Water resistance forecasting of the icebreaking aircushion platform

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Abstract. The forecasting resistance method of the icebreaking platform, based on dummy tests in NSTU experimental model ice basin is proposed in the article. Experimental research data of ice breaking air cushion platforms resistance in calm water are presented. The dummy tests main results taking into account the key parameters influencing the platform resistance are given. The effect analysis of aircushion pressure, airflow, icebreaking platform velocity, aircushion size ratio in plan and the variable basin depth on wave resistance is made. The formula of water resistance calculation is proposed.

1. Introduction

The icebreaking aircushion platforms are fundamentally different from other hovercraft not only in their functional purpose, but also in their operating features. The characteristic features of icebreaking platforms are relatively high-pressure values in an air cushion, about 5–10 kPa, and low operating speeds (up to 15 km/h). Basically, icebreaking aircushion platforms are non-self-propelled and their movement mode corresponds to subcritical speeds, when displacement-Froude number does not exceed 0.3 ($F_{rv} < 0.3$). For solving the optimal design problem of the icebreaking platforms it is essential to know the ship resistance to movement in clear water. Analytically, it can be defined as a combination of different nature and importance components with the proviso of weather and load conditions. In the general case, when the hovercraft moves above the water surface, the total resistance in clear water can be divided into the following components [1]:

$$R = R_a + R_{wave} + R_{w} + R_{wave} + R_{wave}^{\text{dop}},$$

(1)

where $R_a$ – air or aerodynamic resistance, $R_{wave}^{\text{dop}}$ – impulse resistance, $R_w$ – wave resistance, $R_{oct}$ – residual resistance, $R_{wave}^{\text{dop}}$ – additional wave-making resistance.

Due to the low operational speeds, the air resistance of the icebreaking platforms can be neglected; impulse resistance is of small values too, and in the resistance formula, it is taken into account indirectly.

The additional wave-making resistance component is almost entirely determined by flexible seal resistance, although, undoubtedly, both hovercraft wave resistance and impulse resistance will vary in wave’s motion. In the prototype absence $R_{wave}^{\text{dop}}$ can be determined through its relative value $R_{wave}^{\text{dop}}/D_g$, which is determined by the schedule depending on the Froude number and the estimated wave height to the flexible seal height ratio. However, the formula is valid for Froude numbers from 0.5, meanwhile the platforms operate in the range $0 \leq F_{r_L} \leq 0.3$. 

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Due to the fact that icebreaking platforms are characterized by relatively low speeds - about 15 km/h – many of methods for wave resistance determination are not applicable for this type of vehicles. Most of them have a lower speed limit for determining resistance equal to about 7-8 m/s, which exceeds the value of the operational speed of icebreaking air cushion platforms. Formulas Bolshakov V.P. [2], V.P. Bolshakov- V.A. Letvinenko, T.A. Zaitseva contain wave resistance coefficients, whose values are removed from the graphs. The minimum value of the relative velocity for the coefficients included in the above formulas is \( Fr_V = 0.3 - 0.45 \). Newman and Paul, Havelok and others [3] graphs data do not contain the values of wave resistance coefficients for L/B ratio that correspond to icebreaking platforms.

The wave resistance calculated by analytic formula differs significantly from the experimental data (figure 1). Accordingly, resistance forecasting for icebreaking aircushion platforms even for water at low operating speeds causes significant difficulties.

![Figure 1](image1.png)

**Figure 1** The calculation results of resistance to motion in clear water for icebreaking air cushion platform 107P according to analytical dependencies and experimental data.

- resistance experimental data of icebreaking aircushion platform 107P
- data to the analytical formula

As can be seen from figure 1, analytical and experimental data on the resistance evaluation of an icebreaking platform show a large scatter of the obtained values. Recent studies on hovercrafts [4,5,6,7,8] deal with the definition of resistance, but the focus is on the Froude numbers greater than 0.25.

Therefore, to determine the icebreaking platform resistance at low operating speeds, and at corresponding pressures and air flow rates, dummy tests were carried out in the NSTU experimental model ice basin.

2. **Investigated models and equipment for experimental data**

The models basic characteristics are presented in Table 1.

| Model number | Aircushion length, m | Aircushion breadth, m | Depth, m | L/B ratio | Flexible seal height, m |
|--------------|----------------------|-----------------------|----------|----------|------------------------|
| 1            | 0.83                 | 0.71                  | 0.10     | 1.14     | 0.060                  |
| 2            | 0.83                 | 0.59                  | 0.10     | 1.41     | 0.060                  |
| 3            | 0.59                 | 0.83                  | 0.10     | 0.71     | 0.060                  |
Models are made of polyfoam and plexiglas, and a flexible seal - from a fabric «waterproof nylon cloth». On models a lifting complex is installed, consisting of a DC motor and a centrifugal fan. During the tests, the air cushion pressure was varied by taking the solid ballast, and the airflow - by varying the fan speed. The model weight, air cushion pressure, airflow rate, the model speed and the resistance were measured during the tests. Ballasting of icebreaking platform models was carried out by placing cargo to the required values of displacement and pressure in the air cushion. When studying the shallow effect on the resistance, wooden chocks were placed on the basin bottom, which were subsequently covered with iron sheets. The water level was measured along the accelerating and measuring section entire length. Due to the chocks the necessary pool depth was reached. A model tests fragment of icebreaking air cushion platforms is presented in figure 2.

Figure 2. Model tests fragment of icebreaking platforms in clear water

3. Model tests results
The icebreaking aircushion platforms resistance depends on many factors, such as length, weight, pressure, flow rate, speed, and others. The icebreaking platforms resistance in clean water can be written in the form

\[ R = f_1(m, L, B, H_b, g, \rho_a, P_{\text{tip}}, Q, \ldots) \]

By selecting the most important parameters, in our view, formula (6) is written as follows:

\[ \frac{R}{Dg} = f_1(Fr_v)^m \cdot f_2(q) \cdot f_3\left(\frac{L}{B}\right)^n \cdot f_4\left(\frac{H_b}{H_{\text{tip}}}ight)^p, \]

where \( Fr_v \) - displacement-Froude number; \( q \) - dimensionless airflow; \( L \) - aircushion length, m; \( B \) - aircushion breadth, m; \( H_b \) - basin depth, m.

Model 1 with \( L/B\approx1 \) was accepted as the base, and the model weight varied from 14 to 21 kg while keeping constant airflow rates. Dimensionless resistance for this model is expressed by formula:

\[ \frac{R}{mg} = f_1(Fr_v) = \alpha \cdot Fr^0, \]

Using least-squares method in Microsoft Office Excel the unknown quantity has been found. Consequently, the formula takes the form:

\[ \frac{R}{mg} = 0.32 \cdot Fr_v^{2.5} \]

A standard deviation not exceeding 10%. Formula (5) corresponds to experimental conditions and is valid for ranges \( 0 \leq Fr_v \leq 0.40 \), \( 0 \leq Fr_L \leq 0.30 \).
In test with model 1 the dimensionless airflow has been also estimated. Two ranges of dimensionless airflow rates are considered in the article. The first ranged from 0.0007 to 0.0013. The tests in clear water showed that such a change is insignificant, however it affects the resistance. The resistance results of model 1 are shown in figure 3.

\[ \frac{\Delta - Q}{\bar{q}} = 0.00932 \text{m}^3/\text{s}, \quad \bar{\Delta} - Q = 0.01266 \text{m}^3/\text{s}, \quad \cdot - Q = 0.01337 \text{m}^3/\text{s} \]

Figure 3. Dimensionless resistance of model 1 (weight 17.58 kg)

× - Q = 0.00932 m³/s, \( \bar{\Delta} - Q = 0.01266 \text{m}^3/\text{s} \), • - Q = 0.01337 \text{m}^3/\text{s}

An analysis of the data obtained showed, that function \( f_2 \) takes the following form:

\[ f_2 \left( \frac{-q}{q} \right) = 0.07 \cdot \left( \frac{-q}{q} \right)^{-0.41} \] \hspace{1cm} (6)

The second airflow range \( \bar{q} \) was investigated from 0.0020 to 0.0036[10]. Clear water tests showed that this change practically did not affect the resistance. Thus, the value of a function in the range can be taken as one \( f_2 \left( \bar{q} \right) = 1 \) [10].

In test with models 1, 2 and 3 the L/B ratio on models resistance has been estimated. These L/B ratios were in limits 0.71 < L/B < 1.41 characteristic for already built and designed icebreaking aircushion platforms. When the L/B ratio changed, the pressure in the air cushion remained constant. The resulting curves can be seen in figure 4.

\[ \bullet \cdot - m = 14.6 \text{kg}, \quad \text{PCA} = 263.5 \text{Pa}, \quad Q = 0.01266 \text{m}^3/\text{s}, \] \( \bar{\Delta} - m = 14.6 \text{kg}, \quad \text{PCA} = 263.5 \text{Pa}, \quad Q = 0.01266 \text{m}^3/\text{s}, \) \( \cdot - m = 14.6 \text{kg}, \quad \text{PCA} = 263.5 \text{Pa}, \quad Q = 0.01266 \text{m}^3/\text{s} \), \( \cdot \cdot - \text{L/B} = 1.41 \)

Figure 4. L/B ratio influence on the resistance of icebreaking platform models

\( \bullet \cdot - m = 14.6 \text{kg}, \quad \text{PCA} = 263.5 \text{Pa}, \quad Q = 0.01266 \text{m}^3/\text{s}, \) \( \bar{\Delta} - m = 14.6 \text{kg}, \quad \text{PCA} = 263.5 \text{Pa}, \quad Q = 0.01266 \text{m}^3/\text{s}, \) \( \cdot - \text{L/B} = 1.17 \); \( \bullet \cdot - m = 14.6 \text{kg}, \quad \text{PCA} = 263.5 \text{Pa}, \quad Q = 0.01266 \text{m}^3/\text{s}, \) \( \cdot \cdot - \text{L/B} = 1.41 \)
The function \( f_3(L/B)^m \) is represented by the following form:

\[
f_3\left(\frac{L}{B}\right)^m = \left(\frac{L}{B}\right)^{-0.31}
\]

Its values are valid in the specified velocities and \( L/B \) ratio range.

In test with model 1 the resistance in deep water and shallow water has also been estimated. A characteristic dimensionless parameter that determines the shallow water effect, can serve as a \( \frac{H_6}{h_{kn}} \) ratio. For each displacement-Froude number, dimensionless resistance values were taken for a model with the corresponding \( \frac{H_6}{h_{kn}} \) ratio and the resulting curves were constructed. The results analysis allowed to establish that the function \( f_4\left(\frac{H_6}{h_{kn}}\right) \) in the range of velocities considered is determined by the dependence, which can be approximated in the form:

\[
f_4\left(\frac{H_6}{h_{kn}}\right) = \left(\frac{H_6}{h_{kn}}\right)^{1.05} + 1
\]

Consequently, the formula of resistance to ACV motion in clear water takes the form:

\[
0.0007 \leq q \leq 0.0013 \Rightarrow R = \left(0.32 \cdot Fr_v^{2.5}\right) \times \left(0.07 \cdot \left(\frac{L}{B}\right)^{0.31}\right) \times \left(\frac{1.05}{\frac{H_6}{h_{kn}}^{1.6}} + 1\right) \cdot m \cdot g
\]

\[
0.0022 \leq q \leq 0.0036 \Rightarrow R = \left(0.32 \cdot Fr_v^{2.5}\right) \times \left(\frac{L}{B}\right)^{0.31} \times \left(\frac{1.05}{\frac{H_6}{h_{kn}}^{1.6}} + 1\right) \cdot m \cdot g
\]

4. **Conclusion**

In order to assess the obtained dependence adequacy, the full-scale data results of icebreaking aircushion platforms VP-1 and 107P were used in deep water. The formula shows a good convergence with the full-scale data (figure 5, figure 6). With this in mind, icebreaking platform models testing and comparison with full-scale data allows to recommend the formula (9) for icebreaking platform resistance forecasting at low speed in clear water.

![Figure 5](image_url)

**Figure 5.** Resulting curves full-scale data of VP-1 icebreaking platform with the proposed formula (9)

- - full-scale data - theoretical resistance curve
Figure 6. Resulting curves full-scale data of 107P icebreaking platform with the proposed formula (9)

- full-scale data
- theoretical resistance curve

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