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Publication date:
2015

Document Version
Peer reviewed version

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Citation (APA):
Spietz, H., Hejlesen, M. M., & Walther, J. H. (2015). *Simulation of external flows using a hybrid particle mesh vortex method*. Poster session presented at The 68th Annual Meeting of the American Physical Society's Division of Fluid Dynamics (DFD) , Boston, United States.

DTU Mechanical Engineering
Department of Mechanical Engineering

Simulation of external flows using a hybrid particle mesh vortex method

Henrik Spietz [1,*], Mads Mølholm Hejlesen [1], Jens Honore Walther [1,2]

[1] Technical University of Denmark, [2] ETH Zurich, [*] hejusp@mek.dtu.dk

1 Introduction

The long-term goal of this project is to develop and apply state-of-the-art simulation software to enable accurate prediction of fluid structure interaction, specifically vortex-induced-vibration and flutter of long-span suspension bridges to avoid error-prone structural designs. In the following a hybrid particle-mesh vortex method is applied for the simulation of uniform flow past stationary solid obstacles of arbitrary shapes.

2 Governing equations

We simulate the incompressible flow past solid obstacles by solving the vorticity-velocity formulation of the Navier-Stokes equations by adding a Brinkman penalization term to the vorticity transport equation

$$\frac{D\boldsymbol{\omega}}{Dt} = (\boldsymbol{\omega}\cdot\nabla)\boldsymbol{u} + \nabla^2\boldsymbol{\omega} + \lambda\nabla\times\left[\chi(\boldsymbol{u}-\boldsymbol{u}_s)\right].$$

χ is a function that localizes the solid obstacle within the combined solid and fluidic domain

$$\chi(\boldsymbol{x}) = \begin{cases} 0 & \boldsymbol{x}\in\Omega_f \\ 1 & \boldsymbol{x}\in\Omega_s. \end{cases}$$

Velocity is related to the immediate vorticity field through the Poisson equation

$$\nabla^2\boldsymbol{u} = -\nabla\times\boldsymbol{\omega}.$$

3 Solution strategy

The vorticity transport equation is solved in an explicit time-splitting algorithm through the steps:

1. Iterative penalization [2] of mesh velocity to enforce the solid boundary condition
$$\frac{\partial\boldsymbol{\omega}}{\partial t} = \lambda\nabla\times\left[\chi(\boldsymbol{u}-\boldsymbol{u}_s)\right].$$
2. Diffusion and stretching of vorticity sampled onto discrete particles (by computing differential operators on the mesh) these particles are then pushed with their local velocities
$$\frac{d\boldsymbol{\omega}_p}{dt} = (\boldsymbol{\omega}_p\cdot\nabla)\boldsymbol{u} + \nabla^2\boldsymbol{\omega}_p, \quad \frac{d\boldsymbol{x}_p}{dt} = \boldsymbol{u}(\boldsymbol{x}_p, t).$$

We compute velocity for an isolated system on the mesh by solving the Poisson equation using higher-order regularized free-space velocity kernels, $K(\boldsymbol{x})$ [1] with the condition that the velocity induced by the vorticity should go to zero at infinity (free-space)

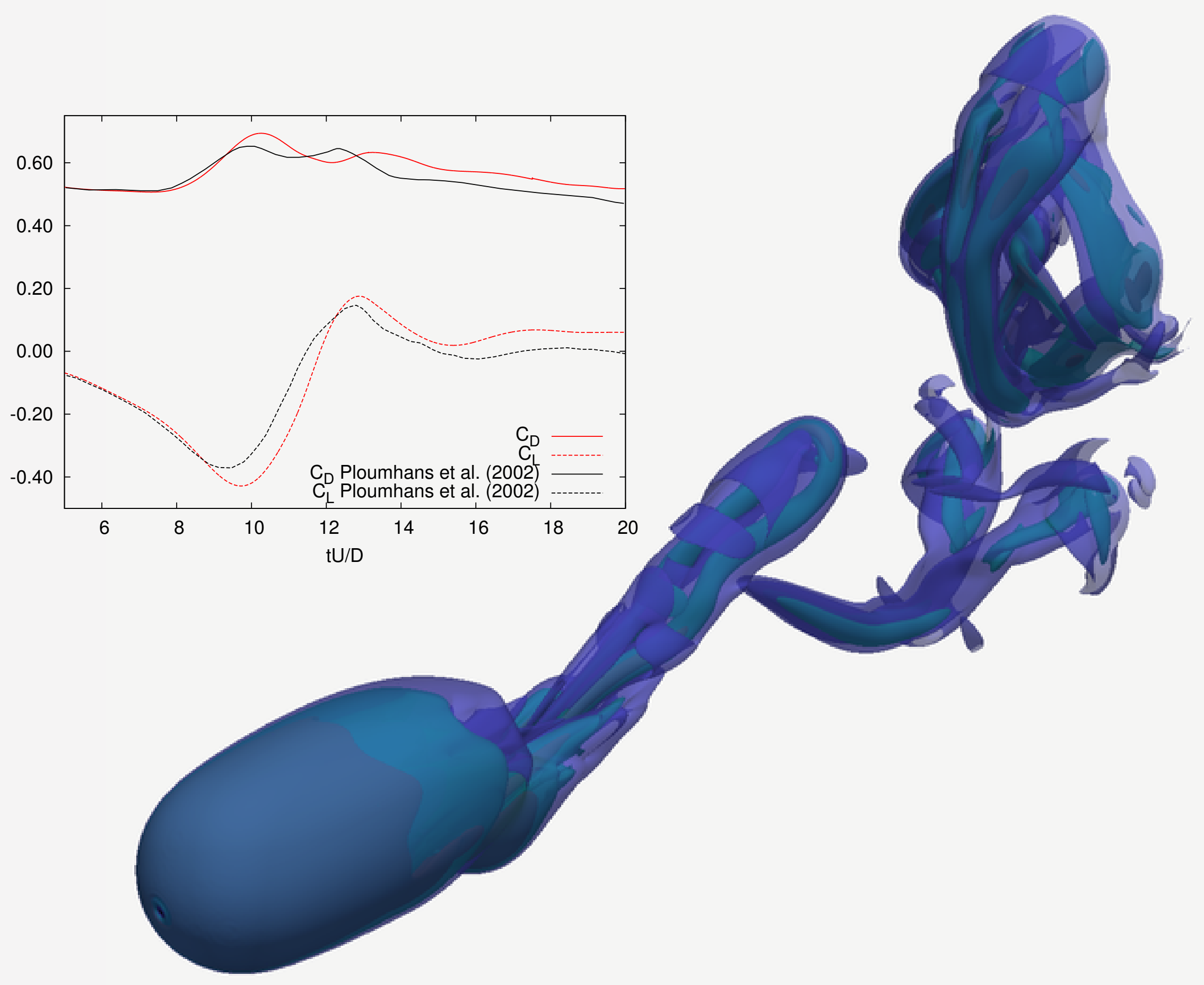
$$\boldsymbol{u} = \int_\Omega K(\boldsymbol{x}-\boldsymbol{x}')\boldsymbol{\omega}(\boldsymbol{x}')\,d\boldsymbol{x}'.$$

The velocity for a semi-periodic domain of length L in the periodic direction is approximated using a truncated series of free-space kernels for the infinite array of image domains

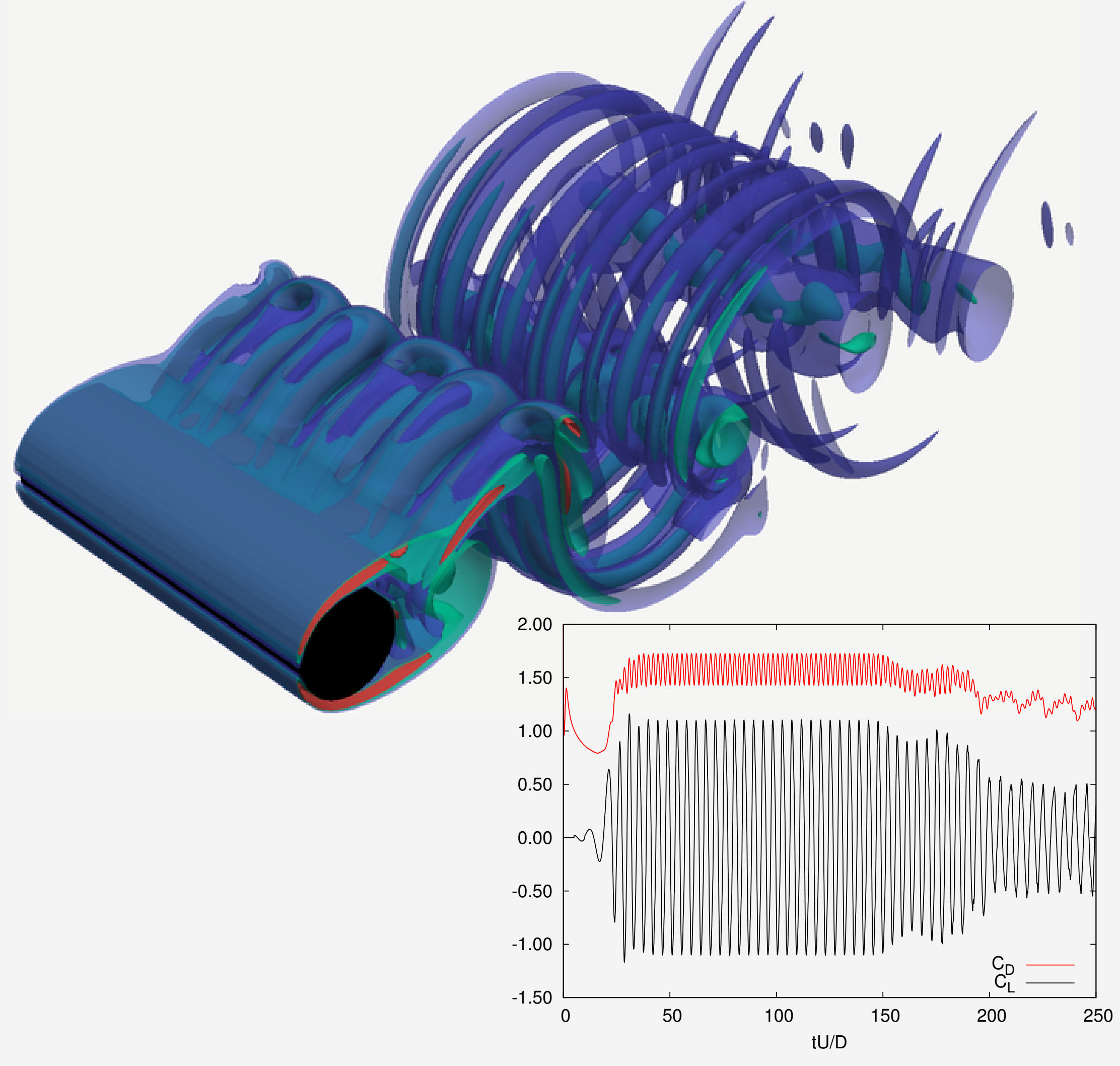
$$\boldsymbol{u} = \int_\Omega \tilde{K}_N(\boldsymbol{x}-\boldsymbol{x}')\boldsymbol{\omega}(\boldsymbol{x}')\,d\boldsymbol{x}',\ \tilde{K}_N = \sum_{n=-N}^{N} K(\boldsymbol{x}+nL).$$

4 Results

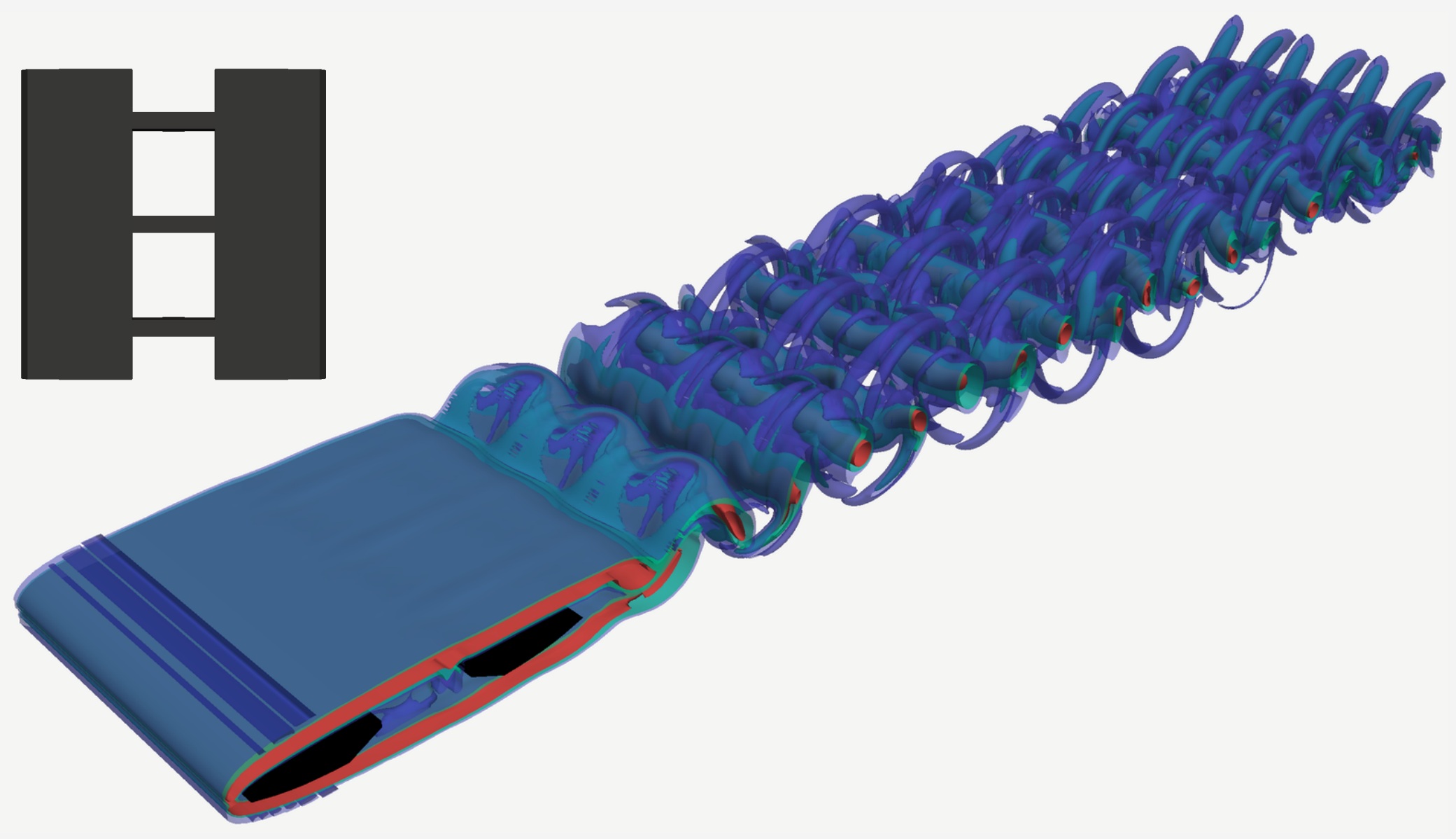
The method for free-space conditions is initially illustrated for the flow past a sphere at $Re = 1000$. A regular wake is not observed, in agreement with experimental observations [5]. A complex vortical structure is shed due to a perturbation of the velocity at infinity in good agreement with a similar study using a boundary element method [4].



Mixed free-space periodic boundary conditions allows us to simulate the flow past a circular cylinder for $Re = 400$. Transition through the “mode B” waves [6] to a three dimensional wake is observed, which is associated with a decay in the measured mean drag- and lift amplitude.



The method is well suited for solid obstacles of arbitrary shape. This is illustrated by considering the flow past a twin-deck section with semi-periodic boundary conditions.



In the presented numerical experiment for $Re = 10000$ the flow develops a regular three dimensional wake. The spanwise wave number of the principal mode of the three dimensional wake reflects the three stream wise beams that links the two decks of the section.

5 Summary

- Efficient and compact simulations with hybrid particle mesh method (less strict CFL condition).
- Consistent scheme for mixing free-space and periodic boundary conditions.
- Flexible treatment of solid boundary conditions by combining iterative penalization with higher order Poisson solver.

6 Outlook

- Minimizing artificial wake truncation necessary in practical simulations by local refinement (coarsening the resolution of the far wake).
- Enabling turbulent flow simulations with LES and local refinement. (In bridge aerodynamics the Reynolds numbers typical for wind tunnel tests and operational conditions are in the order of 10^5 and 10^8 respectively.)
- Accounting for the effect of an oncoming turbulent flow within the atmospheric boundary layer [3].

7 References

[1] M. M. Hejlesen, J. T. Rasmussen, P. Chatelain, and J. H. Walther. A high order solver for the unbounded Poisson equation. 252:458–467, 2013.

[2] M. M. Hejlesen, P. Koumoutsakos, A. Leonard, and J. H. Walther. Iterative Brinkman penalization for remeshed vortex methods. 280:547–562, 2015.

[3] M. M. Hejlesen, J. T. Rasmussen, Allan Larsen, and J. H. Walther. On estimating the aerodynamic admittance of bridge sections by a mesh-free vortex method. *J. Wind Eng. Ind. Aerodyn.*, 146:117–127, 2015.

[4] P. Ploumhans, G. S. Winckelmans, J. K. Salmon, A. Leonard, and M. S. Warren. Vortex methods for direct numerical simulation of three-dimensional bluff body flows: Applications to the sphere at Re=300, 500 and 1000. 178:427–463, 2002.

[5] H. Haniu Sakamoto. A Study on Vortex Shedding From Spheres in a Uniform Flow. *Journal of Fluid Engineering*, 112:386–392, 1990.

[6] C. H. K. Williamson. Three-dimensional wake transition. 328:345–407, 1996.