Direct Numerical Simulation on Millimeter-sized air bubbles in turbulent channel flow

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Abstract

Over the past 40 years, frictional drag reduction through air injection has been researched and applied to liquid transport in pipelines and ship surfaces in water. Recently, it’s been discovered that millimeter-sized bubbles can concurrently contribute to both frictional drag reduction and increase, but the mechanism behind these phenomena remains unclear. Furthermore, visualizing the micro-scale film flow between the bubbles and the wall surface using Particle Image Velocimetry (PIV) is nearly impossible. In response, we carried out our research in several stages, using OpenFOAM on the large-scale computer, Fugaku.

(1) **Direct Numerical Simulation (DNS) of turbulent channel flow**: For millimeter-sized bubbles, the deformability of the interface is notably high, and turbulent flow significantly influences this deformation. To evaluate this impact, we reproduced turbulent flow conditions close to experiments through DNS. Also, the flow on the hull surface (Couette flow), which is driven differently from channel flow (Poiseuille flow), has yet to have its effect on millimeter-sized bubbles elucidated. To investigate this, we generated Couette flow in turbulent channel flow.

(2) **Validation of numerical model compared with a series of experiments on single millimeter-sized bubbles**: To validate our numerical model, we compared its results with those from experiments involving a single millimeter-sized bubble in turbulent channel flow. Also, this comparison revealed unique characteristics (direction and deformation of the bubble) in Couette flow that differed from those observed in experiment of Poiseuille flow.

(3) **Reproduction of bubbly flow composed with millimeter-sized bubbles in turbulent channel flow**: Based on the validated model, we reproduced bubbly flow composed with multiple millimeter-sized bubbles. Our simulations showed reasonable agreement with experimental observations. Additionally, we discerned differences according to the flow conditions.