Investigations on Fluid-Structure Interactions using Volumetric Particle-Image Velocimetry

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Fluid-structure interactions (FSI) are induced by the coupling between an unsteady fluid flow and the motion or deformation of a structure. These interactions can be found in many industry-related applications, e.g., in the design of aircrafts, wind turbines or heart valves to mention only a few. In present and future applications with complex multi-physics couplings, the numerical prediction of FSI problems is an important and valuable engineering tool in the design, life cycle analysis and prototyping. Due to enhanced numerical algorithms and the strong increase of the computational power in the last decades, it is now feasible to simulate real-world FSI problems. Thus, a variety of numerical models are currently developed to predict different FSI applications. To evaluate and improve these complex non-linear computations, experimental studies are highly necessary. Thus, in order to provide reliable data for the validation and evaluation of coupled Computational Fluid Dynamics (CFD) and Computational Structure Dynamics (CSD) tools, experimental test cases were developed.

At LSTM Erlangen a variety of FSI test cases in the laminar and turbulent regime were developed to validate numerical simulations within the DFG research unit FOR 493. In the present setup a fixed cylinder with a thicker para-rubber tail and a rear mass is used, which is similar to a numerical FSI benchmark of Turek and Hron (2006). Furthermore, since we are interested in practical applications, the investigations are solely restricted to the turbulent flow regime with special emphasis on delivering data for eddy-resolving methods such as large-eddy-simulations. This FSI benchmark case is denoted FSI-PiS-2.

The experimental setup consists of the Göttingen-type water tunnel, the flexible structure and the data acquisition systems for the flow and structure measurements. The water channel provides a measurement section of 320 x 240 x 180 mm (H, L, D) and can induce flows up to 6 m/s by a 24 kW axial pump. Several preliminary tests were performed to find the best working conditions in terms of maximum structure displacement, good reproducibility and measurable structure frequencies within the turbulent flow regime. With an inflow velocity of $u_\infty = 1.385$ m/s all of these dependencies were satisfied. Based on the inflow velocity chosen and the cylinder diameter (d = 0.022 m) the Reynolds number of the experiment is equal to Re = $3 \times 10^4$.

For comparing experimental and numerical results phase-resolved three-dimensional flow fields are captured with a unique volumetric Particle-Image Velocimetry system (V3V™) developed by TSI™. Due to cycle-to-cycle variations of the structure deflection owing to chaotic irregular fluctuations of the turbulent flow field, the flow measurements are phase-averaged to obtain representative data. For the structure deformations a time-resolved multiple-point laser triangulation sensor is used.

The para-rubber plate mounted behind the cylinder acts as a splitter plate. Nevertheless, periodic vortex shedding occurs. The shed vortices move downstream and start to interact with the flexible structure leading to an oscillating and quasi-periodic motion. The additional steel weight at the end of the tail additionally supports the deflection by the higher inertia of the swiveling system. With the present setup (FSI-PiS-2) the deflections of the para-rubber with the steel tail reaches deflections of $y/d \leq 0.65$ in the second swiveling mode and an oscillation frequency of 11.2 Hz. With the volumetric flow measurements it is now possible to study three-dimensional flow structures (e.g. Fig. 1: two vortex rolls) in the wake of the structure. This work is the first step towards a verification of the volumetric measurement system for more complex three-dimensional coupled FSI problems. Complementary FSI-LES predictions are currently performed with similar boundary and operating conditions at PfS Hamburg.

Fig. 1 Phase-averaged structure and flow results showing the structure motion at $t = \pi$, grey isosurfaces present the dimensionless velocity magnitude $u/u_\infty = 0.79$. 2.3.2