Thesis title: Modeling of the evolution of three-dimensional vortex structures in viscous fluids using vortex particle methods and parallel computations

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Abstract

Mutual interactions of the velocity and the vorticity fields cause the vorticity to concentrate in coherent structures resembling tubes (hence called vortex tubes). Those structures undergo two basic processes: interaction with a solid wall and interaction with other structures. During that second process a phenomena called as a reconnection of the vortex lines may occur. It is very common in the nature but is still not well explained in the literature. It is believed that it plays important role in the fluid motion.

In this thesis a three-dimensional vortex particle method was used to study the evolution of vortex structures. In this method particles that carry information about vorticity field are used. In the algorithm used the particles are initiated according to the initial distribution of vorticity field on a numerical grid. The velocity field is calculated from the so called vector potential obtained from the solution of the the Poisson equation. To simulate the viscous flow the so called viscous splitting algorithm was used. It involves splitting each time step into two substeps. In first the incompressible fluid flow equation is solved. In the second substep the viscous effects are modeled by the solution of the diffusion equation. In the algorithm used particles are remeshed onto the nodes of the numerical grid in every time step.

Solving the three-dimensional fluid flow equations is a time-consuming process independently on the method used. In the recent years the computational power of a single core of a processor has stopped rising. This is the reason why multiprocessor architectures have to be used to shorten the computational times. Surprisingly, graphics processing units (GPUs), built mainly for video games, can be used for scientific calculations. Vortex particle method suits very well for parallel computations. Its most time-consuming part - movement of the particles and interpolation of the vorticity to the numerical grid nodes has a local character and is independent on other particles/nodes. Due to this fact a single particle/node computations may be mapped onto a single computational thread and thus calculations may be run in parallel. In order to increase the amount of the available RAM memory and thus the use of denser meshes a multiGPU version of the VIC method was implemented. For the communication between the cards a hybrid MPI-OpenMP programming was used. This allowed for the implementation of the VIC method to be executed on clusters of computers with different configurations of nodes and number of GPUs. The parallel implementation of the VIC method allowed for nearly 50 times faster computations comparing to a single core.

In the thesis a reconnection of the vortex tubes phenomena was investigated. A detailed description of this process was given depending on a different initial configuration of the vortex tubes. An influence of the Reynolds number on the occurrence of the reconnection process was investigated. A head-on collision of two vortex rings was presented.