Simulation of the flexible body moving in viscous fluid

Yaroslav A. Dynnikov[1], **Galina Ya. Dynnikova**[2], **Sergey V. Guvernyuk**[1,2]

[1] T-Services
Leninskii pr. 113/1, 117198 Moscow, Russia
yaroslav.dynnikov@gmail.com

[2] Research Institute of Mechanics
M. V. Lomonosov Moscow State University
Michurinskii pr. 1, 119192 Moscow, Russia
[dyn, guv]@imec.msu.ru

Abstract

Non-iterative method [1] is applied for solving the problem of strongly two-way coupled interaction between the flapping foil and incompressible viscous flow. For simulation of an incompressible flow the two-dimensional numerical method of viscous vortex domains (VVD) [2], [3] based on Navier-Stokes equations is used. The VVD method is a kind of the Diffusion Velocity Method (DVM) [4] but it uses other discrete formulas for calculating diffusion velocity. They allow more accurate simulation of the vorticity evolution than one does in the manner of [4].

The VVD method is fully lagrangian. The vortex region of the flow is represented by the set of vortex particles which move at diffusion velocity relative to the fluid. New vortex particles are generated at the body surfaces at each time step. The values of the new particles circulation must provide the no-slip boundary conditions. These conditions are written as the linear algebraic equations relative to circulations and to unknown velocities of the surface segments. On the other hand we have the equations of the body dynamics and the hydrodynamic forces expressed via the vorticity streams (i.e. via the circulations of the new particles), velocities and accelerations of the surface segments. Thus we obtain the closed system of linear algebraic equations relative to all unknown values. This system allows us to find a new body speed and to satisfy boundary conditions simultaneously at each time step.

The method is demonstrated on the problem of flapping profile composed of several sections which are connected by the elastic hinges (see Figure 1).

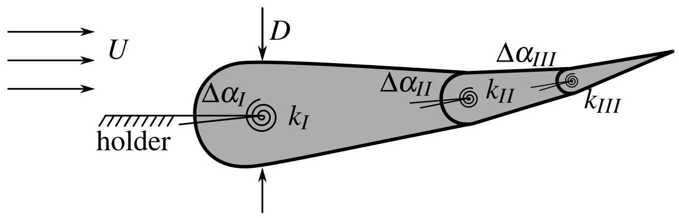

Figure 1: The model of flexible foil.

The shape of the unloaded foil is the same as in paper [5] where the rigid foil was investigated experimentally. We obtained a good agreement with the experiment for the case of rigid foil performing determined oscillations.

Here we consider the next task. The holder performs determined oscillation $\alpha = A\sin(2\pi f t)$. All sections move under the action of flow and the hinge torques which are proportional to the angle differences $\Delta\alpha_I$, $\Delta\alpha_{II}$ and $\Delta\alpha_{III}$ with coefficients k_I, k_{II} and k_{III}.

In Figure 2 the foil shape and the vortex pictures at successive times are shown. The computations were carried out for the next values of parameters: $\mathrm{St} = fD/U = 0.5$, $A = 0.122$, $k_I = 800\cdot\rho DU^2$, $k_{II} = k_I/4$, $k_{III} = k_{II}/4$, $\rho_\mathrm{f} = \rho$, $\mathrm{Re} = UD/\nu = 250$, $t = \tau U/D$. Here D is the foil thickness, U is the flow velocity, τ is physical time, ρ and ρ_f are the body and fluid densities respectively, ν is the kinematic viscousity of fluid.

The black points represent vortices circulating clockwise and white points — counter-clockwise. It is seen that the vortex wake is not symmetrical about the horizontal axis while the holder performs symmetrical oscillations. This phenomenon for the case of the rigid foil was observed in [5]. In paper [6] the influence of the foil flexibility was investigated. The method presented here can be applied for numerical studying of this phenomenon at different parameters of movement and flexibility.

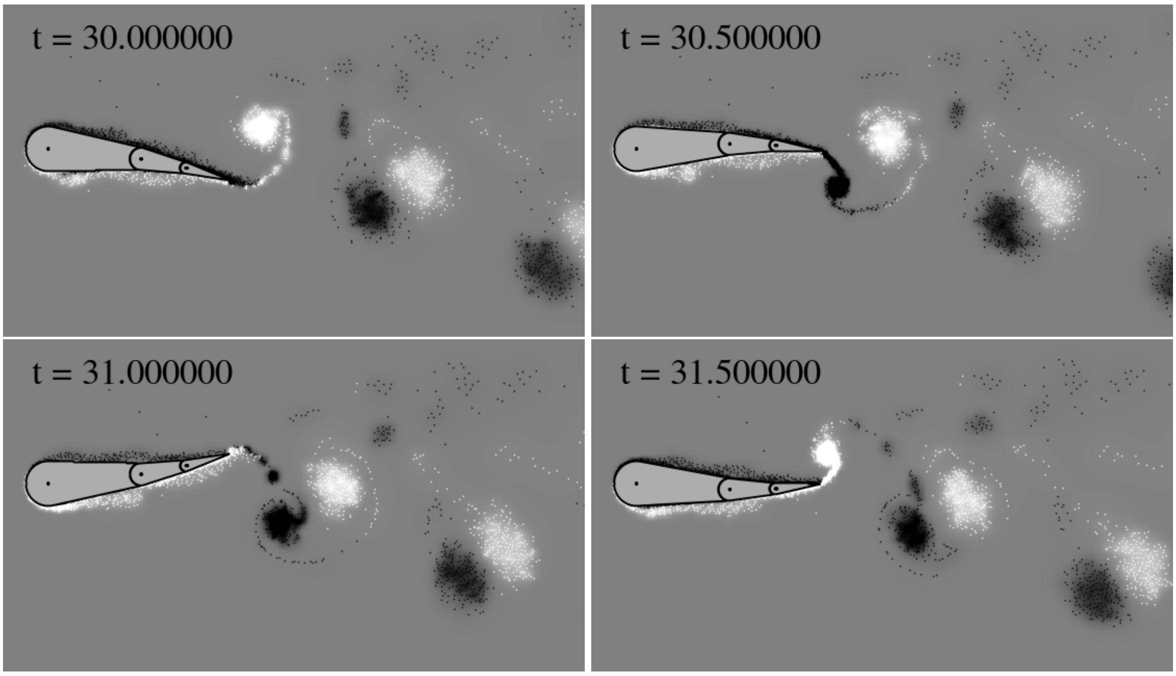

Figure 2: The foil shape and the vortex pictures at successive times.

The work was supported by the Ministry of Education and Science of the Russian Federation (Agreement No. 14.576.21.0079, project id RFMEFI57614X0079)

References

[1] Ya. A. Dynnikov, G. Ya. Dynnikova. Application of viscous vortex domains method for solving flow-structure problems. In Z. Terze (Ed.) Proceedings ECCOMAS Thematic Conference on Multibody Dynamics, Zagreb, Croatia, 2013.

[2] G. Ya. Dynnikova. The Lagrangian approach to solving the time-dependent Navier-Stokes equations. Doklady Physics, Vol. 49, No. 11, pp. 648–652, 2004.

[3] P. R. Andronov, S. V. Guvernyuk, G. Ya. Dynnikova. Vortex methods for calculating unsteady hydrodynamic loads (in Russian). Moscow University Press, Moscow, 2006.

[4] Y. Ogami, T. Akamatsu. Viscous flow simulation using the discrete vortex model. The Diffusion Velocity Method. Computers and Fluids, Vol. 19, 3/4, pp. 433–441, 1991.

[5] R. Godoy-Diana, J. L. Aider, J. E. Wesfreid. Transitions in the wake of a flapping foil. Phys. Rev. E 77, 016308, 2008.

[6] C. Marais, B. Thiria, J. E. Wesfreid, R. Godoy-Diana. Stabilizing effect of flexibility in the wake of a flapping foil. Journal of Fluid Mechanics, Vol. 710, pp. 659–669, 2012.