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DNS and Multi-Scale Modeling of Multi-Phase Flows

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Direct numerical simulations (DNS) of multiphase flows, where every continuum length and time scale is fully resolved, have now advanced to the point where it is possible to study in considerable detail fairly complex systems, such as the flow of hundreds of bubbles, drops, and solid particles. Here we discuss such simulations from a multi-scale perspective, focusing on two aspects: First of all, DNS results can help with the development of closure relations of unresolved processes in simulations of large-scale "industrial" systems. As an example we discuss recent results for deformable bubbles in weakly turbulent channel flows. The lift induced lateral migration of the bubbles controls the flow, but the lift is very different for nearly spherical and more deformable bubbles, resulting in different flow structures and flow rates. Nevertheless, the results show that the collective motion of many bubbles leads to relatively simple flow structure in both cases, emphasizing the need to examine as large a range of scales as possible. The other multi-scale aspect results from the fact that multiphase flows often produce "features" such as thin films, filaments, and drops that are much smaller than the "dominant" flow scales. The geometry of these features is usually simple, since surface tension effects are strong and inertia effects are relatively small. In isolation these features are therefore often well described by analytical or semi-analytical models. Recent efforts to capture thin films using classical thin film theory, and to compute mass transfer in high Schmidt number flows using boundary layer approximations, in combination with direct numerical simulations of the rest of the flow, are described.