The Impact of Coupling and Particle Volume Fraction on Fluid-Particle Interactions in a Turbulent Channel Flow

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ABSTRACT

Direct numerical simulation, facilitated by Patera's (1984) spectral element method, was used to simulate a multiphase fluid flow through a channel at a shear Reynolds number of 300. Following a validation of the simulation against the DNS results of Marcholi and Soldati (2007), a channel flow was simulated utilising a Lagrangian particle tracker to model 300,000 particles with a diameter of 100 microns, having a density ratio equivalent to that of water to glass, and a particle-fluid volume fraction of approximately 0.001. This was run over multiple levels of coupling between the particles and the flow; one-way, two-way and four-way. The mean streamwise velocity of the fluid and the particles, along with the shear and normal stresses, were compared for the different coupling methods. The differences between them were analysed, and though they were found to be small, they were consistent over the channel and showed interesting trends, including a consistent overestimation of streamwise velocity and normal stresses for runs using lower order coupling methods.

A second set of runs was performed using in excess of 2 million particles in order to facilitate a tenfold increase in the particle-fluid volume fraction, to 0.01, whereby the particles are expected to have a greater impact upon the properties of the fluid. The statistics of the fluid and particles in these simulations were then compared with those from the simulation with a lower concentration of particles in order to determine the magnitude of the effect the particles have on the fluid in this flow as well as the effect's physical direction. The effects of the different couplings on the flow were much greater here, due to the increased number of particles affecting the flow. Also, the presence of the particles was seen to increase the turbulent levels of the fluid, especially in the streamwise direction.

The accuracy of the simulation clearly increases with the level of coupling. However, the speed of the simulation decreases. One way of achieving decreased run times, for both the 0.001 and 0.01 volume fractions, is to use a faster stochastic version of the particle tracking code for the four-way coupled case. This was tested, replacing the Lagrangian collision mechanics in the four-way coupled simulations with a probabilistically determined mechanistic model developed by Sommerfeld (2001). For the lower volume fraction, the normal stresses of the particles were exaggerated somewhat, suggesting that this method requires some fine-tuning. The results from the higher volume fraction showed less exaggeration, and also a greater simulation speed compared to the Lagrangian four-way coupled run.

The different effects of coupling and particle volume fraction on the turbulent flow will be assessed and discussed based on all of these results. Emphasis will be placed on the impact of the particles on the fluid flow.

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