Hydrodynamic interaction of two particles

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GPS Génie par la simulation
SBES Simulation - Based Engineering Science

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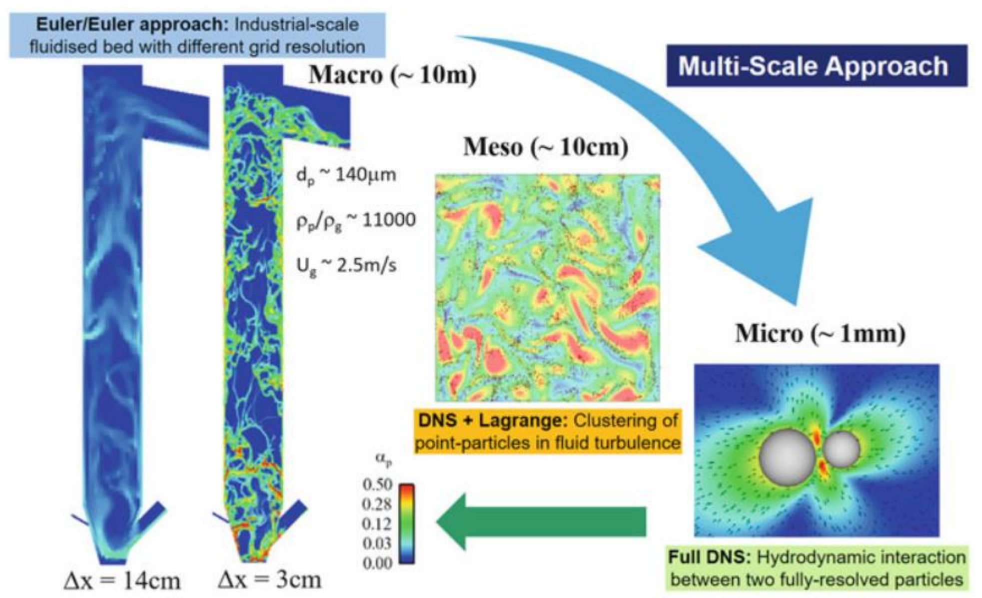
MOTIVATION

Analysis of particle clusters dynamics using resolved computational fluid dynamics coupled with the discrete element method (CFD-DEM).

- Determine the conditions that lead pair of particles to interact strongly (behavior of drafting kissing and tumbling DKT) in a fluid flow.
- Develop a new pair wise closer model for large-scale simulation (e.g. Unresolved CFD-DEM).



Link between the different scale of the solid-fluid resolution [1]

CFD-DEM THEORIES

Finite element formulation of the incompressible Navier-Stokes equation with streamline upwind Petrov–Galerkin and pressure-stabilizing Petrov–Galerkin (SUPG/PSPG) stabilizations.

$$\nabla \cdot \boldsymbol{u} = 0$$

$$\frac{\partial \boldsymbol{u}}{\partial t} + (\boldsymbol{u} \cdot \nabla)\, \boldsymbol{u} = -\nabla p^* + \nabla \cdot \boldsymbol{\tau} + \boldsymbol{f}$$

$$\boldsymbol{\tau} = \nu \left((\nabla \boldsymbol{u}) + (\nabla \boldsymbol{u})^T \right)$$

We obtain the fluid force from the fluid simulation that needs to be applied to the particles. The particle position is tracked in a lagrangian manner (Newton-Second law).

$$\frac{d\boldsymbol{v}_i}{dt} = \frac{1}{m_i} \left(\sum_{\substack{j=1 \\ i \neq j}}^{n_b} \left(\boldsymbol{F}_{ij}^{c} + \boldsymbol{F}_{ij}^{l_c} \right) + \boldsymbol{F}_i^{w} + \boldsymbol{F}_i^{f} + \boldsymbol{g} m_i \right)$$

$$\frac{d\boldsymbol{\omega}_i}{dt} = \frac{1}{I_i} \left(\sum_{\substack{j=1 \\ i \neq j}}^{n_b} \left(\boldsymbol{T}_{ij}^{c} \right) + \boldsymbol{T}_i^{w} + \boldsymbol{T}_i^{f} \right)$$

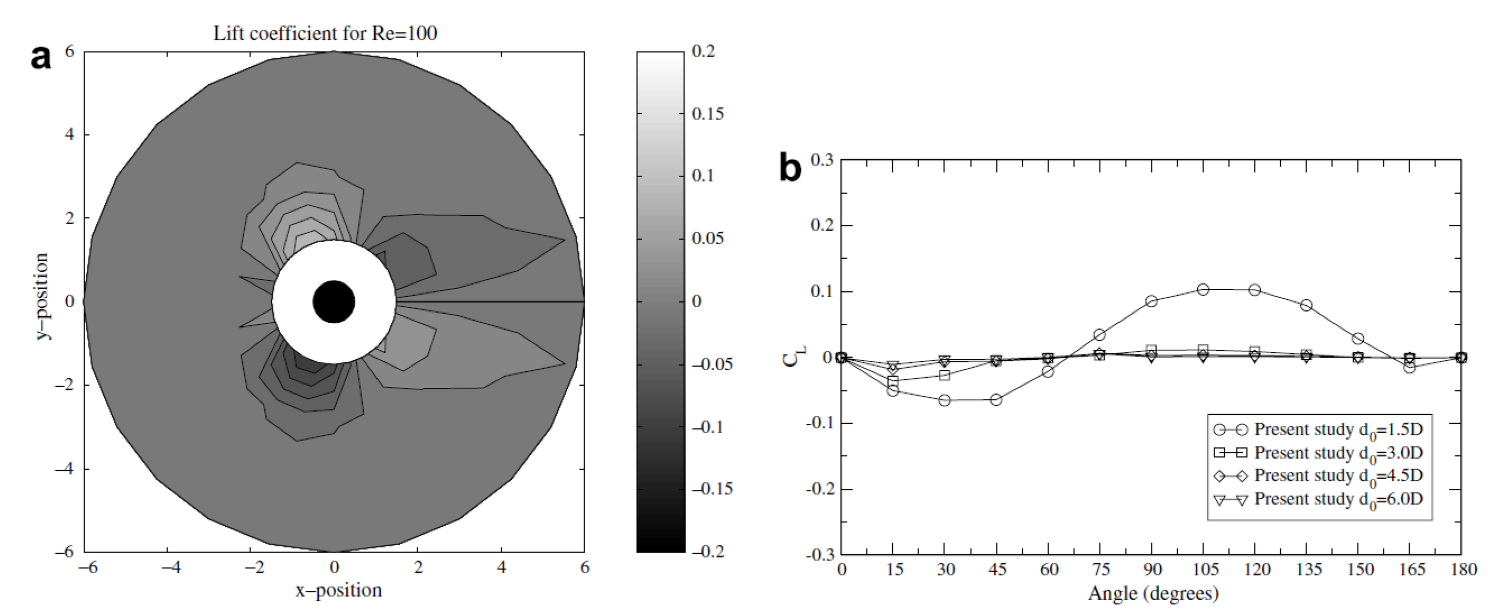
$\boldsymbol{F}_{ij}^{c}$-$\boldsymbol{T}_{ij}^{c}$ Contact force and toque between particle *i* and *j*
$\boldsymbol{F}_{i}^{w}$-$\boldsymbol{T}_{i}^{w}$ Particle-wall contact force and torque
$\boldsymbol{F}_{i}^{f}$-$\boldsymbol{T}_{i}^{f}$ Fluid force and torque
$\boldsymbol{F}_{ij}^{l_c}$ Lubrication force correction between particle *i* and *j*

OBJECTIVES

- **Measure the hydrodynamic force due to particles interaction (induce drag, induce lift) in a static particle configuration. Characterize the impact of the initial conditions on the sedimentation trajectory of two particles.**
- **Propose a force model for the hydrodynamic interaction between two particles.**

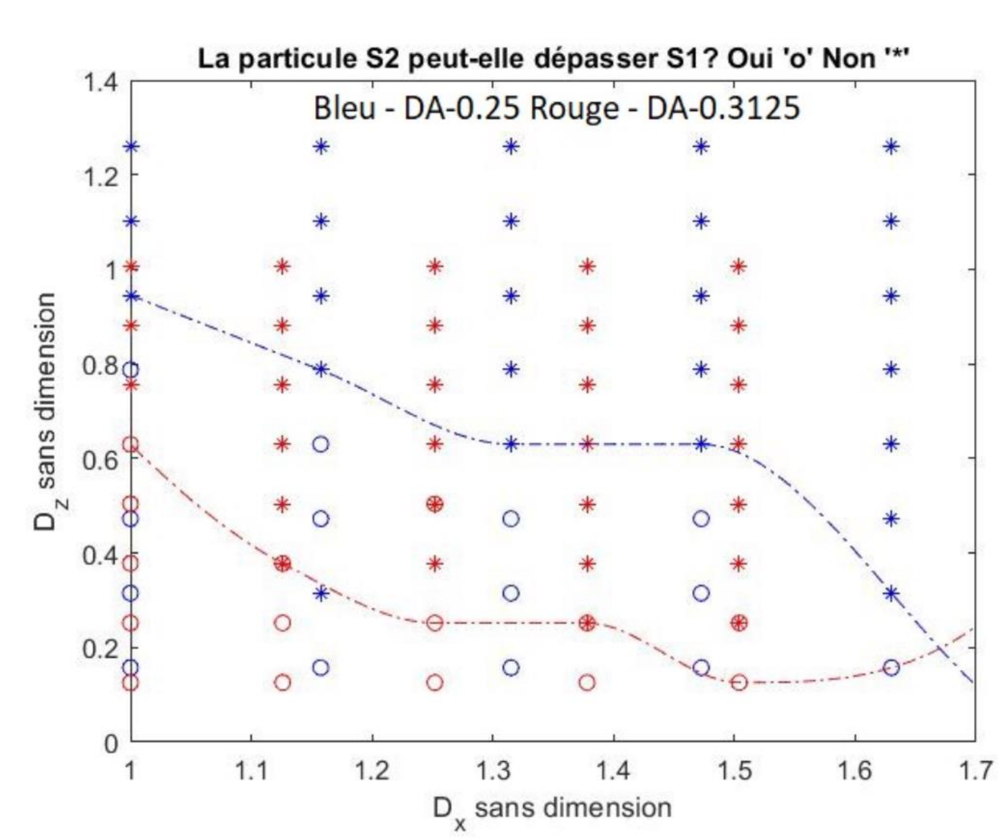
METHODOLOGY

- Simulate pairs of particles with various relative positions and Reynolds numbers
  - Measure the variation of the drag and lift forces due to the presence of another particle.



Example of results obtained for the lift coefficient modification due to the presence of an other particle at a Reynolds of 100. Results obtained numerically by Prahl (2007)[2]

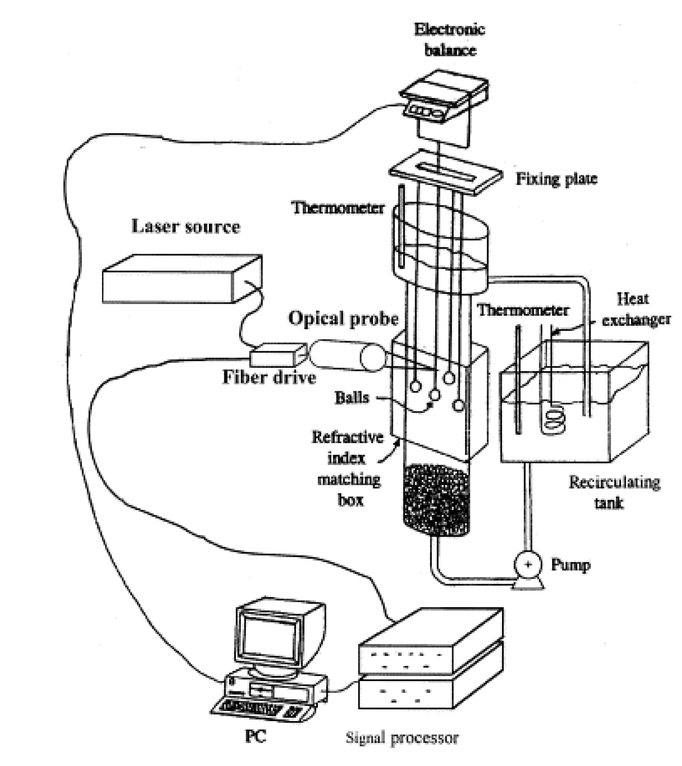
- Simulates the sedimentation of pairs of particles with various relative initial positions.
  - Determine an envelope of initial conditions that lead to drafting kissing and tumbling (DKT) of particles.
  - Measure the impact of the relative motion of the particles on their hydrodynamic force interaction based on the interaction forces without the relative motion of the particles.



Mapping of the interaction between pairs of particles depending on their relative position for two Archimedes numbers. Results obtained experimentally by Deng (2022) [3]

VALIDATION

- Comparison of the numerical results with the experimental results of Chan and Wu (2000) for the modification of the drag and lift force of pair of particles.



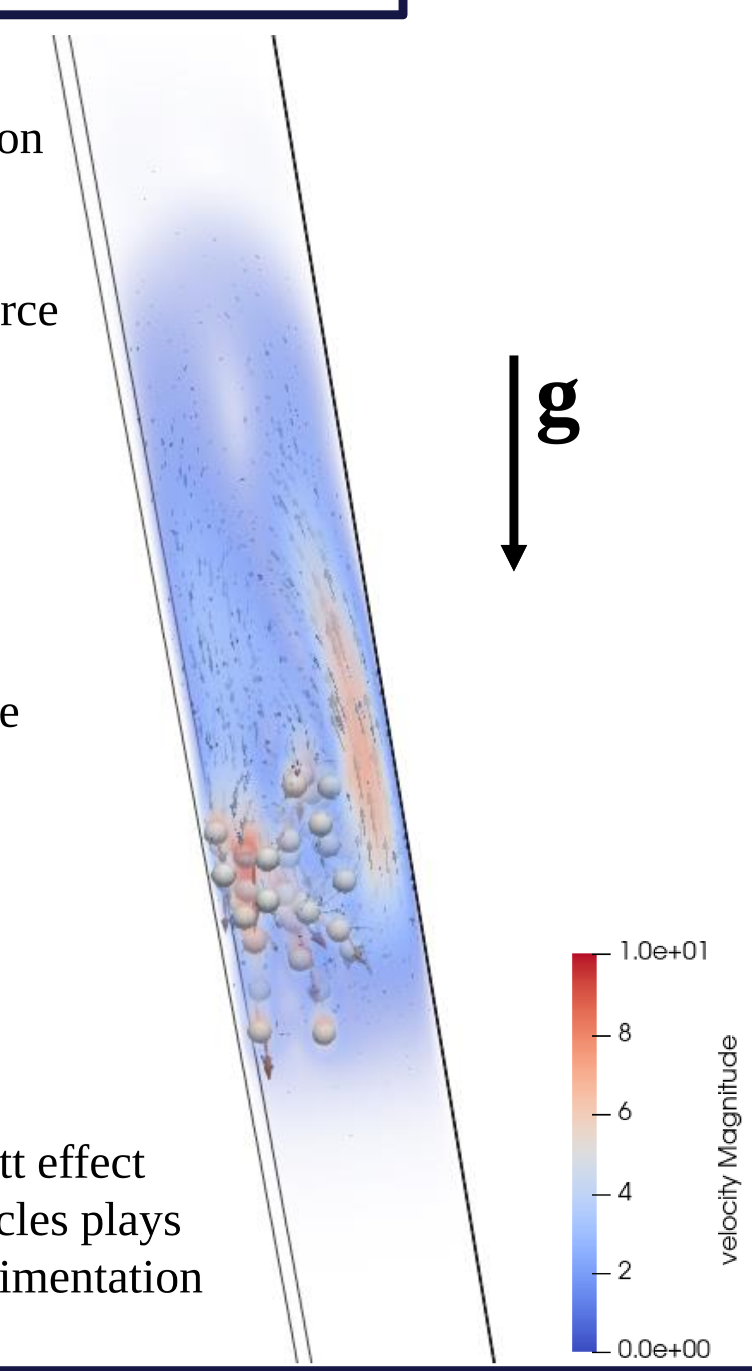
Experimental apparatus used by Chan and Wu to measure the hydrodynamic force interaction of particles. [4]

CONCLUSIONS

We improve the fundamental understanding of the fluid interaction force between particles by:

- Measuring the hydrodynamic force in a static configuration.
- Defining an envelope of initial conditions that leads to DKT of particle.
- Propose a pairwise force model.

This opens the door for new closure models that consider the relative position of particles.



Resolved CFD-DEM of the Boycott effect where the local interaction of particles plays an important role in the cluster sedimentation speed.

REFERENCES

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3. J. Deng, Etude exp´erimentale des interactions entre deux particules sph´eriques, rel^ach´ees dans l'eau stagnante, Master's thesis, Polytechnique Montr´eal (April 2022).
4. Chen RC, Wu JL. The flow characteristics between two interactive spheres. Chemical Engineering Science. 2000 Mar 1;55(6):1143-58.

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