Collisions and Breakup of Droplets in a Thick spray

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Sprays are complex flows where dispersed particles (droplets) coexist with a fluid phase. We use an Eulerian-Lagrangian description, in which the droplets are described by a particle distribution function, solution of a kinetic equation (of Vlasov-Boltzmann type), while the surrounding gas is described thanks to macroscopic quantities and standard equations of fluid mechanics (Euler or Navier-Stokes). In so-called thick sprays, the coupling between the phases is made through the volume fraction of droplets, and through a drag force.

The kinetic equation for the droplets writes

$$\partial_t f(t,x,v,r,e) + v \cdot \nabla_x f(t,x,v,r,e) + \nabla_v (F(t,x,v,r)\, f(t,x,v,r,e))$$

$$+\nabla_e (q(t,x,r,e)\, f(t,x,v,r,e)) = Q(f)(t,x,v,r,e),$$

where $f(t,x,v,r,e)$ is the density of droplets which at time t and point x move with velocity v, have radius r and internal energy e, where F and q are the drag and energy transfer from the gas to the droplets, and Q is a kernel for all the complex phenomena.

In [2] and [3] are described models in which those phenomena (like collision, coalescence or breakup), are taken into account.

In particular, rigorously defined kernels are given, corresponding to the T.A.B. model (see [1]), and corresponding to inelastic collisions in which internal energy as well as kinetic energy are exchanged between the droplets.

As far as numerical simulation is concerned, a particle (Monte-Carlo) method is used for the droplets.

The distribution function of the droplets is approximated at each time by a discrete measure ("the numerical particles")

$$f \simeq \sum_{i=1}^{N} \omega_i(t^n) \delta_{x_i(t^n), v_i(t^n), r_i(t^n), e_i(t^n)},$$

where N is the total number of numerical particles, and ω_i (the numerical weight) is the number of real particles represented by the numerical particle i.

The kinetic equation is solved thanks to an operator splitting between the transport (Vlasov) term, the collision/coalescence term and the breakup term. We consider that in each cell, the distribution function does not depend on the spatial variable x. So we solve the collision and breakup steps in each cell independently.

At this point, several methods can be used for the collision step. Bird's method consists in sampling couples of particles. Its advantages are that mass and momentum and energy are exactly conserved. It has however in many situations the drawback of being tractable only with constant numerical weights. The alternative Nanbu's scheme consists in sampling only one particle, so that mass, etc. will be conserved only when averaging over many realisations, but it is better suited when one wants to use non constant weights.

Those two methods are by all means combined with the so-called "spurious collisions" trick, that enables to decrease significantly the computational cost.

We wish to present in detail the modeling and the simulation method described above, together with some results in a somewhat realistic context.

References

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