Numerical Simulation of Shear Induced Wetting

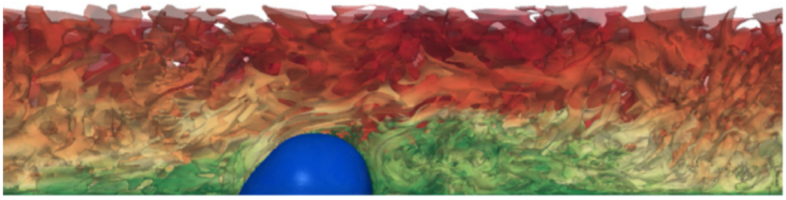

Figure 1: Simulation of a milimeter-sized water drop in turbulent channel flow

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Introduction

To optimize functionalities and to increase the safety of industrial applications such as in printing, coating or the exterior water management of vehicles it is necessary to properly understand the motion of drops and rivulets in shear flow. For this purpose, the specific interplay of multi-phase flows, three-phase contact line dynamics, and turbulent flow fields on a multitude of length and time scales are to be modeled and discretized in such a way that complex geometries are representable. The sensitivity of the drop and rivulet motion on small length scales is the main motivation of this study since a detailed description of wetting phenomena on large-scale applications is necessary but not affordable.

Methods

To cover multi-phase flow, wetting, and turbulent shear flow in cases motivated by industry, high-performance techniques and the ability to handle complex geometries are required. Therefore, in each of this research areas novelties are presented in this work. They are combined in one solver based on OpenFOAM, which is extensively validated and successfully applied to relevant cases. To efficiently discretize multiple length scales with transient transport processes, such as moving two-phase interfaces and reduce computational effort, Adaptive Mesh Refinement represents a powerful tool. The respective refinement algorithm in OpenFOAM is enhanced, abstracting the basic 3D refinement and the underlying single criterion refinement to a versatile application in 2D, 2.5D, and 3D and a multi-criterion refinement. Thereby, severe bugs are revealed and fixed to ensure accurate and stable simulations. To maintain the benefits of Adaptive Mesh Refinement on highly parallelized computations, Dynamic Load Balancing is required. Both, the developments in Adaptive Mesh Refinement and Dynamic Load Balancing in Open-FOAM his published in Rettenmaier et al. (2018, 2019). A major focus of this work are the many phenomena related to the dynamic three-phase contact line. A variety of models for the discretization of the position of the contact line, the contact line velocity, the dependence of the contact angle on the contact line velocity, the contact angle hysteresis is implemented. All these models are part of a unique contact line library which is successfully validated and presented in Rettenmaier et al. (2016), Gurumurthy et al. (2018) and Rettenmaier (2019). Shear flow in industrial applications is often turbulent. For high Reynolds numbers, the small turbulent scales cannot be resolved with a reasonable computational effort, therefore, turbulence models are necessary. The combination of turbulence models with multi-phase flow is a field of ongoing research and requires a particular treatment at the two-phase interface. On this behalf, two models, the WALE model and the VLES model is analyzed. The results point out, that only the latter model yields satisfactory results at the interface (Rettenmaier, 2019).

Results

The point of incipient motion of a drop on a slowly tilting plate is accurately matched in 2D and 3D with theoretical and experimental results for different surfaces and drop volumes (Rettenmaier et al., 2017). Simulations of the continuous motion of drops sliding down a tilted plate show the characteristic cornered tail of a drop, which forms to a cusp and eventually emits droplets. These regimes are equally found in experiments. The path of a rivulet on a tilted plate can be categorized as straight, quasi-static meandering and dynamic meandering for increasing volumetric flow and constant wetting conditions. As a novelty in literature, simulations of this study recover all three regimes. The quasi-static meandering path can only be achieved when accounting for the contact angle hysteresis and the related pinning of the contact line (Rettenmaier, 2019). A novelty in the Literature is the simulation of the incipient motion of drops in turbulent shear flow with the Volume of Fluid method and a Very Large Eddy Simulation modeling the turbulence. Relevant experiments by Seiler et al. (2018) are compared with good accordance. Even the characteristic drop oscillation and the caterpillar-like motion of the drop are recovered in simulations (Rettenmaier, 2019).

Discussion

All in all, the numerical framework including high-performance techniques, interface, and dynamic contact line handling, as well as turbulence modeling in combination with multi-phase flows are successfully validated with experiments. The trustworthy validation builds a stepstone for future work on drops and rivulets in turbulent shear flow and complex geometries.

Publications

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