УДК 629.5.022.22
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STUDY OF THE TOWING RESISTANCE OF PASSENGER CATAMARANS VIA CFD MODELING

ДОСЛІДЖЕННЯ БУКСИРУВАЛЬНОГО ОПОРУ ПАСАЖИРСЬКИХ КАТАМАРАНІВ ЗА ДОПОМОГОЮ CFD-МОДЕЛЮВАННЯ

DOI 10.15589/SMI. 2018.01.19

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Abstract. The towing resistance of the projects AVP 07, AVP 07m, AVP 09 and AVP 11 has been studied in accordance with the needs of Artel LLC. The AVP 07m differs from the AVP 07 by the shape of the bottom at the aft end; thus, the impact of this shape on resistance is assessed. For the AVP 09 with non-standard, simplified contours, its towing resistance is estimated and its performance characteristics are defined. For the AVP 11 project, the effect of lateral clearance on its towing resistance is studied. The main research method is CFD modeling.
Keywords: towing resistance; influence of the hull shape parameters; CFD modeling.

Анотація. Відповідно до потреб ТОВ «Артіль» проводилося дослідження буксирувального опору проектів AVP 07, AVP 07м, АПВ 09 і AVP 11. Для AVP 07м, яке відрізняється від AVP 07 формою днища в кормовій частині виконувалася оцінка впливу цієї форми на опір. Для AVP 09 з нестандартними, спрощеними обводами, визначався буксирувальний опір і оцінка ходових якостей. Для проекту AVP 11 досліджувався вплив поперечного кліренсу на буксирувальний опір. Основним методом дослідження служить CFD-моделювання.
Ключові слова: буксирувальний опір; вплив параметрів форми корпусу; CFD-моделювання.

Аннотация. В соответствии с потребностями ООО «Артель» производилось исследование буксировочного сопротивления проектов AVP 07, AVP 07м, АПВ 09 и AVP 11. Для AVP 07м, которое отличается от AVP 07 формой днища в кормовой оконечности выполнилось оценка влияния этой формы на сопротивление. Для AVP 09 с нестандартными, упрощенными обводами, определялось буксировочное сопротивление и оценка ходовых качеств. Для проекта AVP 11 исследовалось влияние поперечного клиренса на буксировочное сопротивление. Основным методом исследованием служит CFD-моделирование.
Ключевые слова: буксировочное сопротивление; влияние параметров формы корпуса; CFD-моделирование.

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Problem statement. It is well known that towing resistance essentially depends on the shape of a ship hull. Unfortunately, there is no analytical dependence of the hull shape on its resistance due to the complexity of the hydrodynamic equations and the necessity to fulfill the boundary conditions precisely on this ship surface. Thus, the effect of the hull shape on resistance is generally studied by trial and error for a particular sequence of project alternatives. The motion resistance for each alternative can be estimated either through a physical experiment in research tanks or by CFD modeling. The latter is an advanced, efficient and most economical tool for the study of hydrodynamic characteristics of the ship movement. Yet, it calls for preliminary determination of such parameters as the number of cells (grid nodes), location and degree of grid adaptation, and time step). It is determination of these parameters and obtaining of practical results that is considered in the present study of the resistance of the catamarans of the AVP projects.

Latest research and publication analysis. At present, there is plenty of publications dealing with determination of towing resistance of multi-hull vessels (catamarans) [1, 2, 3]. However, customers may change the target function of designing so that it would not involve minimizing the ship's resistance. For example, when creating the AVP catamaran series, the customer's prioritized simplified contours in order to minimize the costs of the hull construction. Thus, the towing resistance of such vessels can be determined in two ways: through physical simulation in a research tank, which may be feasible for constructing large series of such vessels, or by using CFD modeling, which is much more economical and takes less time. In addition, the customer often requires a change in the shape of the hull of serial models to place propellers or other underwater devices there, which will definitely affect the magnitude of towing support. Apparently, CFD modeling can provide a prompt solution in this case as well.

THE ARTICLE AIM to apply CFD modeling to establish the impact of the hull shape on the towing resistance of the catamarans of the AVP projects.

Basic material. The procedure of determining towing resistance of catamarans is different from that for regular vessels. The towing resistance of catamarans depends not only on the shape of hull contours, but also (and considerably) on the horizontal clearance. A comparative analysis of the towing resistance coefficients involved appropriate data for the AVP 07, AVP 07m, APV 09 and AVP 11 models. For each design, a 3D model was constructed using Solid Works software, and a modeling project was created in the Flow Vision CFD package. To further provide for the accuracy of the Flow Vision modeling results, the impact of the number of cells and the time step was studied for low- and medium-power computers.

Special features of the contours of the AVP catamarans. A comparative analysis involved four AVP projects manufactured by the Artel LLC.

The AVP 07 has complex contours. The ship hull has two bilges, a flat-keel bottom, and a stern arrangement of the engine compartment and the deck house. The APV 07m has flat contours in the stern part of the vessel and keel contours in the bow part. The AVP 09 has simpler contours, with a flat bottom along the entire length of the ship. The AVP 11 has smoother contours, three bilges and a flat-keel bottom. Figures 1 – 4 present the data of the models built via Solid Works 2015, and Table 1 lists their basic characteristics.

Determining the towing resistance via the software system Flow Vision.

CFD modeling provides the possibility of a prompt, accurate and flexible simulation of fluid flows and heat

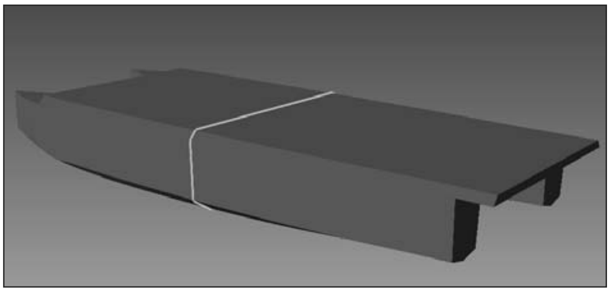

Fig. 1. 3D model of the AVP 07 project

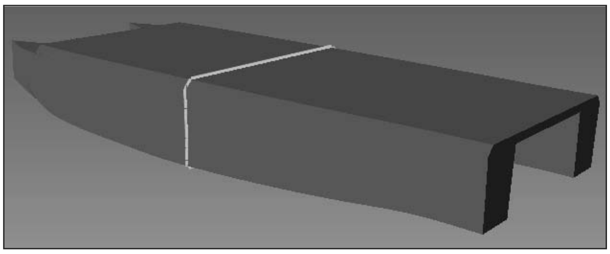

Fig. 2. 3D model of the AVP 07m project

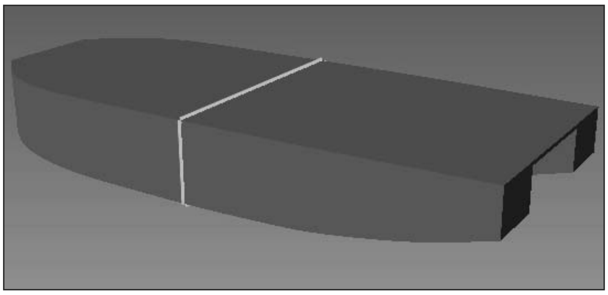

Fig. 3. 3D model of the AVP 09 project

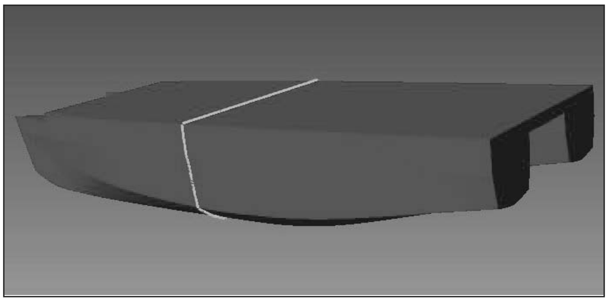

Fig. 4. 3D model of the AVP 11 project

transfer processes. It helps predict the behavior of products during operation, optimize their design, and comprehensively examine the projects before they are put into production. The approach reduces the need for expensive prototypes, accelerating the market launch of innovative products. The project research environment and automation tools allow comparing project alternatives and provide understanding of the impact of the changes introduced by the engineer. CFD packages help make more informed decisions even at the early stages of project development.

The CFD package adopted for the resistance studies is Flow Vision 2.5 [4]. It is applied to solve the dynamic equation (Reynolds equation, continuity equation) for a viscous fluid with a free surface. This package employs the finite volume method. A standard *k–s* model is used for turbulence description. The minimum dimensions of the box are set; the level of hull adaptation is equal to 2; the total number of cells for the projects lies within 320 – 540 thousand cells. The calculation results are given in Tables 2–4. The resistance coefficients were determined according to the following formulas.

The total resistance coefficient is calculated with the help of the following expression:

$$C_T = (2R_T)/(\rho v^2 \Omega),$$

where R_T is the total resistance (kN), ρ is the density (m³/s), v is the running speed (m/s), Ω is the wetted surface area (m³).

The residual resistance coefficient is calculated as follows:

$$C_R = C_T - C_F,$$

where C_F is the friction resistance coefficient for an equivalent plate, which is determined by the formula below:

$$C_F = 0{,}455/(lg\mathrm{Re}^{2.58}),$$

where Re is the Reynolds number.

The ship wave pattern for the AVP 09 project is shown in Fig. 5 as an example.

Fig. 6 presents an example of wave formation pattern for the AVP 11.

In this study, three values of the lateral clearance are considered for the AVP 11 project: S/L_{wl} = 0.24; 0.30; 0.36. The calculation results are presented in Tables 5 – 7. Graphical representation of the calculation results is given in Fig. 7.

Table 1. Project passport data

No.	Name	Symbol	AVP 07	AVP 07m	AVP 09	AVP 11
			Value			
1	Maximum length	L_{max}, m	16.85	16.85	16.85	21
2	Length on designed waterline	L_{DWL}, m	15.81	15.81	16.262	20.262
3	Maximum width	B_{max}, m	6.7	6.7	6.75	10.16
4	Midship width on designed waterline	B_{DWL},m	1.528	1.528	1.902	2.65
5	Draft	d, m	1.12	1.12	0.87	1.69
6	Displacement	V, t	32	33	50	83.95
7	Block coefficient	C_b	0.59	0.59	0.72	0.451
8	Waterplane fineness coefficient	C_w	0.841	0.841	0.85	0.766
9	Midship section coefficient	C_m	0.775	0.775	0.71	0.589
10	Prismatic coefficient	C_p	0.77	0.77	0.78	0.76
11	Wetted surface area	Ω, m²	88.3	88.3	92.64	164.82

Table 2. Results of calculation of the residual resistance coefficient of the APV 07 project in the software complex Flow Vision.

Symbol	Running speed	Running speed	Froude number	Towing resistance	Residual resistance coefficient
	v, knots	v, knots	Fr	R, kN	C_R
Value	4	2.056	0.027	4.60	0.0106
	5	2.57	0.043	6.20	0.0089
	6	3.084	0.061	8.20	0.0080
	8	4.112	0.109	15.80	0.0090
	10	5.14	0.171	24.80	0.0091

Table 3. Results of calculation of the residual resistance coefficient of the APV 07m project in the software complex Flow Vision.

Symbol	Running speed	Running speed	Froude number	Towing resistance	Residual resistance coefficient
	v, knots	v, knots	Fr	R, kN	C_R
Value	4	2.056	0.027	4.96	0.0117
	5	2.57	0.043	6.69	0.0098
	6	3.084	0.061	8.85	0.0089
	8	4.112	0.109	17.04	0.0099
	10	5.14	0.171	26.76	0.100

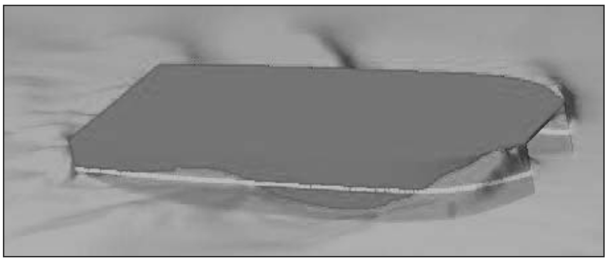

Fig. 5. Wave formation pattern for the AVP 09

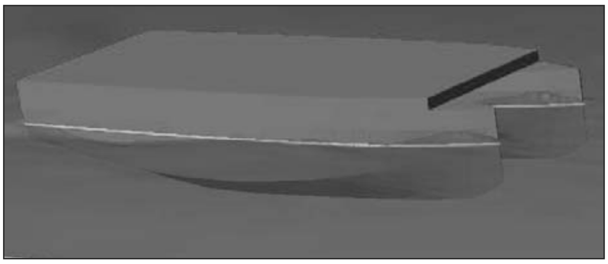

Fig. 6. Wave formation pattern for the AVP 11

Table 4. Results of calculation of the residual resistance coefficient of the APV 09 project in the software complex Flow Vision.

Symbol	Running speed	Running speed	Froude number	Towing resistance	Residual resistance coefficient
	v, knots	*v*, knots	*Fr*	*R*, kN	C_R
Value	4	2.056	0.026	6.11	0.0150
	6	3.084	0.058	12.58	0.0136
	8	4.112	0.102	22.59	0.0139
	9	4.626	0.130	30.40	0.0149
	10	5.14	0.160	35.51	0.0141

Table 5. Impact of the lateral clearance S/L_{wl}= 0.24 on the residual resistance coefficient

Symbol	Running speed	Running speed	Froude number	Towing resistance	Residual resistance coefficient
	v, knots	*v*, knots	*Fr*	*R*, kN	C_R
Value	5.49	2.82	0.040	2.47	0.0013
	8.23	4.23	0.090	9.56	0.0042
	10.97	5.64	0.160	19.43	0.0052
	12.34	6.34	0.202	58.47	0.0155
	13.71	7.05	0.250	114.03	0.0257

Table 6. Impact of the lateral clearance S/L_{wl} = 0.30 on the residual resistance coefficient

Symbol	Running speed	Running speed	Froude number	Towing resistance	Residual resistance coefficient
	v, knots	*v*, knots	*Fr*	*R*, kN	C_R
Value	5.49	2.82	0.040	2.47	0.0013
	8.23	4.23	0.090	9.26	0.0040
	10.97	5.64	0.160	22.12	0.0062
	12.34	6.34	0.202	61.87	0.0165
	13.71	7.05	0.250	84.64	0.0185

Table 7. Impact of the lateral clearance S/L_{wl} = 0.36 on the residual resistance coefficient

Symbol	Running speed	Running speed	Froude number	Towing resistance	Residual resistance coefficient
	v, knots	*v*, knots	*Fr*	*R*, kN	C_R
Value	5.49	2.82	0.040	2.53	0.0014
	8.23	4.23	0.090	8.05	0.0031
	10.97	5.64	0.160	20.78	0.0057
	12.34	6.34	0.202	55.07	0.0144
	13.71	7.05	0.250	76.25	0.0165

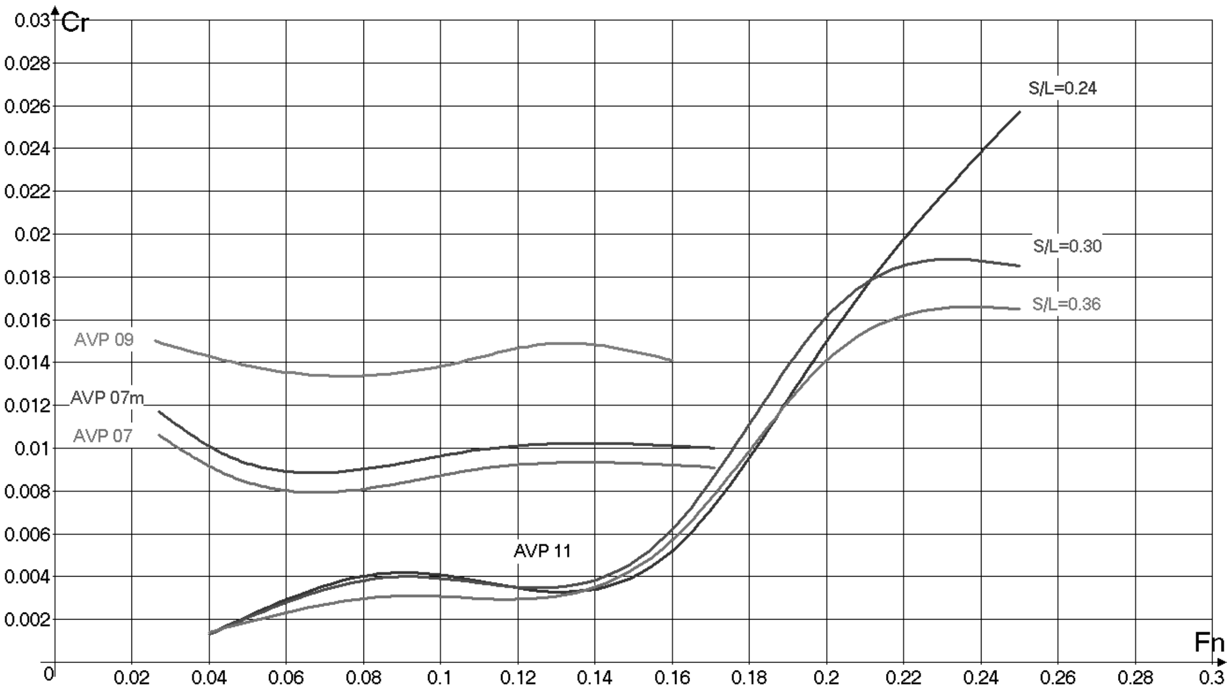

Fig. 7. Dependence of towing resistance coefficients on the Froude number

CONCLUSIONS. The paper studied the issue of towing resistance and the factors that affect its magnitude. Through CFD modeling in the Flow Vision 2.5 environment, the curves of dependence of the residual resistance coefficients on the Froude numbers were drawn for each of the projects. As shown by the comparative analysis, the simplified contours of the AVP 09 hull cause an increase in the residual resistance coefficient, which means that the power of the main engine should be increased, otherwise the vessel's running speed will decrease.

The most favorable results were shown by the AVP 11 project, as the value of its residual resistance coefficient is 1.5 times lower than that of previous models. Therefore, the hull of the AVP 11 project can be regarded as the most optimal among these models. In addition, the impact of lateral clearance on towing resistance was analyzed. As it was revealed, lateral clearance virtually does not affect the value of the residual resistance coefficient for small values of the Froude numbers. Meanwhile, for the Froude number being equal to 0.2 and above, the lateral clearance of 0.36 is the most optimal value. The obtained results have already been introduced to the catamaran production at the Artel shipyard.

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