SIMULATION OF THE FLOW AROUND AN ELASTIC SQUARE CYLINDER

EIKE TANGERMANN[1], MARKUS KLEIN[2]
[1]*Universität der Bundeswehr München, eike.tangermann@unibw.de*
[2]*Universität der Bundeswehr München, markus.klein@unibw.de*

Keywords: *Fluid-Structure-Interaction, Square Cylinder, Vortex Street*

In analogy to the circular cylinder the flow around a square cylinder can feature a vortex street with alternating separations of vortices depending on the Reynolds number of the flow. Various simulations of this phenomenon have been performed in two- and three-dimensional configurations as presented in [1, 2]. The vortices induce alternating pressure on the surface of the cylinder, leading to oscillating forces on the cylinder walls. If the cylinder is elastic or elastically mounted these forces can excite its displacement or deformation. Breuer and Münsch [3] have performed Large Eddy simulations of the flow around rigid circular and square cylinders in a mass-spring system showing their periodic response to the vortex street excitation.

The present study features an elastic square cylinder in a channel exposed to incompressible flow with a Reynolds number of $Re = 5000$ based on the edge length of the square. All channel walls are free slip walls, the velocity is prescribed at the inlet boundary, while at the outlet the pressure is fixed. The edge length is $0.05m$ and the cylinder has a length of $0.4m$. Its elasticity has been chosen so it can easily be bended by the forces appearing in the flow leading to an modulus of elasticity of $E = 10^4 N/m$, which is of the order of magnitude of natural rubber.

Top and bottom of the beam are fixed in terms of their coordinates, while the gradient is basically free. However, since the location is fixed across its lateral extension, the gradient cannot change completely free, thus it behaves inbetween a supported and a fixed beam. Analytically determined [4] the first eigenmode of a supported beam with the present properties is at a Strouhal-number of 0.281, for a fixed beam is 1.06. The latter is far higher than the aerodynamic frequencies featured in this flow.

Simulations have been performed using FOAM-extend 3.1 for the fluid-structure interaction and OpenFOAM® 3.0 for reference simulations with a rigid beam. The FSI simulation does not feature a turbulence model. However, the reference simulations with and without turbulence modelling show, that eddy viscosity for this flow is generally lower than the molecular viscosity and that the influence of turbulence on the spectra of the forces is negligible. Figure 1 gives a qualitative impression of the vortices downstream of the bending beam.

A series of images from both the rigid and the elastic beam are shown in Figure 2. In the images contours of velocity magnitude are shown in the central plane. The beam moves away as a vortex separates and towards the formation of the next vortex. Thus the departing vortex has more space and forms a more complex wake region. The vector indicates the displacement velocity of the beam. Since the drag is also oscillating, the beam moves in streamwise direction, too. Figure 3 shows its trajectory. According to Lissajous curves it clearly is visible, that the ratio of the frequencies is 1:2. The drag fluctuates with each vortex separation while the side force changes its sign depending on the side of the separation.

Figure 4 shows the spectra of side force fluctuation as well as of the sidewise deflection of the elastic beam. In the force spectrum a slight reduction of the dominating frequency can be observed from the rigid to the elastic case. The beam seems to appear wider to the flow, because it moves away from the departing vortex towards the upcoming vortex as seen

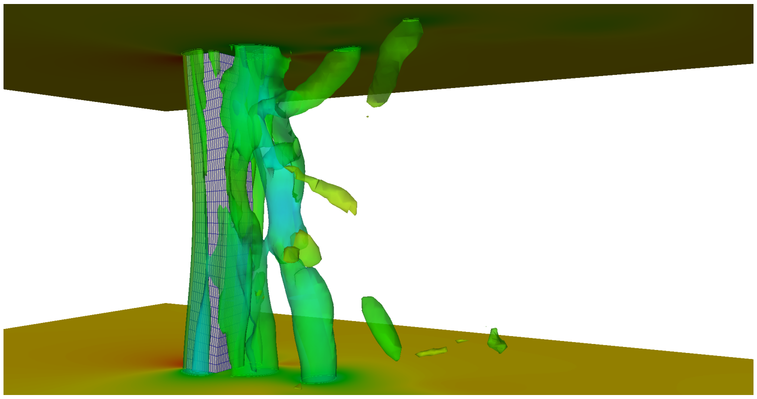

Figure 1: Vortex street behind the square cylinder (isosurface of Q).

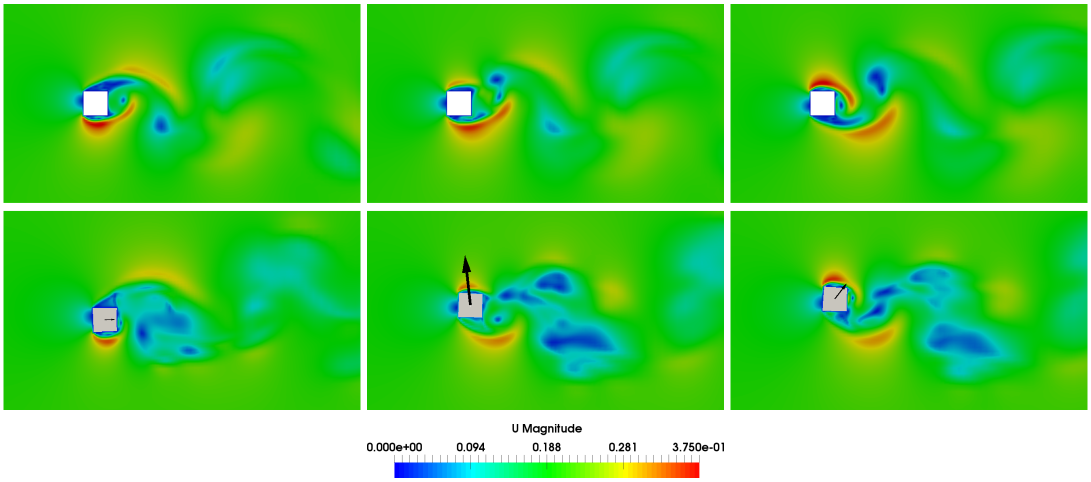

Figure 2: Sequence of velocity contours in centre plane. Rigid beam (top) and elastic beam (bottom) with a vector indicating displacement velocity.

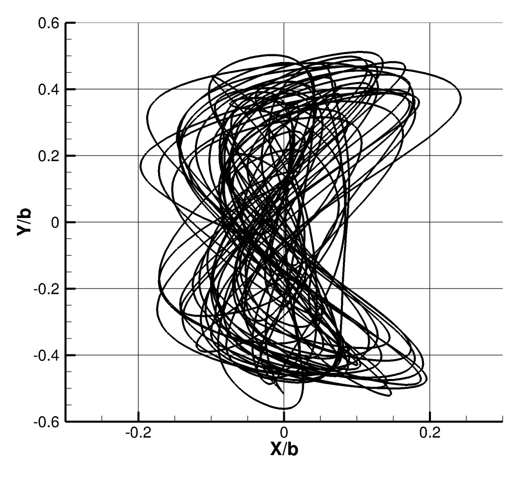

Figure 3: Trajectory of beam centrepoint.

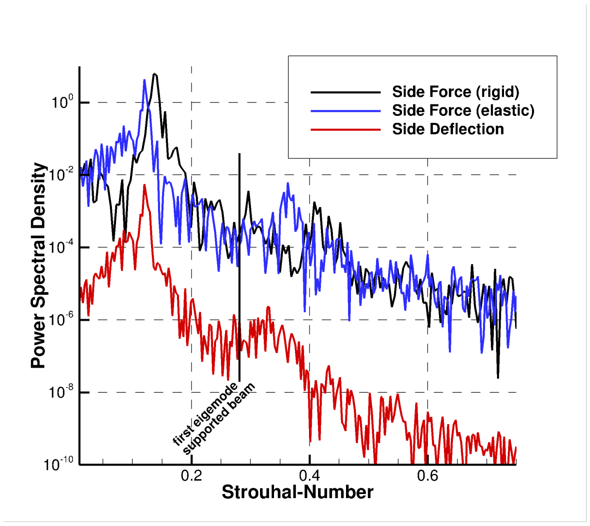

Figure 4: Spectra of side force for rigid and elastic cylinder and of side deflection.

in Figure 2. With a greater width a lower frequency results. The second mode representing the vortex separation on both sides, which occurs for the rigid beam at $Sr = 0.3$, is damped in the elastic case and does not appear as a distinct peak in the spectrum. The excitation of an eigenmode of the beam cannot be observed. It appears to be closer to the fixed beam than to the supported beam and thus its frequency is far higher than the aerodynamic frequencies of the vortex separation occuring in this context.

In future work excitation of the beam eigenmodes will be focus of the investigation. The resulting feedback to the flow in particular by higher eigenmodes might lead to significant differences. Considering turbulence modelling will be a further issue in order to simulate the flow at higher Reynolds numbers.

References

[1] A. Sohankar, C. Norberg, and L. Davidson, “Simulation of three-dimensional flow around a square cylinder at moderate reynolds numbers,” *Physics of Fluids*, vol. 11, pp. 288–306, 1999.

[2] J. Robichaux, S. Balachandar, and S. Vanka, “Three-dimensional floquet instability of the wake of a square cylinder”,” *Physics of Fluids*, vol. 11, pp. 560–578, 1999.

[3] M. Breuer and M. Münsch, “Fluid-structure interaction using les-a partitioned coupled predictor-corrector scheme,” *PAMM*, vol. 8, no. 1, pp. 10 515–10 516, 2008.

[4] J. P. D. Hartog and G. Mesmer, *Mechanische Schwingungen*. Springer, 1952.