^*) + f_7(L^*) = \\
&= \sum_{i=1}^{k} P_i + \sum_{j=1}^{l} P_j = \sum_{i=1}^{k} f_i(L^*) + \sum_{j=1}^{l} f_j(L^*) \\
&N = \frac{D^n V^m}{C_{mn}} = \frac{f_5(L^*)^n v^m}{\varphi(D, Fr_v)}
\end{aligned} \tag{11}$$

where *f1 (B *), f2 (L *), f3 (L *), f4 (L *),* - respectively, values of the main measurements, *f5 (L *)* - values of the total mass, *f6 (L *)* - values of light-ship displacement , *f7 (L *)* - values of deadweight, *fi (L *)* - value of mass load items in the section "Light-ship displacement», *fj (L *)* - mass load items in the section "Deadweight", presented in the form of functions according to the gauge length interval and *φ (D, Frv)* - values of the coefficient binding the values of total mass, power and speed for the analyzed values of the total mass and speed interval.

To give the rationale for designing the passenger HFV, we determine the main dimensions *L, B, H* (hull), *T* (with no hydrofoils), δ, as well as other dimensions, such as the hull width *B **, ratios *L / B, B / T, H / T*, characteristics of the total mass *D* and its components, as the light-ship displacement D_{lsd} and deadweight D_W, the fuel mass values R_{fuel}, the mass of the crew R_{cr}, the mass of passengers R_{pass}, utilization coefficient according to deadweight *η*, a hull mass cubic module q_{hull} and available power *n / D* according to the gauge length interval *L **. We use the calculation results of the design

characteristics of the standard sized set and carry out regression analysis (Fig. 2). Moreover, we perform the comparison and choose the options according to the economic criterion.
The use of parametric methods significantly reduces the complexity of explaining the choice of the passenger HFV design characteristics, and ensures the design variability that makes it possible to effectively optimize the characteristics of the passenger HFV, with respect to the existing economic limitations. It should be noted that the method which is used for structural and parametric design of the passenger HFV with a composite superstructure provides a significant gain in the costs of the exploratory research in the initial design phase. The results obtained with this method are effective and easy to use further [7].

To ensure the calculation accuracy, the values of individual items of mass load, including the lighship displacement and deadweight of the passenger HFV, were defined in two ways:

- calculation by methods which use regression analysis of the values of individual items of mass load, as well as the total mass, the light-ship displacement and deadweight in the whole standard sized set;
- summation of items of mass load included in the total weight, the light-ship displacement and deadweight for the whole standard sized set.

The values obtained by both calculation methods in the whole size range are sufficiently close, and the divergence between them does not exceed 3%.

Economic characteristics of the passenger HFV are directly related to its speed, as well as the characteristics of its power plant - power, specific fuel consumption and a number of others. Therefore, one of the most important HFV characteristics is the power of the primary motors of its ship power plant and the associated rationale for the selection of the primary motors.

To determine the power of the main engines, we use regression analysis methods for analyzing the available power of the standard sized ships according to the gauge length (see. Fig. 3, right). Subsequently, by multiplying the vessel total mass D and available power N / D, belonging to the same gauge length value, we can obtain the desired value of the main engine power N, which allows us to determine the mass of the passenger HFV.

The main load item in the "Light-ship displacement" for any vessel, including the passenger hydrofoil, is the mass of its body (hull). To correctly determine the load of this load item, we need to use its relation to different geometric characteristics of the vessel.

Figure 4 (left) shows the variation of the cube HFV module for ships of the standard sized set according to the gauge length interval. When geometric dimensions of the passenger HFV hull are increased, the module size is increased as well due to the advanced growth of the total bending load. The correct hull mass definition determines the reception of the balanced values of the overwhelming number of project performance characteristics of the passenger HFV and allows you to perform a qualitative project analysis.

For the correct power - propulsion equation solutions it is necessary to apply the synthetic method. This method consists in the joint analysis of available power characteristics, its speed characteristics, determined by hydrodynamic features of the complex, as well as the characteristics which are in the motor market [3]. In this case, it is advisable to stick to the operating speed range of vessels included in the standard sized set, to ensure the absence of developed cavitation on hydrofoils, their racks and blades of the propellers. After determining the projected HFV speed range as a rough approximation and after checking it according to the criteria specified in the relevant procedures [1-2], regression analysis methods can be applied to determine the HFV coverage range. Fig 4 (right) shows the changing in the coverage range of the standard sized vessels at a fixed rate according to the gauge length interval.

In optimization calculations of the passenger HFV design characteristics we use integral indicators, including various performance parameters of the ship, including its flow characteristics, as well as the capacity (Fig. 5, right). This makes it possible to forecast prospective economic properties of the vessel at the stage of determining the main dimensions and its other basic characteristics.

After determining the main dimensions and other design characteristics of the ship the next step is the decomposition of the subsystem "HFV hull" into the second level subsystems "HFV hull proper" and "HFV composite superstructure". Decomposition involves the definition of the main characteristics of the hull itself and HFV superstructure, including their weight separately, as well as the center of gravity (CG) position of the vessel and the individual elements of its hull. It should be noted that strict requirements are imposed on the CG position in the HFV construction [1-3]. The work describes some features of subsystem "HV hull" decomposition in a high-speed vessel, as well as appearing of subsystem "Composite superstructure"; these features are implemented at the design stage and can be fully applied to the passenger HFV[8]. Moreover, the report deals with characteristic features of determining the cost of building a high-speed vessel, having the large composite elements implemented at the design stage, which can be fully applied to the passenger HFV set [9].

Designing the composite superstructure for the passenger HFV must be preceded by thedevelopment of a common vessel arrangement drawings, in this process the size of the hull is specified. The HFV design characteristics are corrected using a standard sized set data.

As a result of project analysis, taking into account the limitations we identified the passenger HFV design characteristics, close to the projects 17091 "Polesie" ("Woodlands") and "Valdai-45R" (Fig. 1).

The next step is to develop a theoretical drawing of the HFV hull and superstructure. The purpose of using the vessel, its seaworthiness and operation area to a large extent determine the architecture and assembling scheme of the ship and its hydrofoil unit scheme, which gives more or less dynamism to its appearance [1-3]. When developing the form of the passenger HFV composite superstructure, we should consider the form of its topside down to the waterline. It is required to determine the aerodynamic and hydrodynamic flow over the hull. It is important to bear in mind that the shape of the underwater hull and that of the adjacent part of the freeboard of the passenger HFV is determined by its functional purpose, features of motion, first of all, of the hydrofoil unit, as well as by the need to provide the ship with specific seaworthiness. The hydrostatic and hydrodynamic laws define the shape of the mentioned hull elements incomparably more than aesthetic considerations. Also, it is necessary to define the HFV hull areas (including the superstructure elements) which are subjected to shock waves during the operation and when burying the hull as well. [1-3]. The intermediate result of the superstructure theoretical outline decomposition is shown in Fig. 6.

The simultaneous development of the structure, composite and its manufacturing technology makes the process of creating the passenger HFV superstructure special. Various methods are used for this purpose. It is necessary to check the superstructure mass, as well as the strength and stability of its individual elements by approximate methods for the integrated design characteristics before the development of finite element models.

In the design of the HFV superstructure as a multilayer structure of the composites there must be a clear understanding of the loads acting on it. This makes it possible to provide the necessary structural strength at its optimum weight parameters. Various elements of the HFV superstructure are in different operating conditions, in terms of affecting external forces. The action of certain forces may affect both a group of elements of the HFV superstructure and its individual fragments. It is usually difficult to take into account the total impact of the external forces on the superstructure element. In the structural mechanics of the ship there exists a method for calculating the design to ensure the strength against the separate primary loads and subsequently to summarize their effect.

The model which ensures the strength of the passenger HFV superstructure design and uses numerical methods includes the following steps:

- determination of the external loads according to the total bending which act on the subsystem "Hull" of the passenger HFV in basic operational modes;
- identification of local loads which act on the HFV composite superstructure in basic operational modes;
- decomposition of the subsystem "Hull" into subsystems "HFV hull proper" and "HFV composite superstructure";
- determination of the initial matrix and reinforcing composite phases, reinforcement schemes, HFV superstructure manufacturing technology, materials and circuits manufacturing technology, as well as ways to attach the superstructure embedded items;
- development of a constructive force scheme and the scheme of the mutual elements arrangement of the HFV composite;
- development of HFV composite superstructure 3D-model by numerical methods;
- checking the strength of HFV composite superstructure and its optimization design by numerical methods;
- completion of the initial constructive force scheme of HFV composite superstructure after checking its strength.

Determination of external loads from the total bending which act on the subsystem "Hull" of the passenger HFV in basic operational modes of movement, as well as determination of local loads which act on the subsystem "HFV Superstructure", was carried out in accordance with the requirements of Section 5 of Part I of the Rules of classification and construction of inland navigation vessels of the Russian River Register[5].

In determining the load from the total bending which act on the HFV hull (together with the superstructure), we consider the following design conditions for moving hydrofoil vessels:

- HFV is moving in the displacement mode in still water;
- HFV is moving in the displacement mode in choppy water (deflection and inflection);
- HFV is moving in design condition (on the hydrofoils in still water);
- HFV is moving in design condition (on the hydrofoils in choppy water).

The design procedures of external loads from the total bending which act on the subsystem "Hull" in the passenger HFV in basic operational modes of

movement are known and described in the specialist literature[2-4].
The bending moment (moment of deflection) acting on the HFV hull is considered for the most adverse load case when the HFV is moving in two basic modes: when hydrofoil moving and moving in the displacement position for the each mode separately.

For HFV inland navigation, choppiness impact is taken into account as follows. The total bending effect when moving on the hydrofoils is summarized with the wave impacts. Distribution diagrams of bending moments and the shear forces acting on the HFV motion in still water are shown in Fig. 8.

In the HFV motion on the rough surface of the water (choppy water), the bending moments occurring on the hull and hydrofoils because of the wave impact (starting elements) should be added to its bending moment on still water. As the design conditions, we consider two cases: frontal impact of the ship's bows against the water surface, associated with burying the nasal hydrofoils into the wave, and the wave impact against the fore hydrofoil. It is recognized that these forces act at different times, in different planes and at different time duration, and hence cause different mechanical effects on the hull. Thus, if the non-stationary force impact on the load-bearing elements is relatively long in time and causes general ship movement, the wave strikes against the hull and especially, against the hydrofoils are transient and lead to the hull rapidly damped vibrations with a period of free vibrations of the first tone. Methods of determining the bending moments when hydrofoil vessels moving are given in [1, 3-4]. The results of impact load calculations are presented in Fig. 9.

In the HFV motion on the rough surface in the displacement position the total hull bending because of the hydrostatic forces, occurring in still water, is supplemented by the total bending on the wave profile, as well as by bending moments because of the hydrodynamic forces generated when striking waves against the ship's bows and its hydrofoil starting elements. The wave strokes against the hull and hydrofoils also cause the free hull vibrations of the first tone, which at the time of the next stroke are damped. Methods of determining the bending moments at the HFV movement in displacement condition are set forth in [1, 3-4].

Local loads are considered as various values of the design head acting on the various elements of the superstructure. Methods of determining local loads acting on the superstructure of the passenger HFV in major operational cases are presented in [5].

When estimating the subsystem "HFV" decomposition, the development of a constructive force scheme and the scheme of mutual arrangement of the composite HFV superstructure elements, it is convenient to use approximate specific values reduced to a surface area unit or the whole structure, rather than making piecemeal calculation of the construction mass. Therefore it is necessary to calculate the HFV superstructure mass and mechanical characteristics of its individual elements in an enlarged form based on the equation of strength.

The basis for the decomposition is the equation of the HFV strength. In this case the permissible stresses in the composite as well as its average thickness in the most loaded sections are defined on the basis of conditions of the joint deformation with the general bending of an equivalent girder. The equivalent girder consists of a bottom part (in fact, the HFV hull) made of light alloys, and the upper part (HFV superstructure), made of composites. The methodology of this calculation is shown in [9].

The initial matrix and reinforcing composite phase and reinforcement schemes, as well as the rationale for the choice of materials, schemes and methods for fixing the HFV superstructure embedded items are determined in view of its estimated fabrication technology. As the main HFV superstructure fabrication technologies we considered contact molding and vacuum infusion. Preference is given to contact molding as the most flexible technology, implemented in the R & D stage. Considering the need for import substitution, we opted for fiberglass and polyester domestically-produced resin as the main matrix and reinforcing material. As the foam middle layer material, in the absence of domestic analogues, we chose imported PVC having a reduced density.

As the initial documents for the development of the constructive force scheme and the scheme of mutual arrangement of HFV composite superstructure elements, we use theoretical drawing of the hull and the HFV superstructure, the drawing of HFV general arrangement and the constructive drawing of the HFV hull.

The development of the passenger HFV superstructure strength model is preceded by its design 3D-model developed by numerical methods, with the use of CAD / CAE technologies enabling us to get a computer model that is suitable for program transmission of finite element analysis as a initial geometry. The development of the HFV superstructure computer model is carried out in two stages.

First of all, an electronic model of the theoretical drawing of the HFV hull and composite superstructure is developed. After the original data is preliminarily digitized in the two-dimensional editor, the intermediate file obtained is transmitted to the main development media. The theoretical drawing is matched and coordinated again. As the base curves we can use Bezier curves (cubic splines), built through the the corner points of the frames sections in the areas where the shape of the theoretical superstructure surfaces is nonlinear in the longitudinal direction. Thus, a basic family of the longitudinal and transverse curves of the superstructure computer model is formed, and these curves in their turn form the surface. Next, on the basis of the surfaces obtained, schemes of reinforcing the superstructure surfaces, the scheme of arranging the easy frame of the light middle layer and the scheme of local superstructure reinforcements are created (Fig. 7 left). After completing all the process of HFV superstructure elements modeling, including embedded items, the resulting computer model is suitable for the transmission into the programs of the finite element analysis as the initial geometry (Fig. 7, right).

The execution plan is created in the ANSYS Workbench modeling media. The first step is to select the type of problem to be solved (static analysis) for the preparation of FEM model and further solutions of the statics problem. The ACP module is chosen for modeling the composite material. For the further strength analysis of the composite superstructure, ACP modules (Pre) and Static Structural are connected with ACP (Post). Next, geometry is imported from an external file. The geometry import is done through the external file in Parasolid V21 format.

The composite properties for the monolayer are specified by introducing the characteristics of the materials into the established form. This is followed by the material properties being assigned to the geometry. At the same time, the geometry is chosen and predetermined material properties are assigned to its elements. After that, the symmetrical composite package described by angles and pilings thicknesses is specified. This is followed by the size indication of the elements of the selected items, the number of the mesh partitions on the selected surfaces is indicated as well. The next step is to specify the surfaces with a regular zone for the construction of the finite element mesh (Fig. 9, right).

The mesh should deal with the interested areas, details of geometry, as well as the gradients of the key variables. To determine the areas where there are the biggest amount of gradients, there can be applied mesh adaptation (automatic condensation). We should also take into consideration that the mesh dimension is always limited by computer resources. Therefore, it is necessary, based on the available computing resources, to estimate the maximum number of cells in the model. In addition, it is necessary to determine the complexity of the models and the number of equations to be solved for each cell.

When choosing between the structured hexahedron mesh or unstructured tetrahedron mesh we must be guided by the characteristic features of the problem being solved. It should be borne in mind that the hexahedron / quadrilateral mesh may provide a better solution with fewer cells / units in comparison with a tetrahedron / triangle mesh. The hexahedron / quadrilateral mesh in some cases gives a smaller numerical diffusion. But to build such a mesh, as a rule, we need more time and effort.

In some cases the meshes are hybrid, which tend to combine tetrahedron / triangle mesh with other types in the predetermined areas. For example, it is the case with triangular prisms. This mesh gives more accuracy and efficiency than only tetrahedron / triangle mesh.

After substructure is partitioned into finite elements on the surfaces boundary conditions for the passenger HFV superstructure are specified. At the same time the movement in the wall holes in all axes is not allowed, including the rotation angles (bedding-in). The next step is to apply the loads to the superstructure defined in the calculation of the total HFV hull bending in different operational cases, as well as in case of local loads. The calculated values of the shear force and bending moment, as well as design pressure are applied to the finite element model for calculation. A separate step is to calculate the stability of HFV composite superstructure elements. To do this, a separate model is needed. Finally, the models are sent to the solver.

CONCLUSIONS

In analyzing the results of the calculations complicated, one can see that the HFV composite superstructure strength is ensured in all the cases considered (Fig. 10). Distribution of the internal forces acting in the superstructure, in general, has the behaviour described in the specialized literature [1, 3-4], indicating the correct identification of the external loads.

Bauman Moscow State Technical University received a patent for the utility model no. 148323 dated 5 August, 2014, the "Passenger hydrofoil having a composite superstructure".

The calculations made show that due to the hydrofoil vessel 17091 "Polesie" ("Woodlands") project being modernized with the superstructure made of polymer composites, in accordance with the principles set out above, its passenger capacity can be increased from 51 people up to 60 people. Thus, the modernized project excels the HFV project "Valdai-45R" having a seating capacity of 45 persons at the same the primary motor power, in efficiency characteristics by 33%. This advantage is achieved by using the innovative solution - polymeric composite construction - for the HFV passenger superstructure.

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Fig.1. *Passenger HFV 17091 " Poles'e" ("Woodlands") (left) and HFV«"Valdai-45R" project (right)*

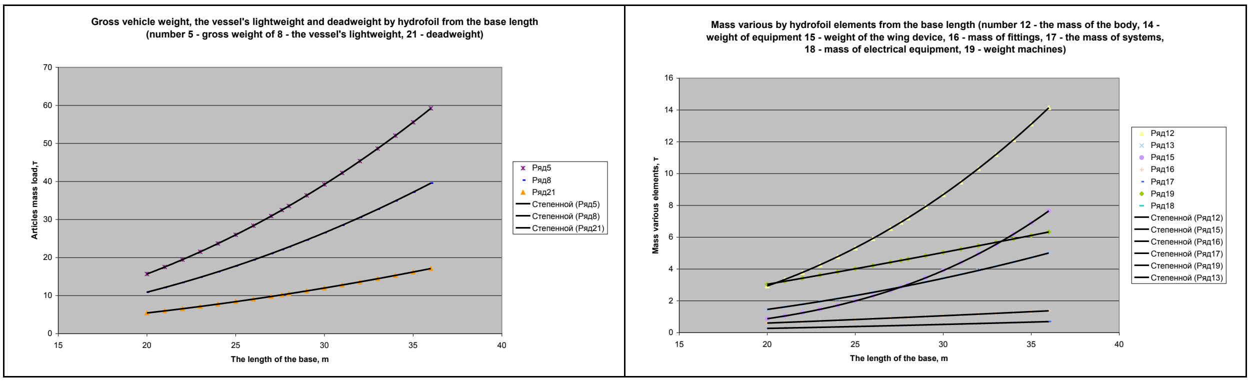

Fig.2. *The total mass, light-ship displacement, deadweight and the main items load mass of the "Light-ship displacement" section for the standard sized HFV set according to the gauge length interval*

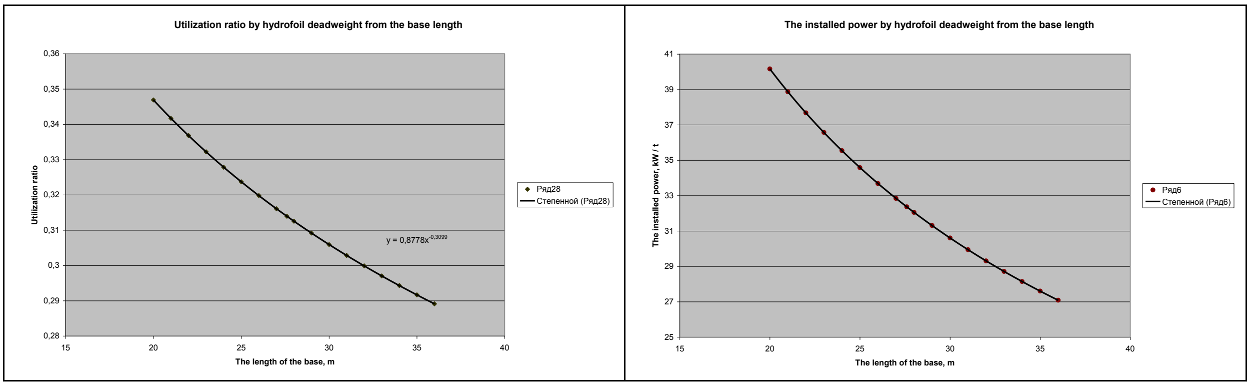

Fig.3. *The utilization coefficient according to the deadweight (payload) and the available power for the standard sized HFV set according to the gauge length interval*

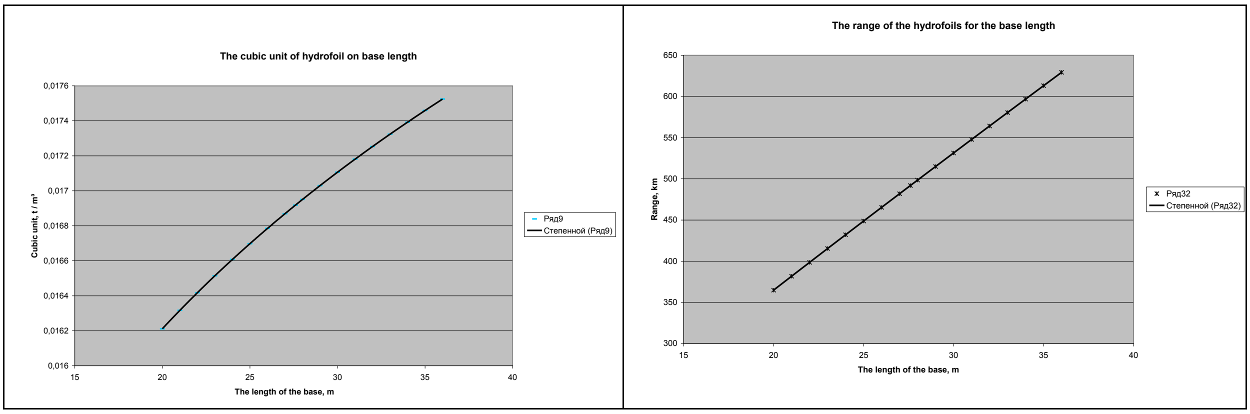

Fig.4. *Cubic unit and the ship coverage range for the standard sized HFV set according to the gauge length interval*

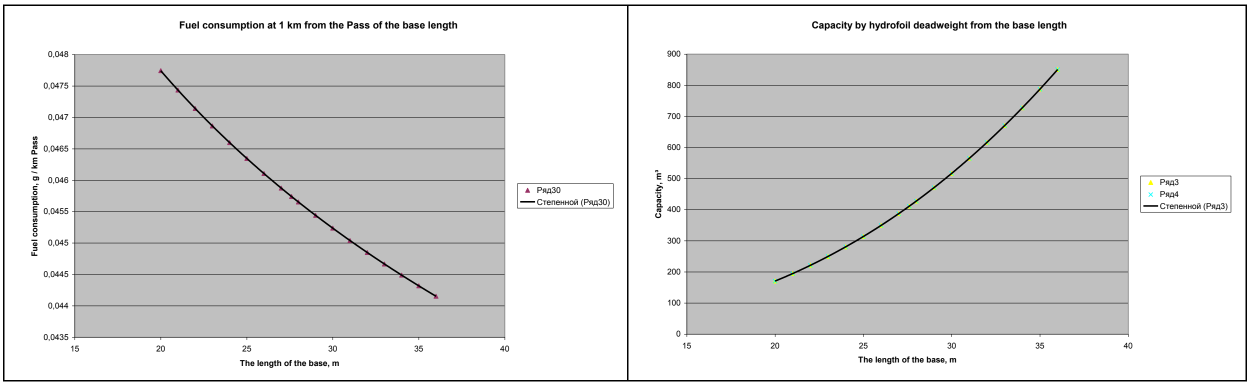

Fig.5. *Changes in fuel consumption per 1 passenger-kilometer and in capacity for the standard sized HFV set according to the gauge length interval*

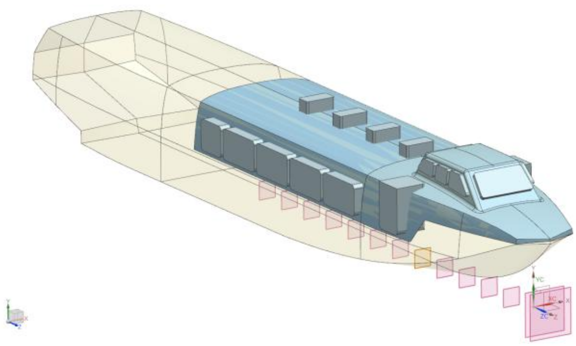

Fig.6. *Intermediate decomposition result of the theoretical superstructure contour*

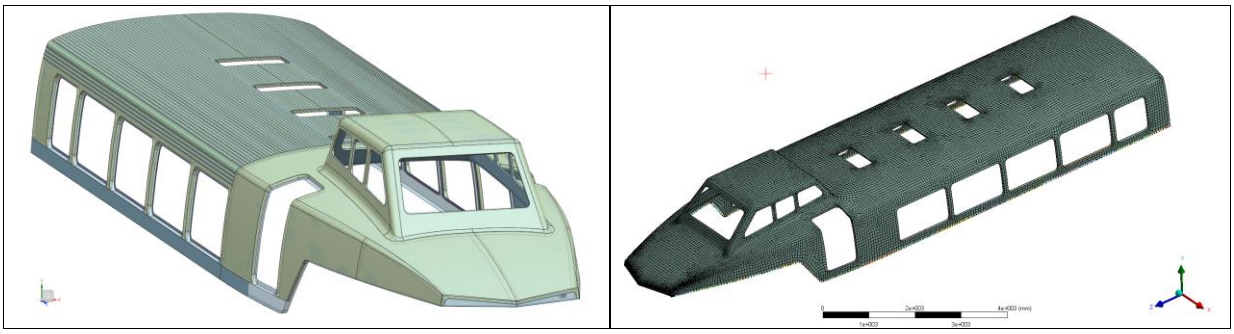

Fig.7. *Initial geometry and finite - element model of the HFV composite superstructure*

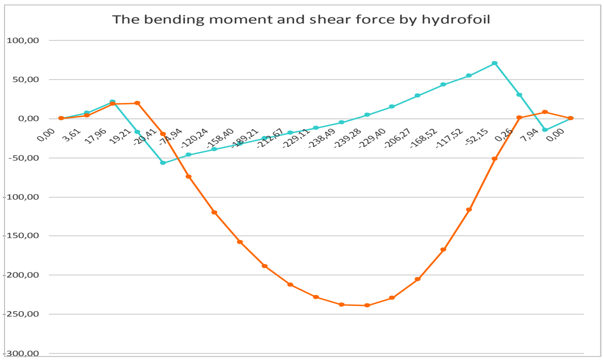

Fig. 8. *Distribution diagrams of bending moments (row 2) and shear forces (row 1), operating by the HFVmovement in still water*

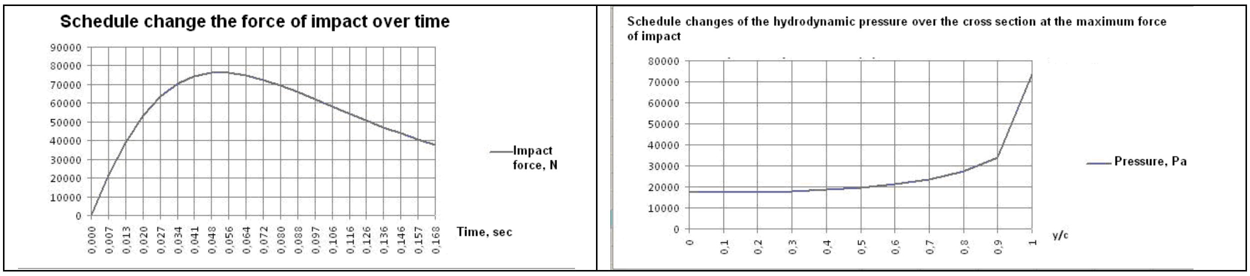

Fig.9. *The calculation results of impact loads acting on the HFV*

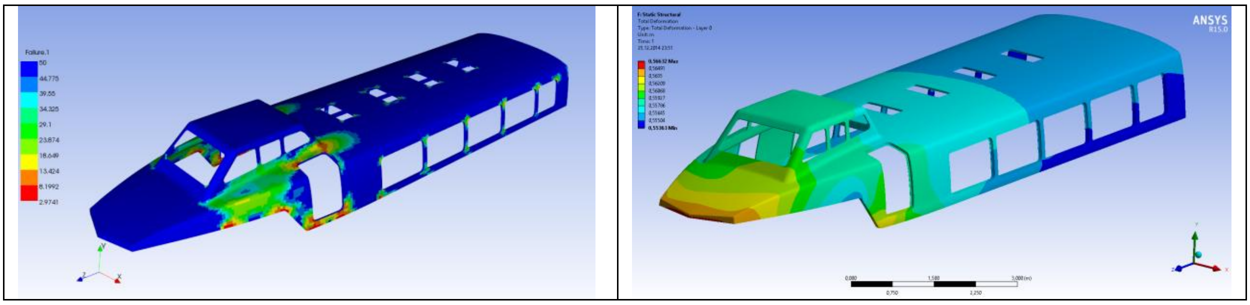

Fig.10. *G forces and deflection of the HFV composite superstructure*