Implementation of Virtual Mass and Lift Forces in MFIX

For the two-fluid model, the added (virtual) mass force can be written as: $\vec{F}_v = C_v \varepsilon_s \varepsilon_g \rho_g \left(\frac{D_g \vec{v}_g}{D_g t} - \frac{D_s \vec{v}_s}{D_s t} \right)$, where D is the substantial derivative. This force is added to the right hand side (RHS) of the momentum equations for continuous (fluid, using subscript g) and dispersed (using subscript s) phases, which can be written as:

$$\varepsilon_g \rho_g \frac{D_g \vec{v}_g}{D_g t} = \vec{B}_g - \overrightarrow{F_v} \tag{1}$$

$$\varepsilon_s \rho_s \frac{D_s \vec{v}_s}{D_s t} = \vec{B}_s + \overrightarrow{F_v} \tag{2}$$

If one wants to treat the virtual mass force semi-implicitly, then a straightforward manipulation of equations (1) and (2) yield:

$$\left(\varepsilon_g + C_v \varepsilon_g \varepsilon_s \right) \rho_g \frac{D_g \vec{v}_g}{D_g t} = \vec{B}_g + C_v \varepsilon_s \varepsilon_g \rho_g \frac{D_s \vec{v}_s}{D_s t} \tag{3}$$

$$\left(\rho_s + C_v \varepsilon_g \rho_g \right) \varepsilon_s \frac{D_s \vec{v}_s}{D_s t} = \vec{B}_s + C_v \varepsilon_s \varepsilon_g \rho_g \frac{D_g \vec{v}_g}{D_g t} \tag{4}$$

In equations (3) and (4), the additional terms on the RHS are treated explicitly as source files in all momentum equations.

The added mass force effectively acts to increase the inertia of the dispersed phase, which generally stabilizes numerical simulations of bubbly flows. Results of fully developed flows are not affected by this force.

The lift force, $\vec{F}_L$ is added to the RHS of momentum equations (3) and (4) as:

$$\left(\varepsilon_g + C_v \varepsilon_g \varepsilon_s \right) \rho_g \frac{D_g \vec{v}_g}{D_g t} = \vec{B}_g + C_v \varepsilon_s \varepsilon_g \rho_g \frac{D_s \vec{v}_s}{D_s t} - \vec{F}_L \tag{5}$$

$$\left(\rho_s + C_v \varepsilon_g \rho_g \right) \varepsilon_s \frac{D_s \vec{v}_s}{D_s t} = \vec{B}_s + C_v \varepsilon_s \varepsilon_g \rho_g \frac{D_g \vec{v}_g}{D_g t} + \vec{F}_L \tag{6}$$

and takes the usual form: $\vec{F}_L = C_L \varepsilon_s \varepsilon_g \rho_g \left(\vec{v}_g - \vec{v}_s \right) \times \left(\vec{\nabla} \times \vec{v}_g \right)$. So it is clear that this force is normal to the direction of slip velocity and to the shear-induced vorticity. Thus, it will induce a lateral motion of the disperse phase. This force is implemented explicitly in source momentum equations in only the x-direction (i.e. it is not generalized to work under all flow conditions, unlike the added mass force; users may want to extend it to other directions if needed). Source_u_s.f and source_u_g.f included under the subdirectory LiftForce may be compiled to use the x-component of the lift force in the simulations.