Mini-Workshop: Theory and Numerics of Fluid-Solid Interaction

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Abstract. This volume contains the abstracts of a series of talks given at a mini-workshop in Oberwolfach on the theory and numerics of continuum mechanical fluid-solid/structure interaction. The characteristics of these coupled multi-field problems are that the displacement of the solid/structure has a direct influence on the surrounding flow and vice versa. This interaction is generally nonlinear making the modeling complicated. The mathematical analysis concentrates on the well-posedness of the models in order to provide a rigorous explanation of fundamental experiments. Various competing numerical approaches are discussed based on different variational formulations and mainly using finite element methods.

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Introduction by the Organisers

The theme of the mini-workshop was mathematical and computational aspects of modeling the interaction of viscous fluids with solids or elastic structures. The characteristics of this fluid-solid/structure interaction (FSI) setting is that the displacement of the solid/structure has a direct influence on the surrounding flow area. One dilemma in modeling the coupled dynamics of flow and solid/structure is that the fluid model is normally based on an Eulerian perspective in contrast to the usual Lagrangian approach for the solid model. This makes the setup of a common variational description difficult and complicates the mathematical analysis of the coupled problem as well as its numerical simulation. The whole area is rich of challenging theoretical, computational as well as application-related problems.
Over the last forty years, the interaction of fluid flow with rigid or elastic bodies or structures has represented one of the major focal points in several branches of engineering research. It is required for many industry applications such as biomedical, aerofoil flutter and civil engineering. A simple example is the motion of single particles in a viscous liquid, which has many practical applications. Another type of FSI problems occurs in the interaction of “exterior” fluid flow with elastic structures, e.g., air flow around an aircraft wing during flight, the cabin acoustics, or the vibration of a civil engineering structure under wind loading. Interesting biomedical applications occur in hemodynamics, e.g., blood flow in elastic vessels for modeling stent design. “Interior” FSI problems occur, for example, when liquids are transported in closed containers, in the mixing of polymers, and in vibration in pipeline systems.

Despite the numerous applications of processes involving FSI, the physical mechanism of even some of the most elementary phenomena is far from being understood. The orientation of symmetric particles in a uniform steady flow of a viscoelastic liquid is a typical example that presents several underlying unanswered questions. For instance, what is the physical characteristic of the liquid that determines the orientation of the particle, and why very simple-shaped symmetric particles, like cylinders, present a different orientation in the same liquid according to whether they have flat or round ends (“shape-tilting”). Further, subtle problems occur in the context of modeling the interaction of flow and elastic structures. Questions are, e.g., the modeling of the collision of rigid particles or the wall touching of elastic structures, boundary conditions for the truncation of large channel systems to smaller portions, and instabilities in the coupling mechanism related to the occurrence of aneurysm in blood vessel walls.

In the last decade another powerful tool has been employed to investigate FSI phenomena including particulate flow, namely, direct numerical simulation (DNS). The results, in some cases, are quite impressive, like those, for instance, simulating the three-dimensional motion of thousands of spheres in a fluidized bed or the 3D simulation of oscillatory blood flow through a piece of an elastic vessel. However, so far, these three different tools (experiments, mathematics, numerics) have been more or less independently used to investigate FSI problems.

The mini-workshop concentrated on the following key questions:

- The first set of questions was related to the flow of a single rigid particle in a viscous fluid, e.g., explanation of the shape-tilting phenomenon, stability of quasi-steady motion depending on particle shape and fluid characteristics, “effective” continuum fluid model for the real fluid and many free particles.
- The second set of questions was related to the interaction of a viscous fluid in a channel with an elastic wall, e.g., conditions for the well-posedness of the mathematical model, non-reflecting artificial boundary conditions, stability of flow through elastic pipe systems.
- The third set of questions was related to special FSI problems occurring in hemodynamics, e.g., the flow of many deformable bodies in a viscous
Newtonian or non-Newtonian liquid and their attachment at the vessel wall.

The fourth set of questions was related to the efficient numerical simulation of processes involving FSI, e.g., strongly coupled versus partitioned solution approach, fixed-grid versus moving-grid methods, ALE versus Eulerian method, treatment of large deformation and collision, sensitivity-driven mesh adaptivity.

The mini-workshop provided the platform for intensive discussion of the problems described above and, by the combined effort of theoretical and numerical analysts as well as experimental physicists, stimulated new ways for attacking the many open questions.