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INFLUENCE OF THE LENGTH-DISPLACEMENT RATIO TO SHIP RESISTANCE IN A TRANSITIONAL MODE

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Abstract. *When the vessel moves in transitional mode, water resistance increases and this phenomenon requires more careful calculations for estimating the value of this resistance. Accordingly, for a vessel it is necessary to choose a higher engine power, which entails higher fuel consumption and more significant air pollution.*

When calculating the water resistance, the change in the area of the wetted surface of the vessel is taken into account when moving at a high relative speed.

Using the method least squares, a formula was derived to estimate the residuary resistance of ships moving at a different relative speed Fr_V.

The formulas for calculating the relative residuary resistance were differentiated and differential equations were obtained.

With the help of these equations, it is possible to estimate the change in the residuary resistance displacement ratio, when the Froude numbers and the length displacement ratio of the vessel are changed.

These formulas are based on an experience gained in various test tanks. A comparison of the test results of Yacht, Patrol boat and Passenger ferry models with water resistance values obtained using statistical formulas is proposed in this paper.

Keywords*: transitional mode, high-speed vessel, resistance of environment.*

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ВПЛИВ ВІДНОСНОГО ПОДОВЖЕННЯ КОРПУСУ СУДНА НА ОПІР ВОДИ В ПЕРЕХІДНОМУ РЕЖИМІ РУХУ

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Анотація. *Коли судно рухається в перехідному режимі, опір води зростає, і це явище вимагає більш ретельних розрахунків для оцінки величини цього опору. Відповідно, для судна необхідно вибирати більшу потужність двигуна, що тягне за собою більшу витрату палива і більш значне забруднення середовища.*

При розрахунку опору води враховують зміну площі змоченої поверхні судна, при русі з великою відносною швидкістю. За допомогою методу найменших квадратів було виведено формули для оцінки залишкового опору суден, що рухаються з різною відносною швидкістю Fr_V .

Зроблено диференціацію формул для розрахунку відносного залишкового опору та отримано диференціальні рівняння. За допомогою цих рівнянь можна оцінити зміну залишкового опору, при різних числах Фруда та різних значеннях відносного подовження корпусу судна.

Ці формули базуються на досвіді, отриманому в різних дослідних басейнах. У цій статті запропоновано порівняння результатів випробувань моделей яхти, патрульного катера і пасажирського порому із значеннями опору води, отриманими за допомогою статистичних формул.

Ключові слова: *перехідний режим, швидкісне судно, опір середовища.*

Introduction. Currently, there are many programs for calculation of the water resistance. These programs are based on model test data in towing tanks, data on real ships, approximate formulas. Preliminary calculation of the water resistance to the movement of the vessel, at the first stages of the project, is extremely important, as it is associated with further improvement of the shape of the ship's contours, assessment of the weights, layout of the premises and many others goals. If it is possible to compare several types of calculations, then there are additional opportunities for analysis. The formulas obtained using statistical analysis, based on data from a large number of tests in the towing tanks, take into account many parameters of ship hulls: length displacement ratio, coefficients, the ratio of the vessel's width to its draft, and much more.

It becomes possible to compare the calculation results using a statistical formula and real data obtained in the towing tanks for a real ship, for different Froude numbers. After differentiating the statistical formulas, it becomes possible to estimate the increase in resistance, with a change in the length displacement ratio. Calculations of water resistance for ships of the transitional mode of motion are specific. When moving at relative speeds of this mode, the trim appears the area of the wetted surface changes. With the increase of the speed of the vessel, during the transitional mode, the bow rises, and the bottom of the vessel will be moved with the angle of attack to the surface of the water. Additional force directed perpendicular to the bottom of the vessel arises. Froude number based on volume is between $1 < Fr_V < 3$.

The purpose of this article is to compare different variants for calculating the resistance of water to the movement of vessels in a transitional mode and to determine the influence of length-displacement ratio to ship resistance in this mode.

Literature review. Regarding resistance of high-speed vessels of the transitional mode, large experimental experience for different relation of main dimensions, type of hull and coefficients of ship exists [1]. Total resistance consists: frictional, residuary, air and appendage resistance.

A series of tests included a large range of values $\frac{L}{B}$, $\frac{B}{d}$, C_B, C_P, and various forms of hull, with the U- and V-shaped contours, vary the half angle of entrance.

There are studies by some authors in the field of preliminary determination of ship resistance for high-speed vessels in transitional mode. For example [2], the article discusses the method of preliminary design of a high-speed monohull ferry. A mathematical model is proposed, but specific recommendations for determining the water resistance are not given.

Another interesting work [3] is devoted to the preliminary determination of the main dimensions of small vessels in the transitional mode. Using the data in this article, the water resistance for a vessel with a limited length and a fixed relative width can be determined.

Article [4] contains extensive recommendations for determining the water resistance of round-bilge high speed craft based on tests in various towing tanks. Hard-chine hull forms are not considered and method for calculating water resistance is not provided.

One of the latest works devoted to the issues of energy efficiency of ships and showing the connection between economics, ship design and operation of vessel is the article [5].

Analysis of data from towing tanks. The data have been obtained from various sources were analyzed to estimate the approximate value of the residuary resistance displacement ratio $\frac{R_R}{\Delta}$ and its dependence on the parameters of transitional mode vessels.

Results of the study based on the residuary resistance displacement ratio $\frac{R_R}{\Delta}$ and values of the length displacement ratio $\frac{L}{\sqrt[3]{V}}$ shown on Figure 1.

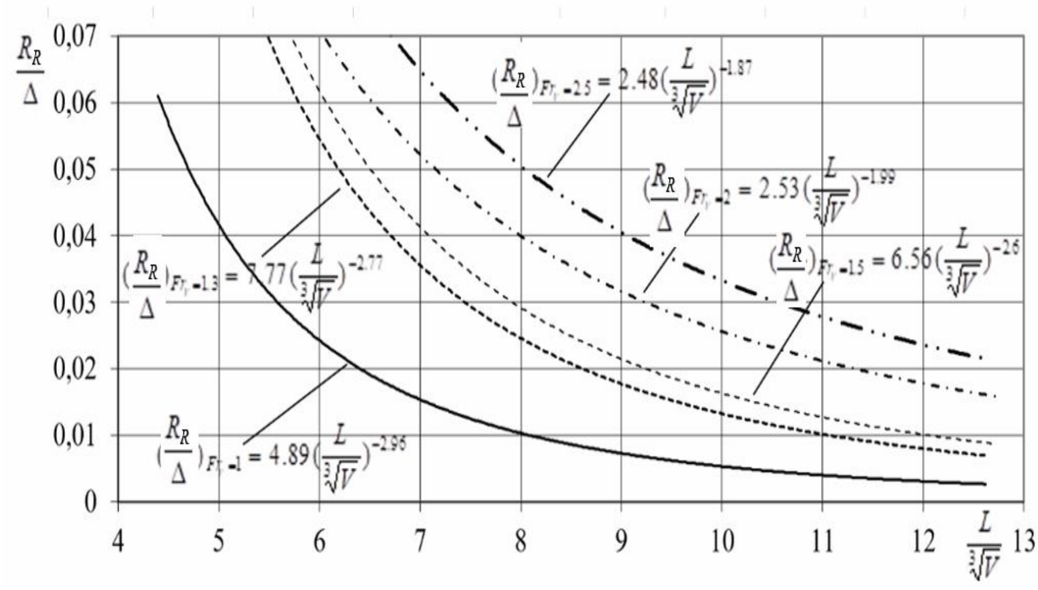

Fig. 1. Residuary resistance displacement ratio $\frac{R_R}{\Delta}$ *on* $\frac{L}{\sqrt[3]{V}}$*, at different* Fr_V

Some of these curves and formulas have been described in [6]. The residuary resistance is quite a large part, on the average, about 70% of the total resistance in the transitional mode.

The curves in Figure 1 and formulas (1-5) were obtained by the least squares method and are characterized by an approximation probability close to 0.9.

$$(\frac{R_R}{\Delta})_{Fr_V=1} = 4.89(\frac{L}{\sqrt[3]{V}})^{-2.96} \quad (1)$$

$$(\frac{R_R}{\Delta})_{Fr_V=1.3} = 7.77(\frac{L}{\sqrt[3]{V}})^{-2.77} \quad (2)$$

$$(\frac{R_R}{\Delta})_{Fr_V=1.5} = 6.56(\frac{L}{\sqrt[3]{V}})^{-2.6} \quad (3)$$

$$\left(\frac{R_R}{\Delta}\right)_{Fr_V=2} = 2.53\left(\frac{L}{\sqrt[3]{V}}\right)^{-1.99} \quad (4)$$

$$\left(\frac{R_R}{\Delta}\right)_{Fr_V=2.5} = 2.48\left(\frac{L}{\sqrt[3]{V}}\right)^{-1.87} \quad (5)$$

This formula allows to estimate residuary resistance displacement ratio at a different relative speed.

After differentiating equations (1), (3) and (5), we obtain

$$d\left(\frac{R_R}{\Delta}\right)_{Fr_V=1} = -14.47\left(\frac{L}{\sqrt[3]{V}}\right)^{-3.96} d\left(\frac{L}{\sqrt[3]{V}}\right) \quad (6)$$

$$d\left(\frac{R_R}{\Delta}\right)_{Fr_V=1.5} = -17.1\left(\frac{L}{\sqrt[3]{V}}\right)^{-3.6} d\left(\frac{L}{\sqrt[3]{V}}\right) \quad (7)$$

$$d\left(\frac{R_R}{\Delta}\right)_{Fr_V=2.5} = -4.64\left(\frac{L}{\sqrt[3]{V}}\right)^{-2.87} d\left(\frac{L}{\sqrt[3]{V}}\right) \quad (8)$$

Using these equations, it becomes possible to estimate how the residuary resistance displacement ratio changes with an increase in the relative speed, with an increase in the length displacement ratio by one unit $d\left(\frac{L}{\sqrt[3]{V}}\right)$.

To check the calculations, using the formulas, three vessels were selected, Fig. (2-4) and Table 1. In the transitional mode, round-bilge and hard-chine hull forms are widely used. A mixed variant, using both options, has also found its application.

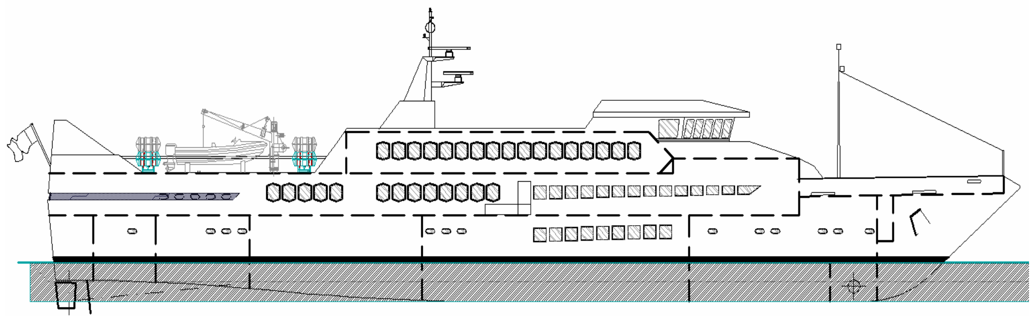

Fig. 2. General arrangement of Passenger ferry

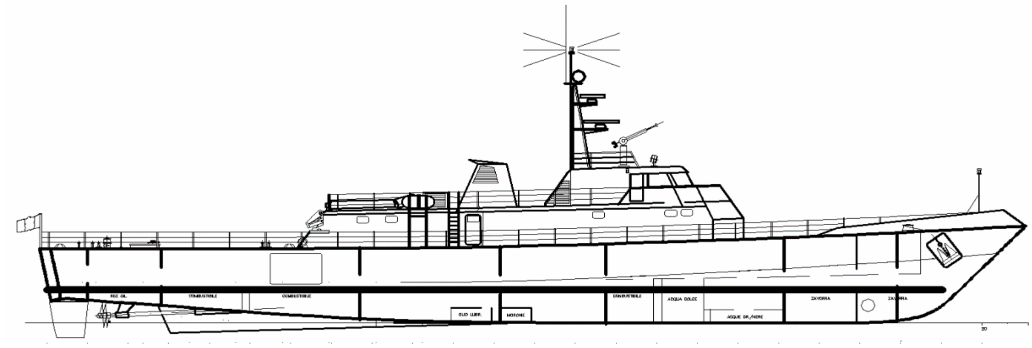

Fig. 3. General arrangement of Patrol boat

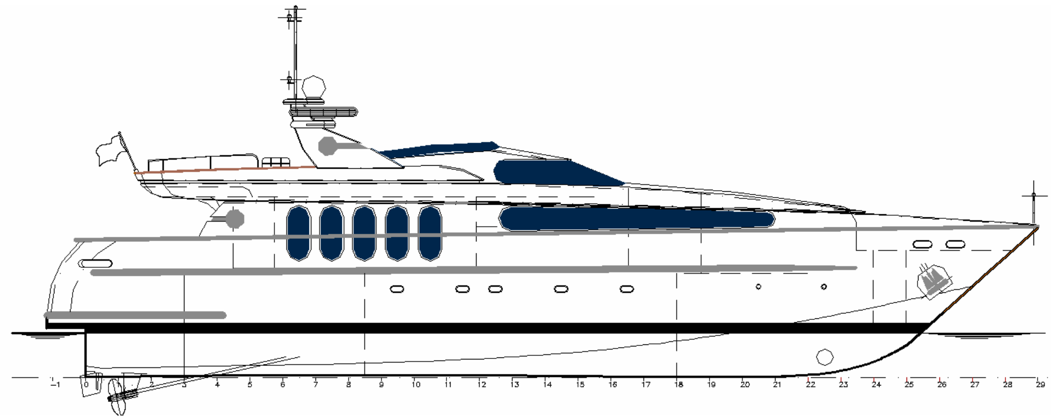

Fig. 4. General arrangement of Yacht

Table 1

Main dimensions of ships

Name	Length L_{pp}, m	Width B, m	Draft d, m	Displacement, t	Block coefficient	Speed v, kn	Fr_V	$\frac{L}{\sqrt[3]{V}}$
Passenger ferry	55,9	9,43	2,17	469,7	0,4	30	1,8	7,3
Patrol boat	51,6	8,13	2,11	360	0,396	34	2,1	7,3
Yacht	28,5	5,46	1,39	105	0,472	27	2,0	6,1

Figure 5 shows the calculation by formulas (6-8) for Passenger ferry and Patrol boat with length displacement ratio $\frac{L}{\sqrt[3]{V}} = 7.3$ and Yacht with length displacement ratio $\frac{L}{\sqrt[3]{V}} = 6.1$ and for several other length displacement ratios.

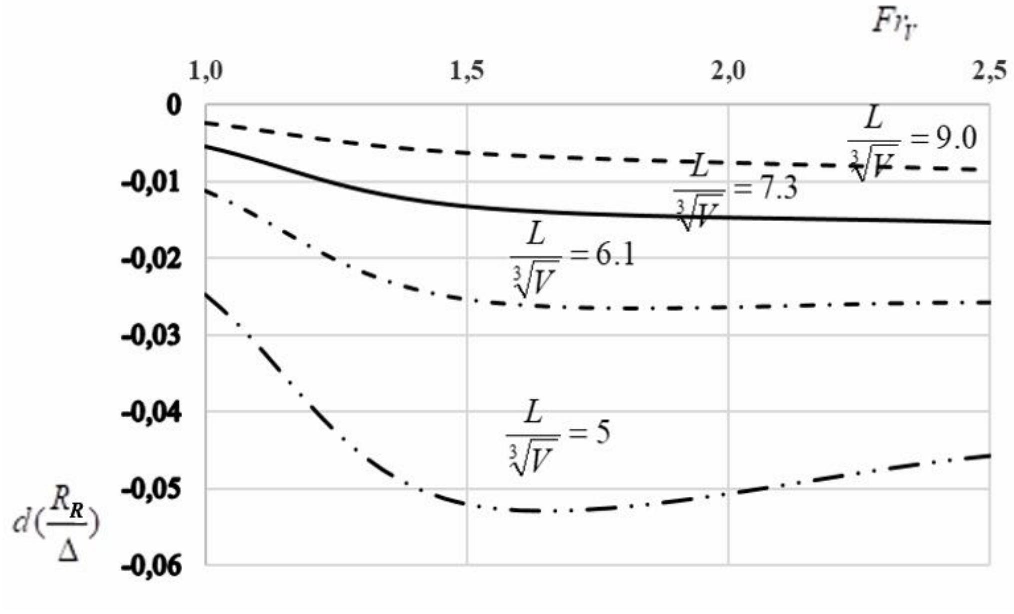

Fig. 5. The influence of the change of the length displacement ratio to residuary resistance displacement ratio

As can be seen from Figure 5, the maximum reduction in the residuary resistance displacement ratio due to a change in the length displacement ratio can be achieved at relative velocities $Fr_V = 1.5$ and more. For ships with a small length displacement ratio, such a decrease in water resistance is clearer.

Models of the vessels, Table 1, were tested in the Maritime Research Institute Netherlands. The ships have a relative speeds of the transitional mode of motion.

In order to compare the results of calculations: tests of models in the towing tank and the calculations made according to the formulas (1-5), Figure 6, were constructed.

It can be seen from the graph, the results of calculations by formulas (1-5) differ from the test results an average of 9 % for Patrol boat and Passenger ferry. The results of calculations by formulas (1-5) differ from the test results an average of 26 % for Yacht.

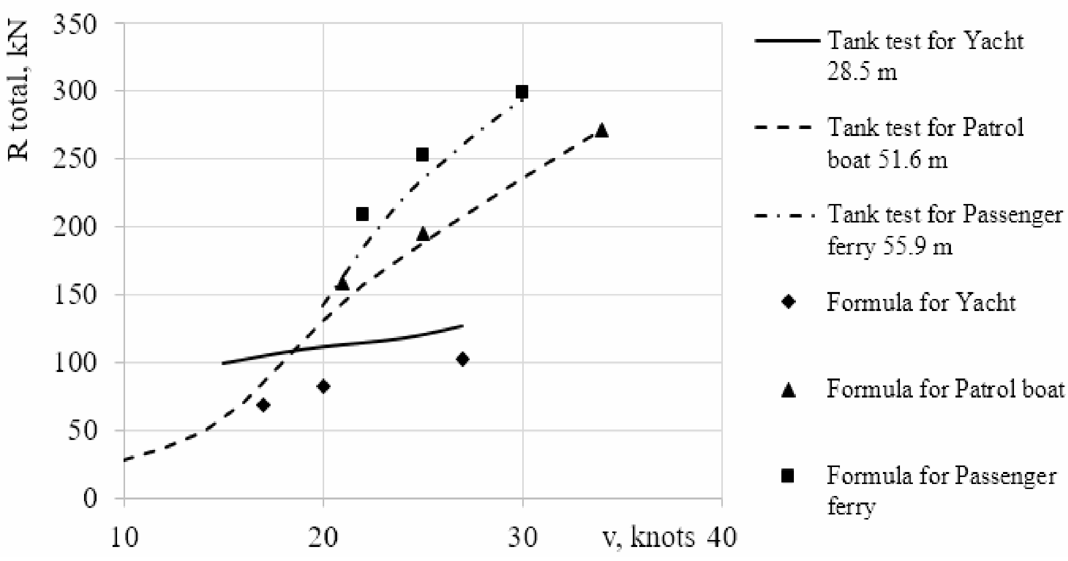

Fig. 6. Results of tests and calculations according to the formulas (1-5)

Conclusions. The values of the water resistance according to the formulas (1-5) were obtained that make it possible to evaluate the accuracy of these methods. The error in applying this method can average range from 9 to 26 % for chosen ships. After the differentiation of formulas (1), (3) and (5), it became possible to evaluate the relationship between the length displacement ratio values, Froude numbers and residuary resistance displacement ratio, Fig. 5. The maximum reduction in the residuary resistance displacement ratio due to a change in the length displacement ratio can be achieved at relative velocities Fr_V = 1.5 and more. Such a decrease in water resistance has more pronounced character for ships with a small length displacement ratio. The method proposed in this article can be used for vessels with a wide range of design characteristics: round-bilge and hard chine hull forms, and not only, for example, round bilge as in article [4]. Using the formulas of our proposed work, the designer can consider a wide range of dimensionless characteristics of the ship's hull: $\frac{L}{B}$, $\frac{B}{d}$, C_B, C_P, U – and V – shaped contours forms of hull, different values of the half angle of the entrance of the waterline. The main novelty of the proposed work is the ability to evaluate, qualitatively and quantitatively, the influence of the change of the length displacement ratio to residuary resistance displacement ratio, at different Froude numbers. In addition, the designer has the opportunity to evaluate the water resistance for high-speed vessels, with a wide range of design characteristics, at the first stage of the project.

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