APPLICATION OF THE VISCOUS VORTEX DOMAINS METHOD FOR TADPOLE MOTION ANALYSIS

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Abstract. Viscous vortex domains method [1, 2] was developed for solving 2D Navier-Stokes equations numerically. It is mesh-free Lagrangian method, which is convenient for the investigation of the flow-body interaction. The feature of the VVD method is to solve dynamic and hydrodynamic equations at the same time without splitting it into 2 steps, which leads to good precision without computational costs encrease even in case of null mass.

In this study existence of tadpole is being investigated from the point of view of its energy consumption. The simplified model of tadpole consists of elliptical body and segment tail. The tail performs rotary oscillations by a given harmonic law. The body can move along the straight line without rotation. Tail length and oscillations amplitude and frequency were varied, and the energy consumption dependency was measured. The aim was to find more power safe mode.

Introduction.

Investigation and simulation of living objects are at great inteest as they can shed light on a problems of nature and to help develop technology. Simulation of body, moving in air or water requires to solve coupled problem of the flow-body interaction. For this purpose the mesh-free methods are the most convenient as they easily allow to simulate deformations.

Statement of the problem.

Motion along a straight line of a tadpole in viscous fluid is being simulated. The coupled problem is being solved in two-dimensional infinite space. Tadpole consist of elliptical body and segment tail (Ffig. 1), which performs rotary oscillations by a given harmonic law. The angle of tadpoles tail is described by the function $\theta(t) = A_\theta \cos(2\pi f t)$, where $A_\theta = \arcsin\left(A / L_t\right)$ is the amplitude, and f is the frequency of an oscillations. In present study body propotions are selected to be realistic as follows: $D_h/L_h = \left(\sqrt{5}-1\right)/2$ (the golden ratio), lenght of tail $L_t/L_h = 2.25$.

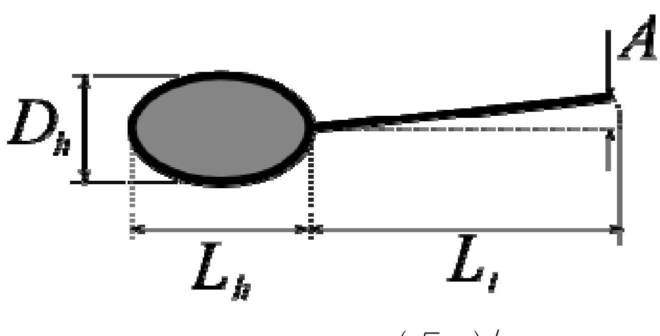

Figure 1. Tadpole model. $D_h/L_h = \left(\sqrt{5}-1\right)/2$. $L_t/L_h = 2.25$

Fluid flow obeys Navier-Stokes equations. Boundary conditions are no-slip on a surface and no-perturbations at infinity.

Results obtained. The main value, obtained in simulations, is the motion plot and consumed energy to support this motion. Example of them is shown at fig. 2. All values plotted are dimentional and agree with case $L_h = 1sm,\ A = 0.4sm,\ f = 4Hz,\ \nu = 10^{-2}\ sm^2/s$ (water). Results for other cases look similar, but has different values.

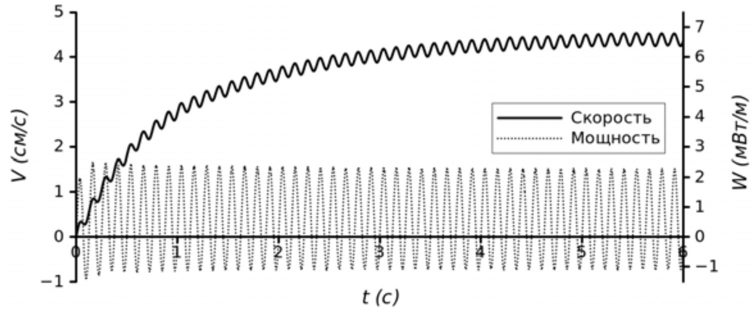

Figure 2. An example of results obtained. $L_h = 1 см,\ A = 0.4 см,\ f = 4 Гц,\ \nu = 10^{-2}\ см^2/с$.
Solid line – motion speed, dotted line – power consumed.

From the Fig. 2 one can see, that after short acceleration section motion becomes quasisteady. Energy consumed changes with period, and sometimes turns out to be negative. It means that tail does negative work. In mechatronic system recuperation is possible; in that case these interims must be taken into account with corresponding coefficient of recuperation. In living systems recuperation doesn't occur, thus the negative works were ignored.

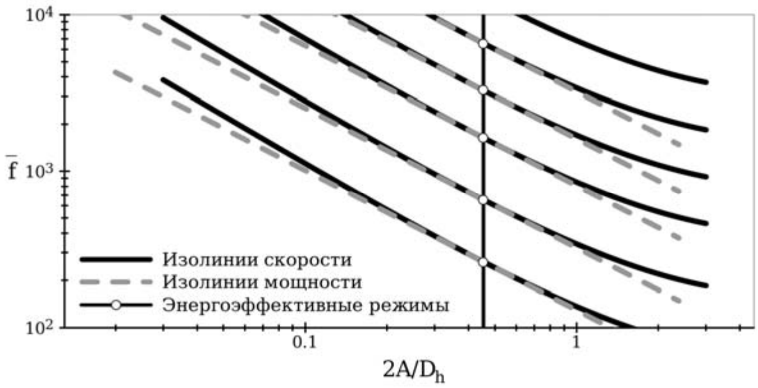

Figure 3. Isolines of speed (solid) and power (dashed) as a dependence of amplitude and frequency of tail oscillations.

Results generalization.

Tadpole motion was simulated at different parameters sets and average values of speed and power were obtained. The empirical dependency of speed can be expressed as

$$\overline{V}_{уст}\left(\left(2A/D_h\right),\overline{f}\right) \approx C_1 \cdot \left(1 - e^{-\frac{2A}{D_h C_2}}\right) \cdot \overline{f}^{C_3},\ C_1 \approx 6.4, C_2 \approx 1.57, C_3 \approx 0.964.$$

Tadpole power is

$$\overline{W}\left(\left(2A/D_h\right),\overline{f}\right) \approx C_4 \cdot \left(2A/D_h\right)^{C_5} \cdot \overline{f}^{C_6},\ C_4 \approx 157.7 \cdot 10^3, C_5 \approx 2.585, C_6 \approx 2.89.$$

Basing on these results the curves of constant speed and power were plotted, which are depicted on fig. 3. As on can see, although the power minimum does exist, it is not that strong. For example, if one set amplitude twice bigger than optimal $2A/D_h \approx 0.45$, power consumption increases only by 10%.

Conclusion.

Straight-line self-motion of tadpole in viscous fluid thru tail oscillations was investigated. Dependencies of motion speed and consumed energy on tail oscillations law are obtained. It's shown, that the lowest energy consumption is achieved at amplitude $2A/D_h \approx 0.45$.

All computations are done using the «Lomonosov» supercomputer located at Moscow State University.

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