The wall-lift matching model for Eulerian-Eulerian two-phase flow simulations

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1 Introduction

Two phase flow dynamics is of primary interest for a wide variety of industrial applications and processes such as energy conversion, compound mixing and wastewater treatment. The Eulerian-Eulerian two-fluid formulation provides a fast tool to compute the dynamics of such systems by solving the coupled Navier-Stoles equations either through the finite volume or the finite difference methods [1]. However, the results obtained so far lack of the necessary generality as the models used within this framework seem to be incomplete or inconsistent.

In particular, the interaction between the two phases is included into the model by using a set of interfacial volumetric forces between them. Every volumetric force results from the Reynolds average of the forces that act on the individual bubbles. We note in this work that current formalism is based on a set of forces that have not been properly identified and separated. Furthermore, it computes the averaging assuming that both the forces and the bubble distributions are homogeneous. This is a quite good approximation in most common flows, except in the near-wall region, where the location of bubbles is restricted by their collision against the wall.

In this work, a new formulation for the transversal interfacial forces is proposed. The new formalism identifies two of the forces as being of identical origin and also takes into account the special characteristics of the Reynolds Averaging of the two field conservation equations in the vicinity of the wall.

2 Current formalism.

Current formalism for the interfacial forces [2] is based on the following set of interfacial volumetric forces:

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$$\mathbf{M}_\varphi = \mathbf{M}_{\varphi,\mathrm{D}} + \mathbf{M}_{\varphi,\mathrm{VM}} + \mathbf{M}_{\varphi,\mathrm{L}} + \mathbf{M}_{\varphi,\mathrm{WL}} + \mathbf{M}_{\varphi,\mathrm{TD}}. \quad (1)$$

These terms are often called interfacial forces as they arise from the Reynolds average of the forces that act onto the surfaces of the individual bubbles/drops in the flow. The different forces are:

- Drag ($\mathbf{M}_{\varphi,\mathrm{D}}$): the particles of the dispersed phase tend to rise or fall by the action of the buoyancy (gravity) term. The drag represents the resistance of the main flow to this movement.
- Virtual mass ($\mathbf{M}_{\varphi,\mathrm{VM}}$): when the particles are accelerated (for instance, when they start to move), a reaction force is exerted by the main fluid (third Newton's law).
- Lift ($\mathbf{M}_{\varphi,\mathbf{L}}$): a velocity gradient of the main phase generates an asymmetric field of velocities (and therefore pressures) onto the particle surface that induces its movement.
- Wall lubrication ($\mathbf{M}_{\varphi,\mathrm{WL}}$): when a particle is close to a wall, the main flow distributes asymmetrically around its surface, thus producing a net force repelling the particle from the wall.
- Turbulent dispersion ($\mathbf{M}_{\varphi,\mathrm{TD}}$): the turbulent eddies from the main phase tend to move randomly the particles. This force acts as a particle diffusion potential.

At its current state of development, this formalism delivers simulation results that are strongly dependant on the mesh spacing near the wall thus limiting its general applicability.

3 Proposed model.

This work points out that both wall lubrication and lift forces arise from the same integral. Wall lubrication force arises from the non-uniform distribution of the flow field around bubbles due to the influence of a close wall [3]. The net force is obtained as the transverse component (with respect to flow streamlines) of the pressure force integrated onto the bubble surface. Lift force results as the transverse component of the pressure force integrated onto the bubble surface when a bubble is inmersed in a fluid where a constant velocity gradient is present [4].

In summary, both forces are the result of the same mathematical procedure, but under way different boundary conditions. Therefore, this work proposes a new formalism that unifies both forces into a new one. The resulting force takes as assymptotic values those given by the aforementioned forces, i.e. the wall lubrication force in the near wall region and the lift force in the bulk region. Figure 1 illustrates the proposed approach: the flow region is partitioned into the near wall region, where the wall lubrication acts, a bulk region where the lift acts, and a transition region between them. In the transition region, the force is assumed to be given by the lift force expression, but with a strength coefficient multiplying the lift expression that increases linearly between zero (at the near-wall limit) and one (at the bulk limit).

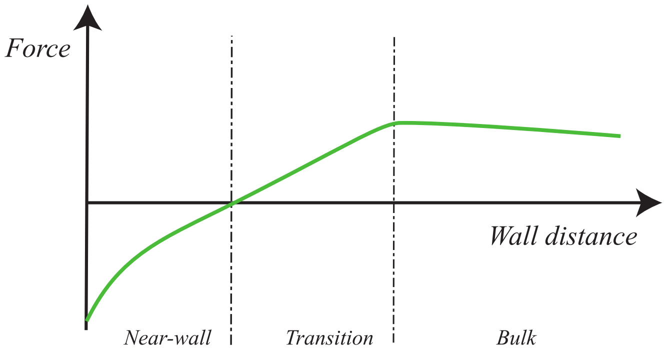

Figure 1: Wall-lift matching between the near-wall and the bulk regions.

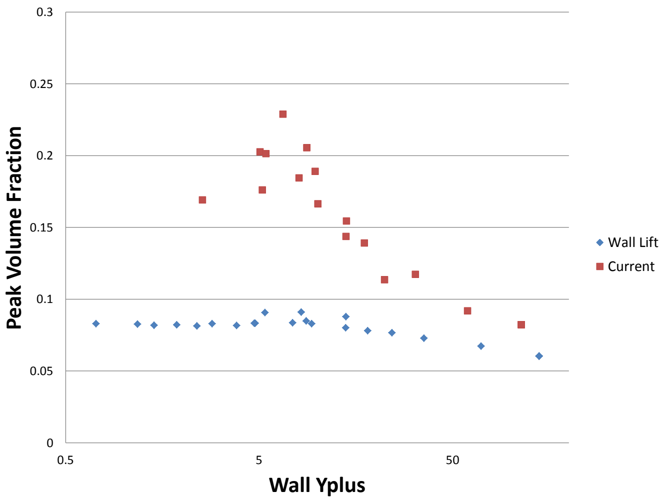

Figure 2: Mesh sensivity study of current and proposed formalism.

4 Results and conclusions

The model has been implemented in the software ANSYS-CFX 17.2 and a mesh sensitivity analysis has been performed to demonstrate the model reliability (see Fig. 2). Finally, the results have been validated against a complete experimental database [5]. Void fraction, fluids velocities and turbulence data have been compared. For the sake of briefty, only the void fraction comparison corresponding to one of these validation cases is shown in Fig. 3.

References

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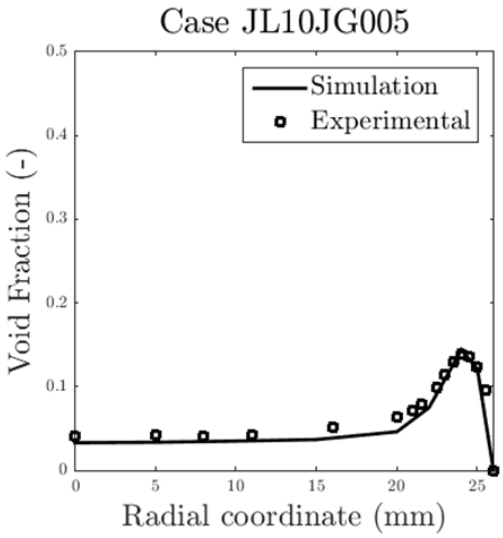

Figure 3: Void fraction comparison for one of the validated cases.

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