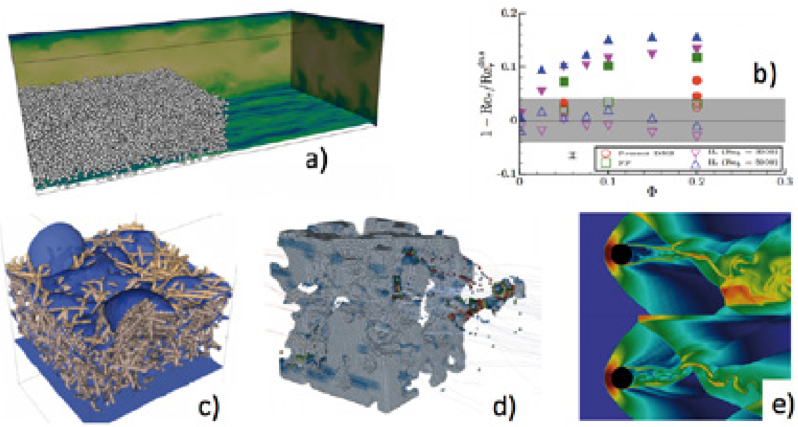
High Performance Computing as Research Tool in Fluid Dynamics

The research activity of the group focuses on high-performance computations of complex flows. These are characterized by chaotic and multiscale behaviors induced by their intrinsic non-linear dynamics leading to turbulence and/or shock-waves. Often their complexity is amplified by the presence of concurrent phenomena as in multiphase/reactive flows, porous media, fluid-structure interaction. The range of involved scales becomes huge, typically from microns (droplets, small vortices, pores) to meters (macroscopic size), which constrains usual computational approaches to rely on extensive models to make simulations affordable. However, the recent developments in supercomputers and efficient algorithms opened new perspectives to researchers in these fields. "Virtual" experiments can now be performed at the condition that minimal models are adopted so that the processes at all scales are directly simulated from first principles (DNS). Despite the high computational cost, these "virtual" experiments give access to an unprecedented view with all observables simultaneously available. The need to efficiently exploit the increasing computational power, running on hundred thousands cores in parallel makes this a truly multidisciplinary field, at the intersection of numerical analysis, fluid dynamics and computer science.
The present group is active both in developing original methods and collaborating with other groups to simulate complex fluid problems. Within the international collaboration with TU-Delft (prof. Breugem) and KTH Stockholm (prof. Brandt), we performed the largest "virtual" experiments of turbulent particle-laden channel flow (ack.: European project PRACE DILPART: 32M core-hours, i.e. 3652 years single-core). From the dataset produced we have proposed new scaling laws relating the friction and flow rate for the wall-bounded turbulent flow of particle suspensions (Fig a,b). Among the collaborations with other groups at DII, we mention the computational studies on porous electrodes of Fuel Cell and Redox Flow Battery (prof. Guarnieri group;Dr. Maggiolo), aiming to understand how the flow through the electrode micropores affects the battery performance. In particular we have characterized the effect of the pore/fiber orientation on the effective diffusion and reaction using a in-house-developed software (based on the Lattice-Boltzmann Method) able to simulate multiphase flows through micropore networks (Fig c).
Moreover, we are developing an innovative algorithm for fluid-structure interaction problems considering solid damages (prof. Galvanetto group), e.g. hydraulic fracturing (Fig d), and a state-of-the-art software to simulate turbulence/shockwave interaction in complex geometries (prof. Benini group), a critical issue in transonic turbines and aerodynamics (Fig e). To conclude, the group is active in developing high performance computing tools for complex fluid problems. We are convinced that in the coming years this field is going to have an increasing impact in the industrial research.



Turbulent suspension flow: a) snapshot, b) new scaling law (open symbols); c) Porous media flow; d) Hydraulic fracturing; e) Supersonic unsteady cylinder flow.

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Main research topics:

- Multiphase flows
- Computational methods for complex flows
- Fluid-structure interaction
- Supersonic flow modeling
- Porous media flow
- Spray and Combustion
- High Performance Computing