About Modeling Vorticity Flux from a Body Surface in Vortex Methods

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ABSTRACT

Vortex methods are widely used in the simulation of incompressible separated flow over bodies. A whole class of vortex methods based on the hypothesis that the vortex wake is a thin surface of discontinuity in an ideal fluid (vortex sheet), which is formed on a given lines of flow separation [1,2]. The disadvantage of this approach is the need to have a priori information about the lines of flow separation. In addition, such methods are poorly applicable in cases where the line of flow separation is movable.

Recently, approaches in which it is assumed that the vorticity is formed over the entire surface of the body are actively developing [3]-[5]. At each integration time step, a new vortex layer is placed on the surface of the body when the problem solve numerically. The intensity of this vortex layer is determined from the boundary condition. This layer is discretized to a system of discrete vortex elements, which are declared to be freely moving. The motion of the vortex elements is considered on the basis of the vorticity transport equation in an ideal fluid. However, the equation for the appearance of vorticity on the surface is usually written in a discrete-time form. In this regard, the formulation of a continuous mathematical model has become the subject of the present work.

A limiting case of a viscous fluid with a Reynolds number tending to infinity, is considered. The Navier-Stokes equations are the basis of the model. The hypothesis that viscosity is significant only in a thin layer on the surface of the body, beyond which the fluid is ideal (no viscosity), is supposed in the same way as in the classical theory of the boundary layer. The hypothesis that the vorticity is orthogonal to its rotor in the boundary layer is also assumed. This is consistent with traditional estimates for the velocity field in the boundary layer. The Navier-Stokes equations in the boundary layer are written using the concept of diffusion velocity [5] on the grounds of these hypotheses. Next the integral equation for the flux of vorticity from the surface of the body into the fluid domain is obtained. This equation, together with the equations for the motion of fluid points, the vorticity equations at these points, the integral representation for the velocity field in the form of a Bio-Savart law, and initial conditions, constitutes a closed mathematical problem for fluid flow within the Lagrangian approach. Note that when this problem is discretized, for example, a numerical scheme of the type [4] arises.

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