[Extended Abstract]

**Turbulent particle-laden and droplet-laden flows:**
**An advanced eddy-resolving simulation methodology with deterministic collision, agglomeration and coalescence models**

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**Introduction**

The increase of the computational resources in the last decade has a strong impact on the prospects of numerical simulations for turbulent disperse multiphase flows. On the one hand, it allows to replace classical Reynolds-Averaged Navier-Stokes (RANS) predictions by more advanced eddy-resolving approaches such as large-eddy simulations (LES) or hybrid LES-RANS approaches. On the other hand, it paves the way to include more physical phenomena in the simulation of the particular phase. Relying on an Euler-Lagrange concept, these effects can be described based on first principles and not on empirical correlations as typically done in the Euler-Euler concept. That is extremely beneficial for the setup of appropriate models. The present contribution gives an overview of recent developments related to the prediction of inter-particle or inter-droplet collisions, the agglomeration of particles, the adhesion of particles at walls and the coalescence of droplets in complex turbulent flows.

**Methodology of LES with agglomeration, coalescence and adhesion models**

Relying on a four-way coupled Euler-Lagrange approach, the continuous phase is solved in an Eulerian frame of reference taking the conservation equations of the filtered quantities used in LES into account. The solution is based on a 3-D finite-volume method for arbitrary non-orthogonal and block-structured grids, which is fully parallelized based on the domain decomposition technique.

The disperse phase is solved in a Lagrangian frame of reference [1, 2, 3]. The equation of motion is given by Newton’s second law, where the fluid forces are derived from the displacement of a sphere in a non-uniform flow. For particles or droplets with a density much higher than the carrier fluid, only the drag, lift, gravity and buoyancy forces have to be considered. The ordinary differential equation for the particles is integrated in physical space. To avoid time-consuming search algorithms, the second integration to determine the particle position on the grid is done in the computational space. Here an explicit relation between the position of the particle and the cell index containing the particle exists [1], which is required to calculate the fluid forces on the particle. Thus, a highly efficient particle tracking scheme results allowing to predict the paths of millions of particles, i.e., flows with high mass loadings where inter-particle or inter-droplet collisions are occurring.

The collisions between particles or droplets within the four-way coupled simulation are predicted deterministically by a recently developed and highly efficient collision algorithm [2]. Inter-particle or inter-droplet collisions are a prerequisite for additional important physical phenomena, i.e., the agglomeration of particles and the coalescence of droplets. For the former an energy-based and a
momentum-based agglomeration model for rigid, dry and electrostatically neutral particles were developed in the framework of the hard-sphere model with deterministic collision detection \([4, 5]\). For surface-tension dominated droplets a similar methodology is proposed which evaluates the collision events of droplets based on the impact parameter and the Weber number. Based on experimental observations five different regimes have to be distinguished for this purpose, i.e., slow coalescence, bouncing, fast coalescence and reflexive or stretching separation leading to different outcomes of the collision event. To identify these regimes, a composite collision outcome model has been developed.

Another physical phenomenon taken into account is the deposition of particles on bounding walls due to the van-der-Waals force. Here, the physically relevant conditions for sticking and sliding inelastic collisions (normal restitution coefficient \(e_{n,w} < 1\)) including friction were recently determined. The modeling assumptions are in accordance with the momentum-based agglomeration model and lead to a new adhesion model \([6]\). This model was validated based on experiments in a horizontal particle-laden channel flow. Exemplarily, Fig. 1 depicts the side view of a stream of particles around a SD7003 airfoil. Note that this is not a contour plot but the particles are shown as scatter points colored according to the velocity in mean flow direction. Two different particle diameters are taken into account, i.e., small (10 \(\mu m\)) and large particles (50 \(\mu m\)). Obviously, there is a significant difference between both cases since small particles closely follow the continuous fluid, whereas large particles can not follow the curved surface of the airfoil at the suction side due to their higher inertia. That leads to different deposition patterns at the airfoil surface as shown below. A detailed summary of these developments including different applications will be provided in the full contribution.

\[ d_p = 10 \mu m \]
\[ d_p = 50 \mu m \]

**Figure 1.** Stream of particles around the airfoil for two different particle diameters colored by the streamwise velocity and corresponding deposition patterns.

**References**


