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Simulation of bluff-body flows using iterative penalization in a multiresolution particle-mesh vortex method

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The ability to predict aerodynamic forces, due to the interaction of a fluid flow with a solid body, is central in many fields of engineering and is necessary to identify error-prone structural designs. In bluff-body flows the aerodynamic forces oscillate due to vortex shedding and variations in the oncoming flow. This may lead to structural instability e.g. when the shedding frequency aligns with the natural frequency of the structure. Fluid structure interaction must especially be considered when designing long span bridges.

A three dimensional vortex-in-cell method is applied for the direct numerical simulation of the flow past a bodies of arbitrary shape. Vortex methods use a simple formulation where only the trajectories of discrete vortex particles are simulated. The Lagrangian formulation eliminates the CFL type condition that Eulerian methods have to satisfy. This allows vortex methods to take significantly larger time steps in convection dominated flows with explicit time integration.

As vorticity is a bounded quantity and the velocity field can be calculated for free-space- or periodic boundary conditions, these method allows for a minimized domain and hence minimize computational efforts.

Pure particle-vortex methods have the disadvantage of being highly costly. The calculation of particle velocities in particle vortex methods has traditionally been done by directly applying the Biot-Savart law yielding an N^2-body problem. However the Poisson equation, that relates the vorticity- to the velocity field, can be solved efficiently using a mesh-based solver with local refinement in the boundary layer regions.

We present a higher-order particle-mesh vortex method, where particle velocities are calculated by solving the Poisson equation on several uniform meshes using Fast Fourier Transforms. This we combine with an iterative penalization method, that allows the simulation of external flows past arbitrary geometries in arbitrary motions such as bridge decks in forced heave and pitch motion.