An Efficient Strategy of Parcel Modeling for Polydispersed Multiphase Turbulent Flows

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composed of a **continuous phase** and a **dispersed phase** in the form of unconnected particles or droplets.

Using **Eulerian-Lagrangian** method (particle tracking)

That is the best-suited for dispersed multiphase flows with **thousands or millions of particles**, and with a flow regime ranging from the very **dilute** up to relatively **dense**.

to simulate the **fuel injection of combustion chambers, cyclone separators, evaporative cooling, dispersion of pollutants, deposition of inhaled medicine** in the human airways

**Coupling Between Particles and Fluid:**

\[
\phi_p = \frac{V_p}{V}
\]
Using Parcels:

- In order to decrease the **computational cost** due to tracking each particle

- Each **parcel** represents the specified number of particles with the same properties

- Two methods for arranging the particles in parcels: **Number fixed method**, NFM and **Volume fixed method**, VFM

- With increasing the volume for the VFM the results are not accurate for the **smaller particles**

- With increasing the Number of particles per parcel for NFM the results are not accurate for the **bigger particles**

**The Objective:**

- Implementing a new approach **NFM-VFM** which is a combination of NFM and VFM
Dispersed phase:

Particle Equations of Motion:
\[
\frac{dx_p^n}{dt} = v_p^n \quad m_p^n \frac{dv_p^n}{dt} = \sum_i F_i
\]

for simplicity is assumed that the drag force is the only significant fluid-particle interaction force:

\[
m_p^n \frac{dv_p^n}{dt} = m_p^n \beta^n \left[ u(x_p^n) - v_p^n \right] \frac{\rho_p}{\rho_p} \quad \beta^n = \frac{3}{4} \frac{C_D \rho u(x_p^n) - v_p^n}{d_p}
\]

Continuous phase:

- **Convective operator:** Symmetry-preserving scheme
- **Pressure-velocity coupling:** Fractional step method
- **Poisson equation:** iterative Conjugate-Gradient (CG) method with Jacobi preconditioner

**Continuity equation:**
\[
\nabla \cdot u = 0
\]

**Momentum equation:**
\[
\rho \left[ \frac{\partial u}{\partial t} + \nabla \cdot (uu) \right] + \nabla p = \mu \nabla^2 u + S_u \quad S_u = \sum_{n=1}^{N_p} \frac{m_p^n \beta^n \left[ u(x_p^n) - v_p^n \right]}{\rho_p}
\]
Designing new approach NFM-VFM:

- The particles with sizes above the Sauter mean diameter, SMD, are arranged with the VFM and the rest of them arranged with NFM.

- Calculating the Sauter mean diameter in terms of a finite number of discrete size classes:
  
  \[ D_{pq} = \left[ \frac{\sum_{i=1}^{\infty} n_i D_i^p}{\sum_{i=1}^{\infty} n_i D_i^q} \right] \]

  \[ \text{p = 3 and q = 2} \]
Benchmark case:

- The flow loop Hercule of Borée et al.\(^1\) which generates an axisymmetric confined bluff body flow
- Particle-laden turbulent flow using two-way coupling approach by means of large eddy simulation (LES)
- Mass loading ratio in the inner jet of M=22%
- Total volume fraction of particles: \(\phi_p = 5 \times 10^{-4}\)
- Diameter distribution: 20 µm, 30 µm, 40 µm, 50 µm, 60 µm, 70 µm, 80 µm, 90 µm, 100 µm

\(^1\) Borée J, Ishima T and Flour I 2001 the effect of mass loading and inter-particle collision on the development of the polydisperse two-phase flow downstream of a confined bluff body *Journal of Fluid Mechanics* **443** 129-165
Validation:

Figure. Radial profiles of fluid mean streamwise velocity for particle-laden configuration (M=22%). Circle: Experiment; solid line: Numerical simulation. (a) z=0.08m; (b) z=0.16m; (c) z=0.20m; (d) z=0.24m; (e) z=0.32m; (f) z=0.40m
Figure. Radial profiles of particle (dp=20μm) mean streamwise velocity for particle-laden configuration (M=22%). Circle: Experiment; solid line: Numerical simulation. (a) z=0.08m; (b) z=0.16m; (c) z=0.20m; (d) z=0.24m; (e) z=0.32m; (f) z=0.40m
Implementing new approach NFM-VFM:

- By comparing the results of dispersed phase for the larger diameters by means of NFM
- Sauter Mean Diameter = 60 μm

**NFM: Number of particle per Parcel = 5**
NFM: Number of particle per Parcel = 10

Introduction
Methodology
Test case
Conclusion
NFM: Number of particle per Parcel = 20
NFM: Number of particle per Parcel = 40

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</table>
\[ dp = 80 \mu m \quad , \quad SMD = 60 \mu m \]

\[ N_p \big|_{80} = 10 \quad \Rightarrow \quad V_p \big|_{80} = N_p \big|_{80} \times \frac{4}{3} \pi \times \left( \frac{d_p}{2} \right)^3 = 10 \times \frac{4}{3} \pi \times \left( \frac{80 \times 10^{-6}}{2} \right)^3 \]

\[ V_p \big|_{80} = V_p \big|_{60} \quad \Rightarrow \quad N_p \big|_{60} = 23.7 \]

\[ N_p \big|_{80} = 20 \quad \Rightarrow \quad V_p \big|_{80} = N_p \big|_{80} \times \frac{4}{3} \pi \times \left( \frac{d_p}{2} \right)^3 = 20 \times \frac{4}{3} \pi \times \left( \frac{80 \times 10^{-6}}{2} \right)^3 \]

\[ V_p \big|_{80} = V_p \big|_{60} \quad \Rightarrow \quad N_p \big|_{60} = 47.4 \]

\[ 23.7 < N_p \big|_{60} < 47.4 \quad \Rightarrow \quad N_p \big|_{60} = 40 \]
Comparing NFM, VFM, NFM-VFM:

- **dp=20μm**
- **dp=30μm**
- **dp=40μm**
- **dp=50μm**

**Streams**: NoParcel, NFM, VFM, NFM-VFM
Comparing NFM, VFM, NFM-VFM:

- **dp=60μm**
  - No_Parcel
  - NFM
  - VFM
  - NFM-VFM

- **dp=70μm**
  - No_Parcel
  - NFM
  - VFM
  - NFM-VFM

- **dp=80μm**
  - No_Parcel
  - NFM
  - VFM
  - NFM-VFM
Comparing NFM, VFM, NFM-VFM:

![Graphs showing Wmean vs Streamwise distance for dp=90μm and dp=100μm.](image)
Comparing NFM, VFM, NFM-VFM:

Figure. Radial profiles of particle (dp=20μm) mean streamwise velocity for particle-laden configuration (M=22%). Numerical simulation. (a) z=0.20m; (b) z=0.24m; (c) z=0.32m; (d) z=0.40m.
Comparing NFM, VFM, NFM-VFM:

Figure. Radial profiles of particle (dp=80μm) mean streamwise velocity for particle-laden configuration (M=22%). Numerical simulation. (a) z=0.20m; (b) z=0.24m; (c) z=0.32m; (d) z=0.40m.
Conclusion:

- According to the results of the new approach, an optimal trade-off between accuracy and computational cost has achieved.

Future work:

- Comparison of time-averaged distribution of particle dispersion, particle volume fraction and computational cost.
- Increasing the mass loading ratio in the inner jet to $M=110\%$ using Hercule Experiment benchmark case using NFM, VFM and NFM-VFM parcel methods.
Thanks For your attention

Any question?

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