VARNA SCIENTIFIC AND TECHNICAL UNIONS

TECHNICAL UNIVERSITY - VARNA

SIXTEENTH INTERNATIONAL CONFERENCE ON MARINE SCIENCES AND TECHNOLOGIES

Black Sea 2022

Dedicated to the 60th Anniversary of Technical University - Varna

PROCEEDINGS

ISSN 1314 - 0957

October 20th, 2022
Varna, Bulgaria

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URL: nts.varna-bg.org
DOI: https://doi.org/10/7546/IO.BAS.2022.8

ISSN 1314 - 0957

Organized by:

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With the Cooperation of:

BULGARIAN NATIONAL ASSOCIATION OF SHIPBUILDING AND SHIPREPAIR (BULNAS)

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C O N T E N T S

Black Sea 2022

PLENARY

DETERMINATION OF THE AERODYNAMIC COEFFICIENTS OF THE STEERING COMPLEX OF THE CAR-PASSENGER FERRY "MARAL" BY THE NUMERICAL METHOD

Volodymyr ZAYTSEV, Valeriy ZAYTSEV,
Dmytro ZAYTSEV, Victoria LUKASHOVA

Abstract. *When developing mathematical models of the plumage of hovercrafts, it is often assumed to separately determine the forces and moments of resistance of the annular nozzles of propellers, propellers and the steering complex (aerodynamic rudder with a flap, taking into account the stabilizer-pylon). However, this approach does not take into account the mutual influence of all elements of the propeller-steering complex of the car-passenger ferry (CPF) "Maral" on the total resistance of the vessel, which may lead to slightly incorrect results.*

In the report, the aerodynamic coefficients of the steering complex of the car-passenger ferry "Maral" are determined by a numerical method to solve the aerodynamic mathematical model of the aerodynamic rudder with a flap, taking into account the pylon stabilizer, the propeller, the annular propeller nozzles in standard situations (in the hover mode of the ship), taking into account their mutual influence.

Key words: *Aerodynamic coefficients of the steering complex, aerodynamic rudder with flap, CPF "Maral", propeller, propeller annular nozzles, steering complex, stabilizer-pylon.*

INTRODUCTION

When creating mathematical models of the hovercraft plumage, it is usually assumed that the forces and moments of resistance of the annular nozzles of propellers, propellers and the steering complex (aerodynamic rudder with a flap, taking into account the stabilizer-pylon) are determined separately. Mathematical models for calculating the resistance of hovercraft plumage are usually conditionally divided into parts. That is, mathematical models of empennage usually include only the consideration of an aerodynamic rudder with a flap, taking into account the pylon stabilizer, and the annular attachments are considered separately. In this case, it is assumed that the total resistance will be equal to the algebraic sum of the indicated resistances [1 – 5].

However, this approach does not take into account the mutual influence of all elements of the hovercraft propeller-steering complex on the total resistance of the vessel, which can lead to somewhat incorrect results.

In the study, it was decided to consider the general problem of an aerodynamic mathematical model of an aerodynamic rudder with a flap, taking into account the pylon stabilizer and an annular nozzle with a propeller in the hover mode of the vessel.

The drag coefficients obtained as a result of blowing one empennage complex for neighboring complexes will be corrected by introducing a mutual influence coefficient. Such a coefficient can be obtained as a result of selective joint blowing of three empennage complexes at several empennage attack angles.

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NARRATION

An aerodynamic model of the steering complex of the automobile-passenger ferry (APF) “Maral” is considered (Fig. 1). It was decided to consider the general problem of the aerodynamic mathematical model (the APF “Maral” empennage) of an aerodynamic rudder with a flap, taking into account the pylon stabilizer and an annular nozzle (AN) with propellers in standard situations in the hover mode of the ship (Fig. 2) [6].

The drag coefficients that will be obtained as a result of blowing one empennage complex (3 such complexes are installed on the APF “Maral”) will be corrected by introducing a mutual influence coefficient. Such a coefficient will be obtained as a result of selective joint blowing of three empennage complexes at several empennage attack angles.

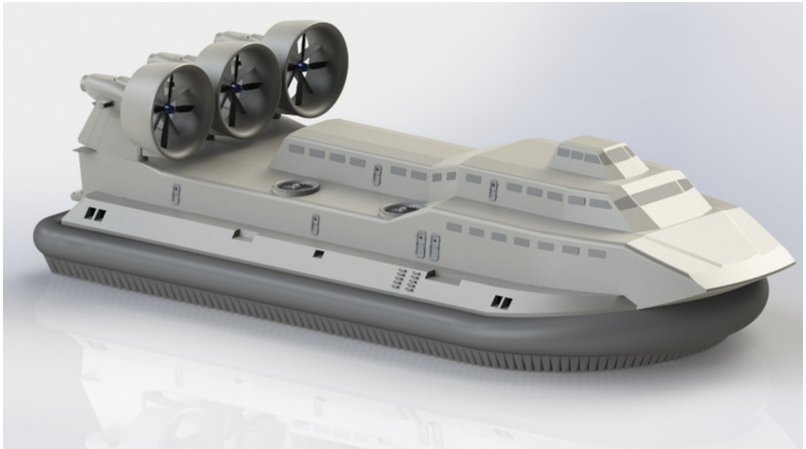

Fig. 1.
Automobile-passenger ferry “Maral”

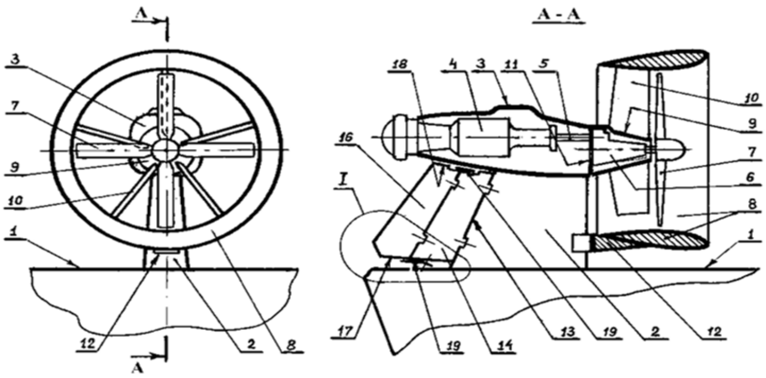

Fig. 2.
APF “Maral” propulsion and steering complex

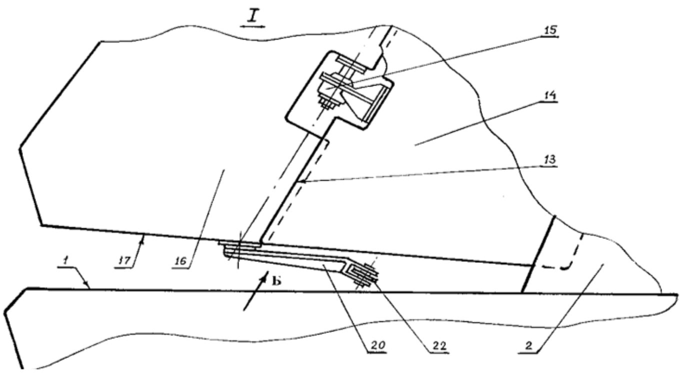

Fig. 3.
APF “Maral” propulsion and steering complex (component 1)

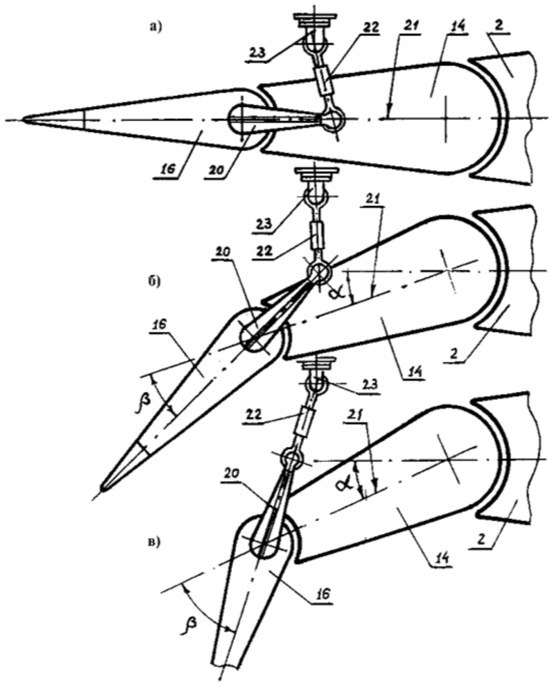

Fig. 4.
APF "Maral" propulsion and steering complex (view along arrow Б)

Figures 2 - 4 indicate:
1 - upper deck APF "Maral"; *2* - pylon-stabilizer; *3* - gondola; *4* - traction engine (TE); *5* - intermediate shaft; *6* - reduction gear; *7* - pulling propeller; *8* - annular nozzle (AN); *9* - fairing; *10* - blades (spokes) of the straightening apparatus (BSA); *11* - bow end of the gondola; *12* - special box part that supports AN; *13* - aft edge of the pylon; *14* - aerodynamic steering wheel (ASW); *15* - hinge connecting ASW to pylon; *16* - flap; *17* - lower end of the flap; *18* - upper end of the flap; *19* - double-lever hinge mechanism (DLHM); *20* - tiller (first lever of DLHM); *21* - longitudinal axis located in the plane of symmetry of the flap; *22* - second lever of DLHM; *23* - fixed bracket.

As a rule, the drag coefficient of hovercraft air rudders $C_{X.Aero\_Rud}$ and $C_{Y.Aero\_Rud}$ and plumage is determined by the results of blowing them in a wind tunnel. However, this method of determining this coefficient is very costly both in terms of time and money.

With the development of computer technology and engineering software, it became possible to significantly reduce these costs. This can be done using software packages that implement the finite volume method (FVM), such as ANSYS CFX or SolidWorks FlowSimulation.

To do this, first of all, you need to create a 3D model of APF "Maral" propulsion and steering complex (PSC) (Fig. 5).

Then, based on the PSC APF "Maral" 3D model, it is necessary to create its simplified 3D model, from which all unnecessary details, such as rudder drive elements, etc., will be excluded. As a result of the transformations, we obtain a simplified 3D model of PSC APF "Maral" (Fig. 6) for further creation of its computational model (Fig. 7).

A simplified 3D PSC model is placed with given rudder angles in a box that represents the environment around the object under study. Two additional objects have been added to the calculated 3D model: *1* - a body of circular cross section, the diameter of which corresponds to the outer diameter of the propeller AB-98; this body is designed to simulate the airflow generated by a propeller; *2* - a rectangular horizontal surface on which the PSC is mounted, it simulates the upper deck of the ship, on which the pylon with AN and rudder is installed. The calculated 3D PSC model is shown in fig. 7.

All work on the creation of a 3D calculation model is carried out in the SolidWorks software product.

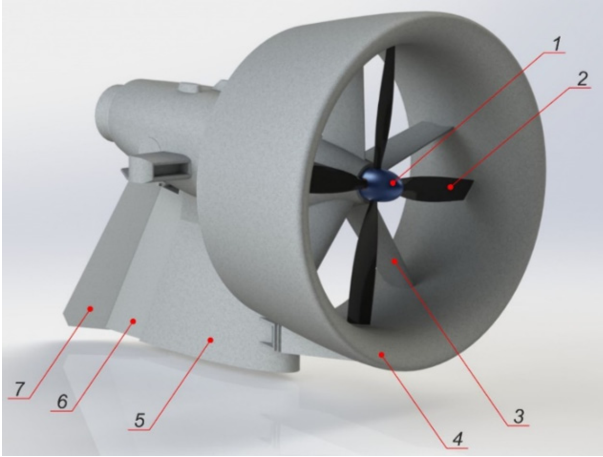

Fig. 5.
General view of the 3D model of PSC APF "Maral" assembly
1 - propeller fairing; *2* - propeller AB-98;
3 - straightener; *4* - annular nozzle; *5* - pylon;
6 - air steering wheel; *7* - air rudder flap

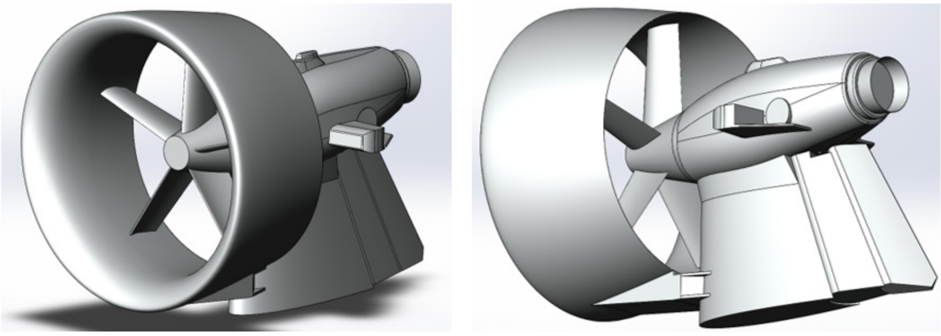

Fig. 6.
Simplified 3D model of PSC APF "Maral" assembly

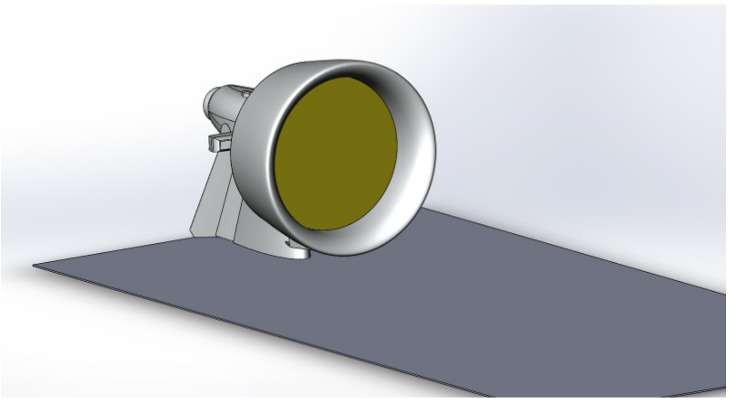

Fig.7.
PSC APF "Maral" 3D calculation model

Further preparation of the numerical experiment is carried out using the FlowSimulation module, which is an integral part of the SolidWorks software. First of all, the dimensions of the calculation area are set (Fig. 8) with the following dimensions: length - 60.0 m; width - 20.0 m; height - 14.5 m.

Then the general settings of the task are performed: task type - external flow; fluid medium - air (Air); flow type - laminar and turbulent; adiabatic walls; wall roughness - 5 microns; pressure - 101.325 kPa; temperature - 293.2 K.

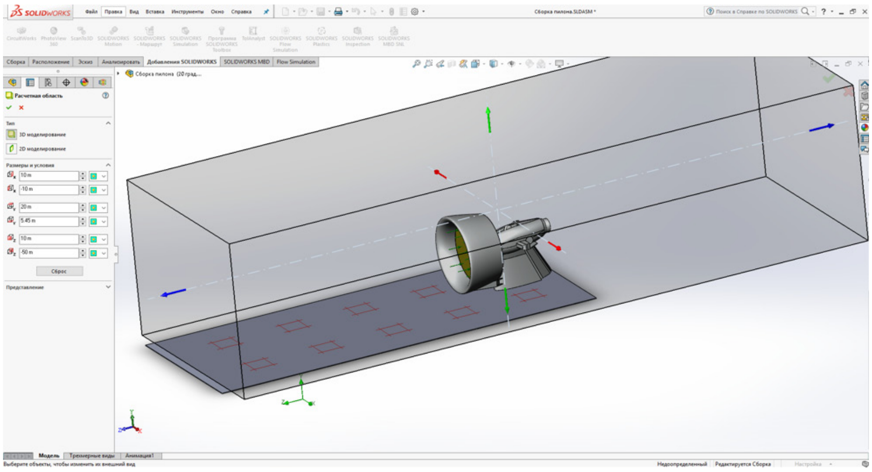

Fig. 8.
PSC APF "Maral" computational domain

Boundary conditions are set. For a plane that simulates the surface of a hovercraft deck, the "Real wall" property is set. A virtual propeller is created in the SolidWorks engineering database and assigned propeller AB-98 parameters. In the calculation model, the input and output surfaces of the propeller are specified.

An initial global mesh of finite volume elements is created inside the computational domain. The mesh generator of the FlowSimulation module has a large number of settings that allow you to create an optimal global mesh (Fig. 9). To improve the accuracy of calculations and obtain reliable results on the surfaces of the calculation model, it is necessary to create a local grid. The local grid is a region of smaller finite volume elements compared to the global grid elements, and they are located in the near-wall region of the computational model.

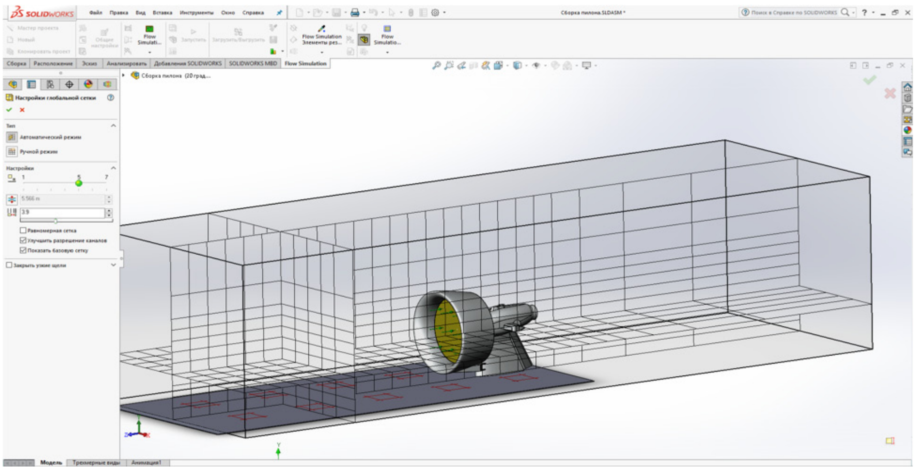

Fig. 9.
Initial global mesh

When creating a finite element mesh, it is necessary to obtain the maximum quality of the elements. The automatic finite element meshing procedure does not provide the required element quality and creates an excessive amount of poor quality finite elements. Such a finite element mesh will increase the duration of the calculation, worsen the convergence of the results, and the reliability of the results will not be too high. The built-in tools for creating a finite element mesh, the mesh generator "Meshing", allow you to achieve the maximum quality of the mesh elements.

In order to obtain the results of interest to us, as well as to monitor the convergence of the calculation, it is necessary to set goals. To solve the problem, it is necessary to know the forces on the surfaces of the air rudder and its flap, the moments relative to the axis of rotation of the rudder and the axis of rotation of the flap. With the help of the corresponding menu, goals were set for the objects of interest to us.

To determine the aerodynamic drag coefficients of air rudders in the entire range of their rudder angles, it is necessary to prepare such a problem for each rudder angle that we will study, from the extreme left position to the extreme right position. For this study, the following rudder angles were adopted: 0 degrees; 5, 10, 15, 20, 24 degrees to port; 5, 10, 15, 20, 24 degrees to starboard.

After completing the settings in the preprocessor, you can begin to solve the problem, which is performed automatically at the user's command and usually does not require the user to be constantly near the personal computer.

The results of the performed calculation for each task (for each rudder angle) are recorded in a separate project folder. The FlowSimulation module has a large set of tools for processing simulation results. It allows you to get an image of a grid of finite volume elements, which was built in the course of solving the problem (Fig. 10).

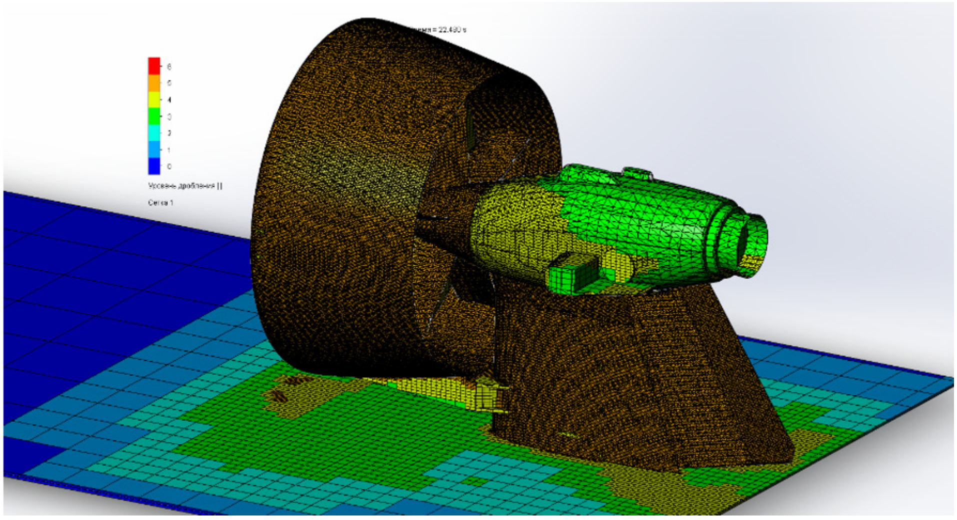

Fig. 10.
Grid of finite volume elements for rudder angle 20° to starboard

Results processing tools allow you to build diagrams in various sections both on surfaces and display such parameters as flow velocity, pressure, temperature, density, vorticity, etc. on them.

Figure 11 shows the diagram of the distribution of velocities in a horizontal section in the area where the main air flow from the propeller passes through the air rudder.

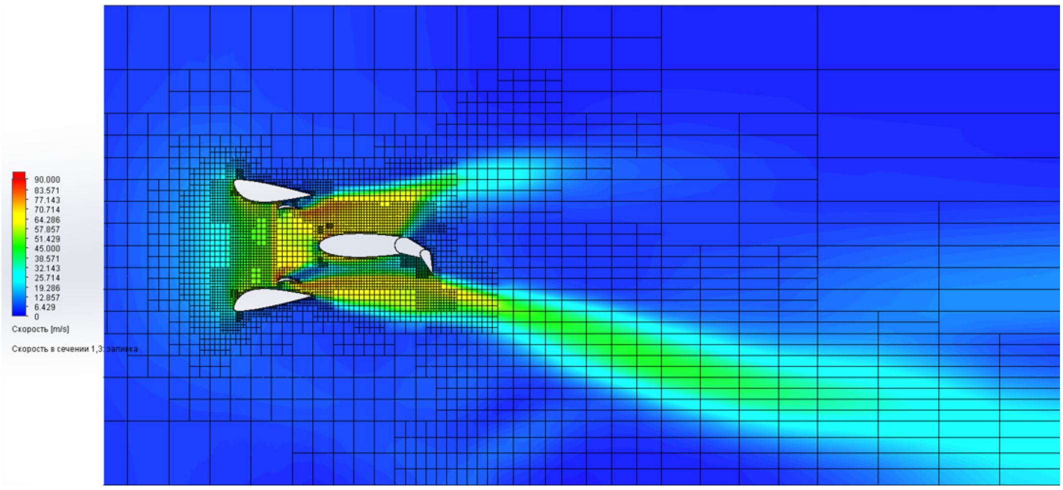

Fig. 11.
Velocity distribution diagram in a horizontal section at a distance of 7.5 m from the main plane for a rudder angle of 24° to port

The picture of the pressure distribution over the surface of the rudder and flap is shown in Fig. 12.

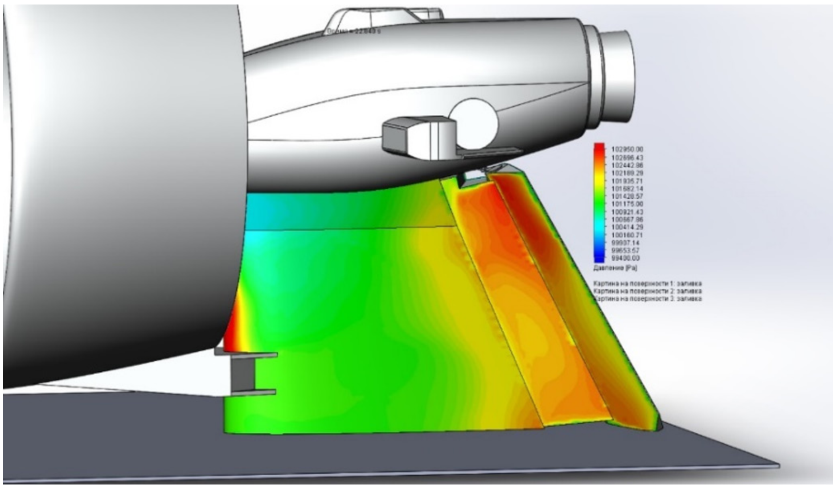

Fig. 12.
Pressure distribution along the rudder and flap for a rudder angle of 24° to port

In addition, all calculation results for all targets are recorded in a separate file, the data of which can be imported into MS Excel. The final calculation data for all rudder angles in the SolidWorks coordinate system are presented in Table 1.

Results of a numerical experiment on blowing the rudder with a flap at different rudder angles in the SolidWorks software coordinate system

Table 1

Target name	Dimension	Port side					0°	Starboard				
		24°	20°	15°	10°	5°		5°	10°	15°	20°	24°
Rudder												
R_P	N	3928	3132	2048	1494	1118	1005	1388	2069	2894	3788	4330
$R_{Xsw.P}$ (X)	N	-3872	-3130	-2027	-1351	-612	248	1087	1982	2872	3786	4301
$R_{Ysw.P}$ (Y)	N	208	18,8	-113	-222	-313	-312	-263	-148	-49,9	124	256
$R_{Zsw.P}$ (Z)	N	-629	-108	269	599	882	923	823	575	358	-55,9	-420
Flap												
$R_{ЗК}$	N	3469	2933	1894	1274	540	193	690	1293	1949	2649	3321
$R_{Xsw.ЗК}$ (X)	N	-1812	-2240	-1725	-1246	-537	142	687	1283	1847	1983	1623
$R_{Ysw.ЗК}$ (Y)	N	1245	779	314	99,9	-31,2	-53,8	-25,2	72,2	278	771	1264
$R_{Zsw.ЗК}$ (Z)	N	-2683	-1725	-717	-246	48,4	118	57,9	-139	-559	-1578	-2607
$M_{ЗК}$	N*m	1307	951	523	322	106	-34,1	-110	-219	-445	-783	-1329
Rudder with flap												
$R_{P+ЗК}$	N	6738	5730	3784	2624	1518	1170	2002	3296	4728	6063	6825
$R_{Xsw.P+ЗК}$ (X)	N	-5685	-5370	-3752	-2597	-1149	390	1774	3266	4718	5769	5925
$R_{Ysw.P+ЗК}$ (Y)	N	1453	798	201	-122	-344	-365	-288	-75,5	228	895	1520
$R_{Zsw.P+ЗК}$ (Z)	N	-3312	-1834	-449	354	930	1041	881	435,5	-201	-1634	-3027
$M_{Б}$	N*m	5368	4621	2923	1890	757	-244	-1017	-1891	-2976	-4113	-5172

Based on the results of the numerical experiment, we determine the necessary aerodynamic drag coefficients for the rudder complex.

The initial data for calculating the aerodynamic drag coefficients for the rudder complex are given below: air flow velocity - 50 m/s; rudder area - 3.76 m^2; flap area - 4.05 m^2; area of the complex - 7.81 m^2; air density - 1.225 kg/m^3; rudder chord - 1.153 m; flap chord - 1.219 m; total chord - 2.372 m.

Aerodynamic drag coefficients separately for the rudder are shown in Table 2.

Rudder drag coefficients

Table 2

Target name	Port side					0°	Starboard				
	24°	20°	15°	10°	5°		5°	10°	15°	20°	24°
Rudder											
$C_{\text{.руля}}$	0,682	0,544	0,356	0,260	0,194	0,175	0,241	0,359	0,503	0,658	0,752
$C_{\text{Y.руля}}$	0,673	0,544	0,352	0,235	0,106	0,043	0,189	0,344	0,499	0,658	0,747
$C_{\text{Z.руля}}$	-0,036	-0,003	0,020	0,038	0,054	0,054	0,046	0,026	0,009	-0,022	-0,045
$C_{\text{X.руля}}$	-0,109	-0,019	0,047	0,104	0,153	0,160	0,143	0,100	0,062	-0,010	-0,073

The aerodynamic drag coefficients separately for the flap are given in Table 3.

Flap drag coefficients

Table 3

Target name	Port side					0°	Starboard				
	24°	20°	15°	10°	5°		5°	10°	15°	20°	24°
Flap											
$C_{\text{.закр}}$	0,559	0,473	0,305	0,205	0,087	0,031	0,111	0,209	0,314	0,427	0,535
$C_{\text{Y.закр}}$	0,292	0,361	0,278	0,201	0,087	0,023	0,111	0,207	0,298	0,320	0,262
$C_{\text{Z.закр}}$	-0,201	-0,126	-0,051	-0,016	0,005	0,009	0,004	-0,012	-0,045	-0,124	-0,204
$C_{\text{X.закр}}$	-0,433	-0,278	-0,116	-0,040	0,008	0,019	0,009	-0,022	-0,090	-0,255	-0,420
$C_{\text{.M.Z.закр}}$	0,173	0,126	0,069	0,043	0,014	-0,005	-0,014	-0,029	-0,059	-0,104	-0,176

The aerodynamic drag coefficients of the rudder complex are shown in Table 4.

Drag coefficients for the rudder complex

Table 4

Target name	Port side					0°	Starboard				
	24°	20°	15°	10°	5°		5°	10°	15°	20°	24°
Rudder complex											
$C_{\text{.компл}}$	0,563	0,479	0,316	0,219	0,127	0,098	0,167	0,276	0,395	0,507	0,571
$C_{\text{Y.компл}}$	0,475	0,449	0,314	0,217	0,096	0,033	0,148	0,273	0,395	0,482	0,495
$C_{\text{Z.компл}}$	-0,121	-0,067	-0,017	0,010	0,029	0,031	0,024	0,006	-0,019	-0,075	-0,127
$C_{\text{X.компл}}$	-0,277	-0,153	-0,038	0,030	0,078	0,087	0,074	0,036	-0,017	-0,137	-0,253
$C_{\text{.М.Б}}$	0,189	0,163	0,103	0,067	0,027	-0,009	-0,036	-0,067	-0,105	-0,145	-0,182

CONCLUSIONS

The described technique made it possible to determine the drag coefficients of the APF "Maral" rudder propeller complex, taking into account the mutual influence of the annular nozzle, propeller, and aerodynamic rudder.

The application of the described technique in the design of hovercrafts will make it possible to create more reliable ships of this type, and in simulation modeling, it will make it possible to more accurately predict their behavior in various operating modes.

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ON MARINE SCIENCES AND TECHNOLOGIES**

**Correction by LARGO CITY Ltd. - DOBRICH
Computer layout by Donika Sarkoleva-Zlateva
Total print: 30, Format 60/84/8**

**LARGO CITY Ltd. - DOBRICH
DESIGN, PRE-PRESS AND PRINTING**

ISSN 1314 - 0957