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Experimental Verification of Mathematical Model of the Supercavitating Underwater Vehicle Dynamics

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Abstract: This paper considers the mathematical model of a supercavitating underwater vehicle dynamics, which is based on the complete set of equations of 6DOF motion of an elongated solid body. An approximation model of a "slender" cavity is used to calculate the supercavitation flow. It is based on the G.V.Logvinovich's principle of independence of the cavity section expansion. To calculate the hydrodynamic forces acting on various structural elements of the underwater vehicle, the approximation dependencies are used. Verification of the developed mathematical model of the supercavitating underwater vehicle dynamics "in whole" was performed by comparing the calculated kinematic parameters with analogous parameters obtained during towing tests of the supercavitating underwater vehicle model in the experimental tank. To determine kinematic parameters of the cavitation flow and the schematized underwater vehicle model, the underwater video-shooting in the coordinates of the towing trolley was used during the tests. During the towing tests, the various variants of the motion of the schematized underwater vehicle model in the cavity were organized. In particular, these were: planing along the lower cavity wall, planing along the upper cavity wall, motion with the fins without touching the cavity walls by the model body, oscillatory motion between the upper and lower cavity walls.

Keywords: supercavitating underwater vehicle, mathematical model of dynamics, towing tests, verification.

1. Introduction

In the process of creating supercavitating underwater vehicles, it becomes necessary to estimate their dynamic properties at the early stages of design. For this, a complete set of equations for the 3D motion of an elongated solid body is used. On its basis, at the Institute of Hydromechanics of the National Academy of Sciences of Ukraine, a mathematical model has been developed for computer simulation of the dynamics of supercavitating underwater vehicles [1-3]. To calculate the cavity shape, we used an approximation mathematical model of a "slender" unsteady cavity based on the G.V.Logvinovich's principle of independence of the cavity section expansion [4,5]. Various approximation dependencies obtained on the basis of experimental data or exact solutions are used to determine the hydrodynamic forces acting on various structural elements of the underwater vehicle (cavitator, body, fins). As a result, the "fast" computational algorithms have been developed that make it possible to observe on a computer screen the dynamic behavior of supercavitating models directly during the computation.

For practical use, verification of the simplified mathematical models of the dynamics of supercaviting underwater vehicles should be performed. Verification is realized by comparing the calculated data with the results of model experiments. As a rule, the model experiments are carried out in hydrodynamic tunnels. In this case, the tested model is fixed motionlessly on a multicomponent dynamometer, and the mainstream direction is changed due to rotary hydrodynamic fins, which are

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mounted in front of the model [6], or a rotary cavitator [7]. This kind of verification fits good for verifying the correctness of determination of the hydrodynamic forces acting on the structural elements of the underwater vehicle. But to verify the mathematical model of the underwater vehicle dynamics "in whole", it is necessary to carry out an experiment in which the model has the ability to move freely in space under action of the hydrodynamic forces. Therefore, *experimental verification of the simplified mathematical models of the supercavitating underwater vehicle dynamics "in whole" seems to be an actual task.*

The work aim is to verify experimentally "in wohle" the mathematical model and computational algorithms developed for computer simulation of the supercavitating underwater vehicle dynamics.

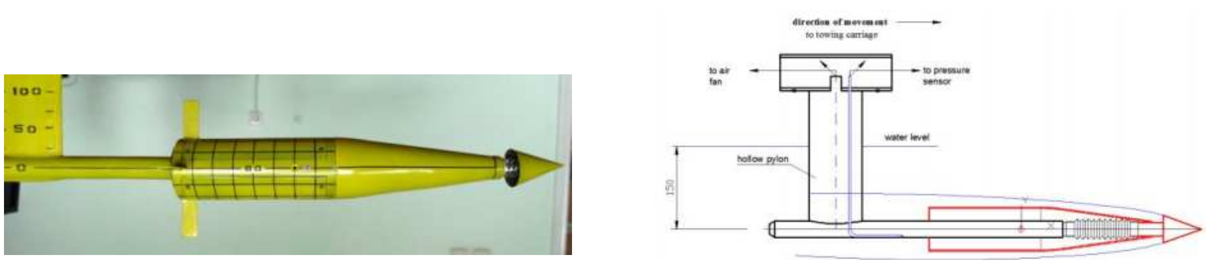
Verification of the developed mathematical model of the supercavitating underwater vehicle dynamics "in whole" was ***performed by comparing the calculated kinematic parameters with analogous parameters obtained during towing tests of the supercavitating underwater vehicle model in the experimental tank.***

2. Description of the test rig and method of the experiment performing

Experimental investigations were carried out in the high-speed experimental tank of the Institute of Hydromechanics of the National Academy of Sciences of Ukraine [8,9]. The high-speed experimental tank has length 140 m, width 4 m and depth 1.8 m. Experimental investigations were carried out by performing the towing tests of models in the range of towing velocities from 8 to 10 m/s.

Earlier, this test rig was used to verify experimentally the relations for the hydrodynamic forces acting on the inclined disk and conical cavitators and on the cylinder planing within the cavity.

To verify the mathematical model of the supercavitating underwater vehicle dynamics "in whole", a schematized model was made (see Figure 1-*a*).



(a) *(b)*

Figure 1. Appearance *(a)* and suspension scheme of the schematized model *(b)*.

The model body is a combination of conical and cylindrical surfaces. The cylindrical surface has diameter 80 mm and length 200 mm. The model was made hollow. There were several lead weights moving along the length inside the model. They were intended to balance the model with respect to the specified mass center. Within the framework of this work, a cone cavitator with the base diameter 50 mm and the cone angle 40 degrees was used. In the aft part of the schematized model, the rotary vertical and horizontal fins were mounted. The fins had a wedge-shaped profile in cross-section. The air was supplied into the cavity through a system of ventilation holes located directly behind the cavitator.

The schematized model of a supercavitating underwater vehicle was mounted to a suspension, the scheme of which is shown in Figure 1-b. The suspension consisted of a hollow pylon, in the upper part of which there were elements for mounting it to the towing trolley of the experimental tank. The lower part of the pylon was connected to the model using a flexible elastic corrugated tube, which allowed the model to turn freely about the suspension point in the longitudinal-vertical plane. The suspension point of the model coincided with its mass center. A drainage tube was laid through the inner hollow of the

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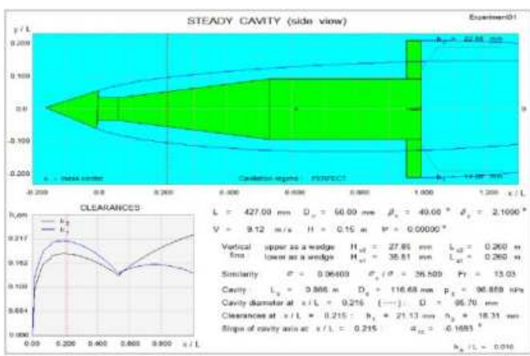
pylon to measuring the cavity pressure. The air was supplied into the cavity forcedly using an axial fan. During the experiments we used underwater video-shooting in the coordinates of the towing trolley to determine the kinematic parameters of the schematized model.

3. Results and analysis of the experimental investigations

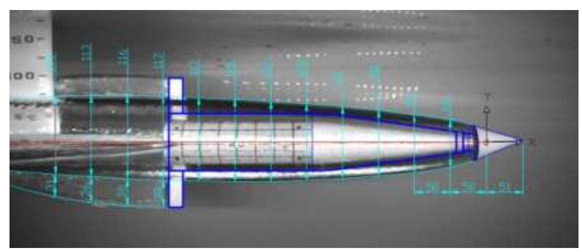
Several series of towing tests of the schematized model were carried out in the experimental tank. In this case, the model immersion depth was set about 150 mm.

To verify the mathematical model, we performed several series of computations of the supercavitating model dynamics. Parameters of calculated model fully corresponded to the schematized model of the underwater vehicle in Figure 1.

First of all, the calculation formulae used to determine the cavity shape and dimensions were verified. In particular, the motion regime without touching the cavity walls with the model body was investigated (see Figure 2). A comparison showed that the cavity dimensions obtained by calculation and in experiment differ in all the cross-sections by no more than 3%.



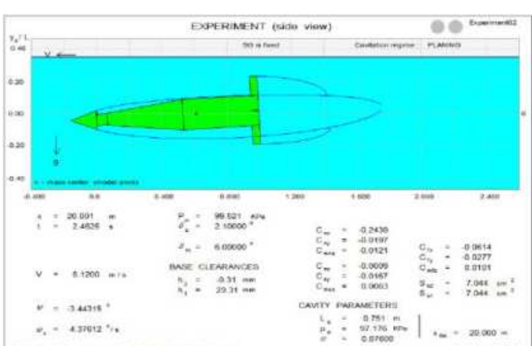
(a)



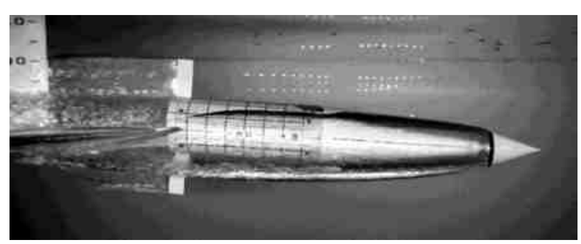
(b)

Figure 2. Comparison of the cavity shape in the motion regime without touching the cavity walls:
(a) calculation; *(b)* experiment

Figure 3 shows the model motion regime with planing along the upper cavity wall. In this regime, the model performs several damped oscillations and reaches the steady-state motion regime with a running trim about $\psi = -3.4°$.



(a)



(b)

Figure 3. Planing of the model along the upper cavity wall:
(a) calculation; *(b)* experiment

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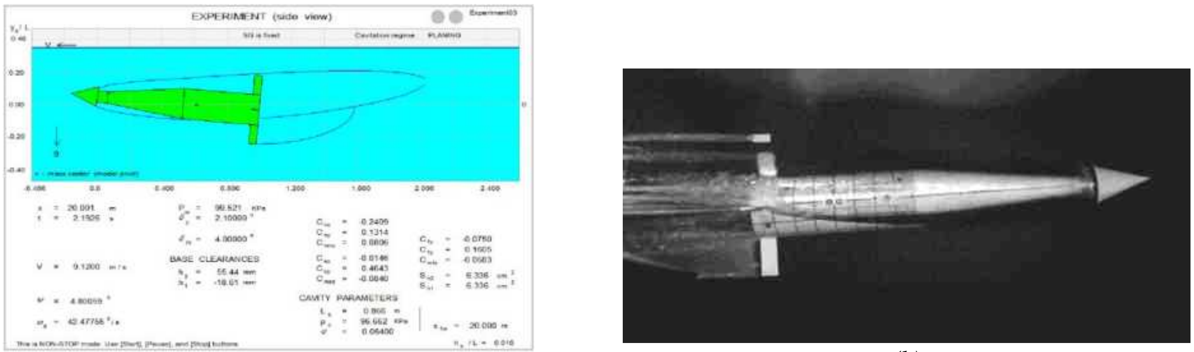
Figure 4 shows the unsteady regime of the model motion. In this regime, the model performs steady angular oscillation ricocheting by turns from both the upper and the lower cavity walls, between the values $\psi = -5.4°$ and $\psi = 4.9°$ with the frequency $f = 4.6$ Hz.



(a) *(b)*

Figure 4. Ricocheting of the model from the upper and the lower cavity walls:
(a) calculation; *(b)* experiment

4. Conclusions

Comparison of the cavity shapes and the kinematic characteristics of the schematized model, obtained by calculation and in experiment, has shown that the mathematical model developed at the Institute of Hydromechanics of the National Academy of Sciences of Ukraine allows to adequately predict the dynamic behavior of supercavitating underwater vehicles with accuracy sufficient for practice.

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