Numerical Analysis of Parcel Tracking in Large Eddy Simulation of Polydispersed Multiphase Flows: Assessment of different Parcel Modeling Techniques

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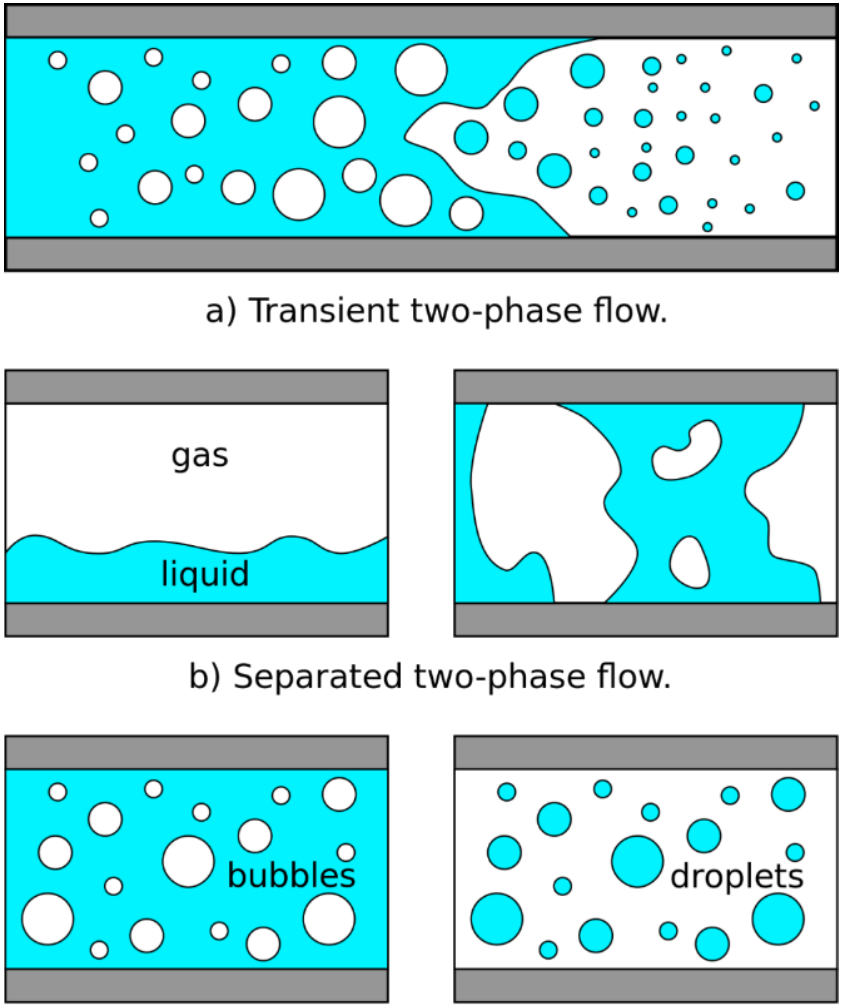
Dispersed Two phase Flows:

- 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



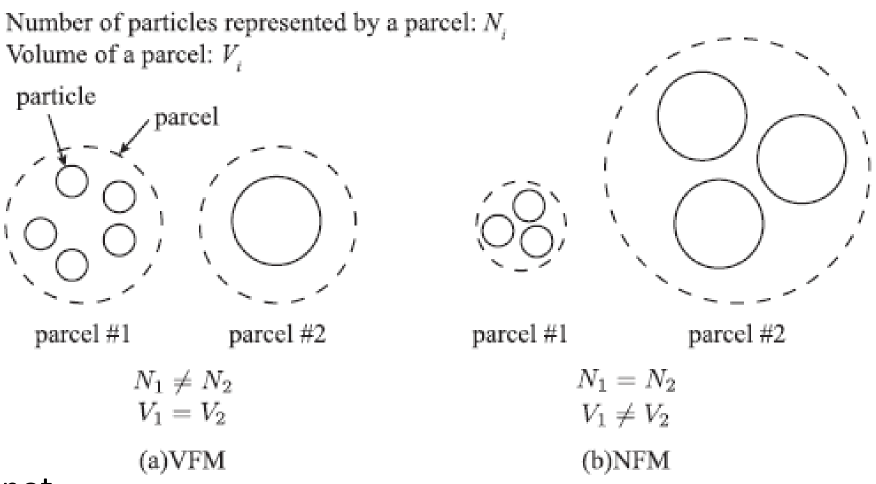
a) Transient two-phase flow.

b) Separated two-phase flow.

c) Dispersed two-phase flow.

Using Parcels:

- In order to decrease the **computational cost** due to tracking each particles
- 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** to enhance the particle behaviour regarding the limitation of the VFM and the NFM
- Analyzing the effect of the Stochastic subgrid model of Bini and Jones (BJ) on particle characteristics

Dispersed phase:

Particle Equations of Motion:

$$\frac{\mathrm{d}\mathbf{x}_\mathbf{p}^\mathbf{n}}{\mathrm{d}t} = \mathbf{v}_\mathbf{p}^\mathbf{n} \qquad m_\mathrm{p}^n \frac{\mathrm{d}\mathbf{v}_\mathbf{p}^\mathbf{n}}{\mathrm{d}t} = \sum_i \mathbf{F_i}$$

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

$$m_\mathrm{p}^n \frac{\mathrm{d}\mathbf{v}_\mathbf{p}^\mathbf{n}}{\mathrm{d}t} = m_\mathrm{p}^n \frac{\beta^n \left[\mathbf{u}(\mathbf{x}_\mathbf{p}^\mathbf{n}) - \mathbf{v}_\mathbf{p}^\mathbf{n}\right]}{\rho_\mathrm{p}} \qquad \beta^n = \frac{3}{4}\frac{C_D \rho}{d_\mathrm{p}}\left|\mathbf{u}(\mathbf{x}_\mathbf{p}^\mathbf{n}) - \mathbf{v}_\mathbf{p}^\mathbf{n}\right|$$

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:

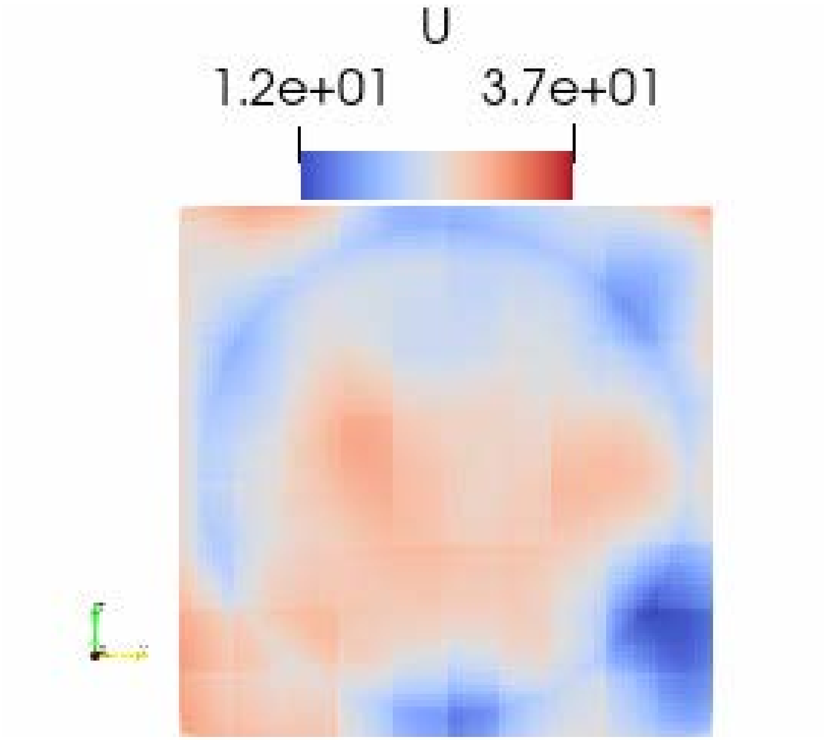
$$\nabla \cdot \mathbf{u} = 0$$

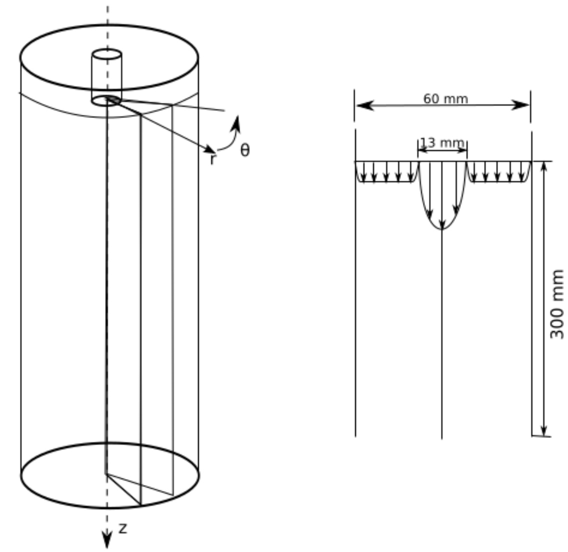
Momentum equation:

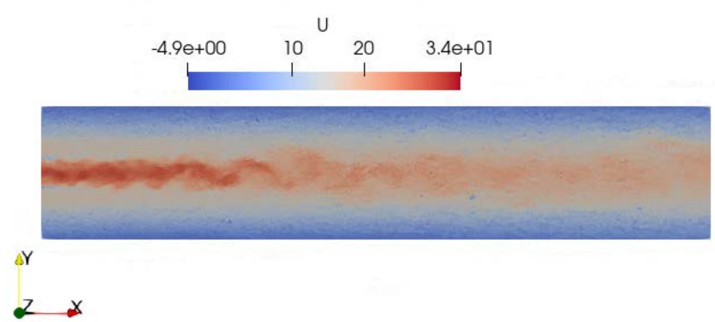
$$\rho\left[\frac{\partial \mathbf{u}}{\partial t} + \nabla \cdot (\mathbf{u}\mathbf{u})\right] + \nabla p = \mu \nabla^2 \mathbf{u} + S_u \qquad S_u = -\sum_{n=1}^{N_\mathrm{p}} \frac{m_\mathrm{p}^n \beta^n \left[\mathbf{u}(\mathbf{x}_\mathbf{p}^\mathbf{n}) - \mathbf{v}_\mathbf{p}^\mathbf{n}\right]}{\rho_\mathrm{p}}$$

Benchmark case:

- The confined jet of Hishida[1]
- Particle-laden turbulent flow using **one-way coupling** approach by means of large eddy simulation (LES), using a synthetic turbulent generator for the inner jet
- Particle mass flow rate in the inner jet = 5×10^{-3}, particle diameters= 64 µm, density= 2590 kg/m^3







[1] Hishida, K. (1987), Turbulence characteristics of gas-solids two-phase confined jet (effect of particle density) Japanese Journal of Multiphase Flow, 1(1), pp. 56-69.

Validation:

Figure. Radial profiles of **fluid** mean velocity. Circle: Experiment; solid line: Numerical simulation. (a) x=0m; (b) x=0.065m; (c) x=0.13m; (d) x=0.26m

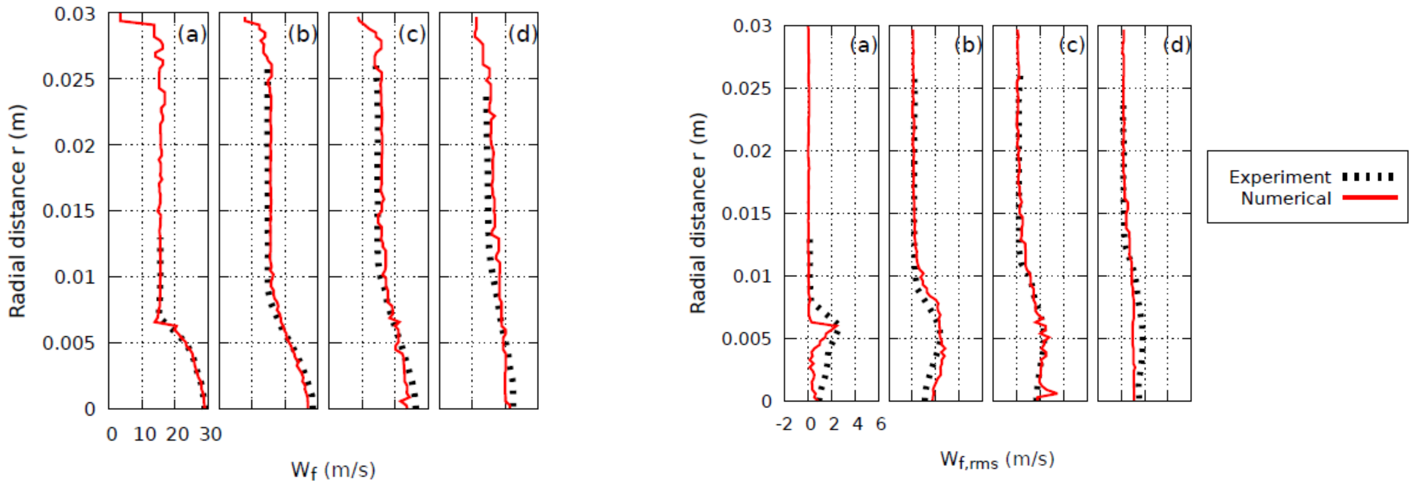
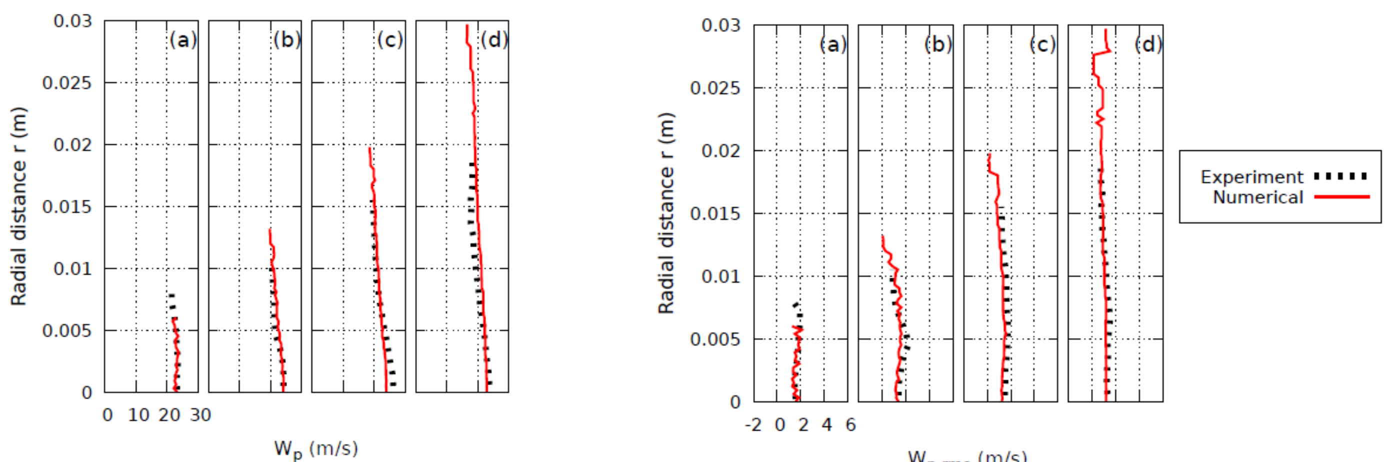


Figure. Radial profiles of **particle (dp=64µm**) mean streamwise velocity. Circle: Experiment; solid line: Numerical simulation. (a) x=0m; (b) x=0.065m; (c) x=0.13m; (d) x=0.2xm

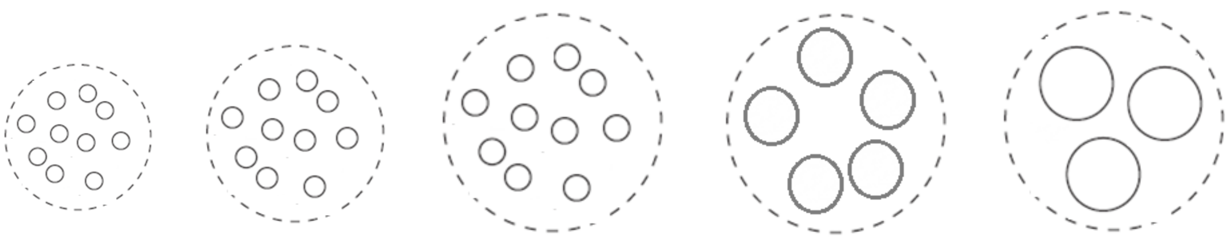


Designing new approach NFM-VFM:

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

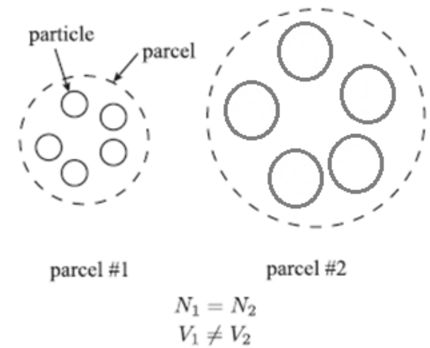
- Calculating the Sauter mean diameter in terms of a finite number of discrete size classes:
  p = 3 and q = 2

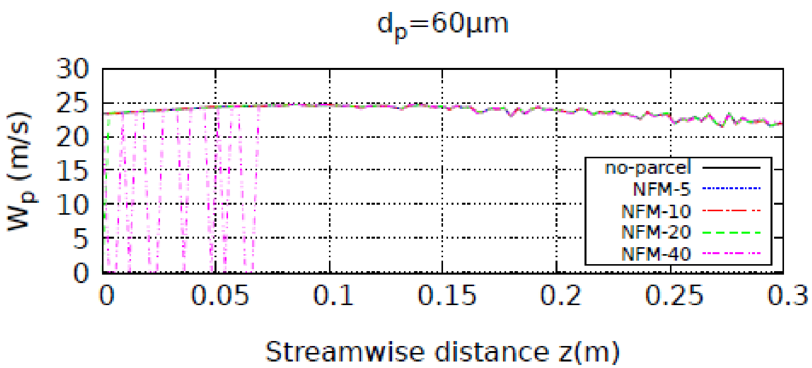
$$D_{pq} = \left[\frac{\sum_{i=1}^{\infty} n_i D_i^p}{\sum_{i=1}^{\infty} n_i D_i^q} \right]^{1/(p-q)}$$

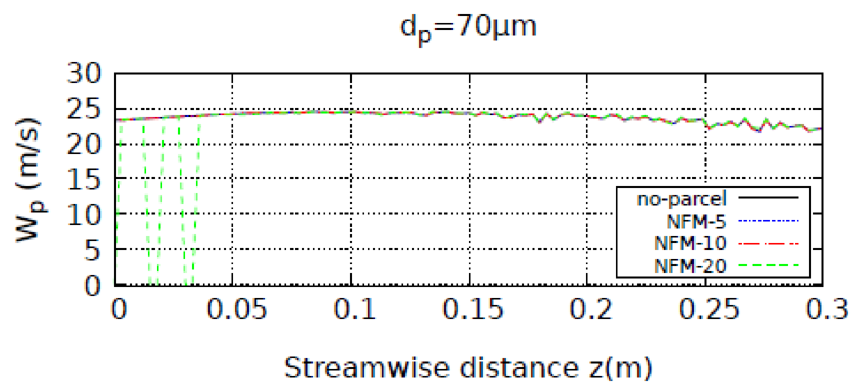


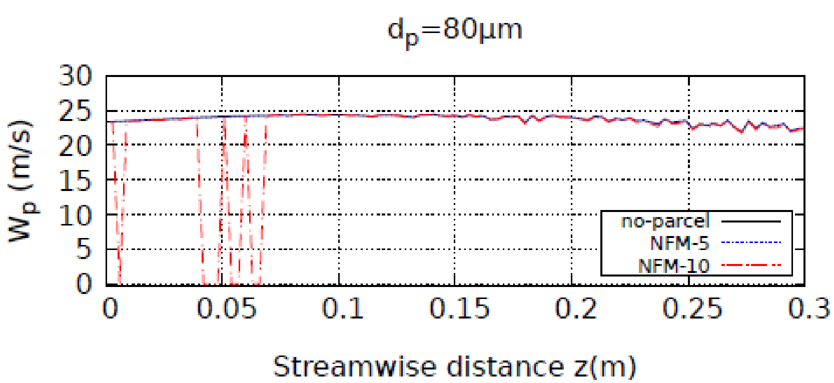
SMD

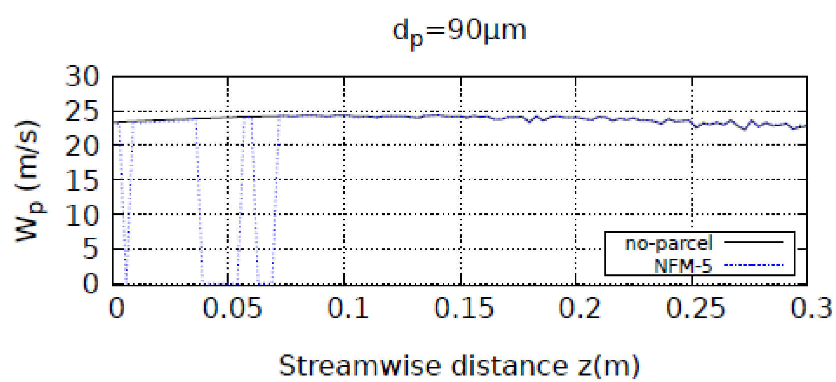
- Diameter distribution: 20 µm, 30 µm, 40 µm, 50 µm, 60 µm, 70 µm, 80 µm, 90 µm, 100 µm
- ✓ By comparing the results of dispersed phase for **the larger diameters** by means of **NFM**
- ✓ **Sauter Mean Diameter = 60 µm**











dp \ Np	5	10	20	40
60 µm	✓	✓	✓	✗
70 µm	✓	✓	✗	✗
80 µm	✓	✗	✗	✗
90 µm	✗	✗	✗	✗
100 µm	✗	✗	✗	✗

$$N_p\big|_{70} = 20 \quad \rightarrow V_p\big|_{70} = N_p\big|_{70} \times \frac{4}{3}\pi \times \left(\frac{d_p}{2}\right)^3 = 20 \times \frac{4}{3}\pi \times \left(\frac{70 \times 10^{-6}}{2}\right)^3 \quad , \; V_p\big|_{70} = V_p\big|_{60} \quad \rightarrow \quad N_p\big|_{60} = 31$$

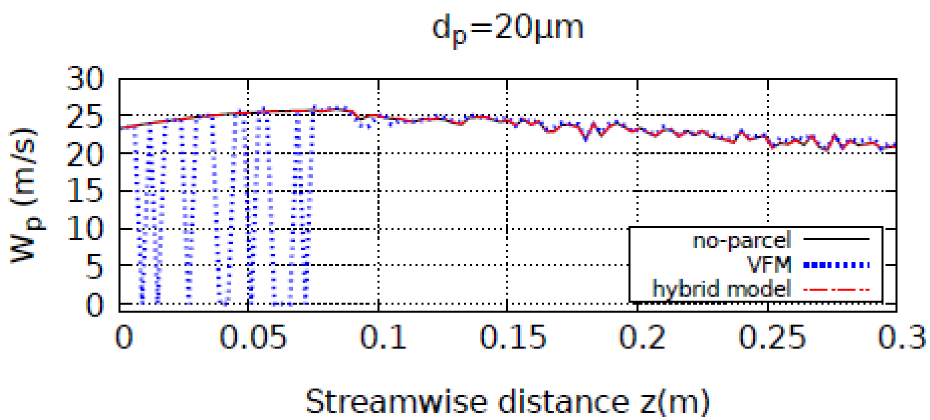
$$N_p\big|_{80} = 10 \quad \rightarrow V_p\big|_{80} = N_p\big|_{80} \times \frac{4}{3}\pi \times \left(\frac{d_p}{2}\right)^3 = 10 \times \frac{4}{3}\pi \times \left(\frac{80 \times 10^{-6}}{2}\right)^3 \quad , \; V_p\big|_{80} = V_p\big|_{60} \quad \rightarrow \quad N_p\big|_{60} = 23$$

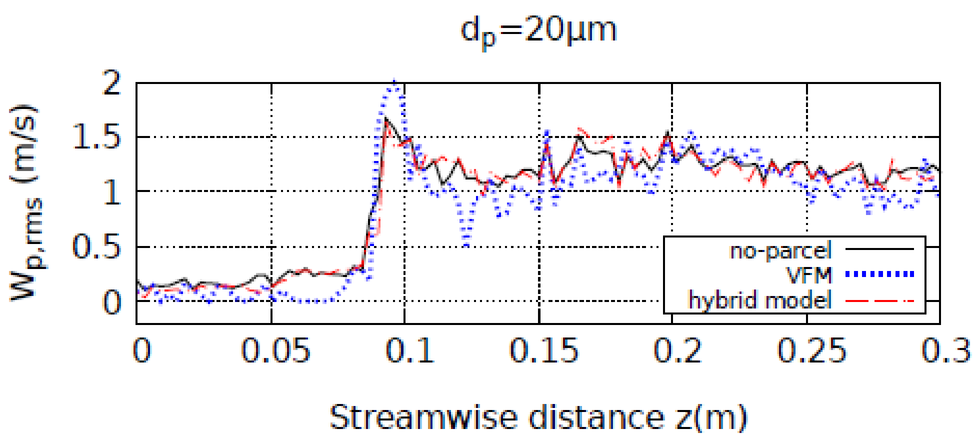
$$N_p\big|_{90} = 5 \quad \rightarrow V_p\big|_{90} = N_p\big|_{90} \times \frac{4}{3}\pi \times \left(\frac{d_p}{2}\right)^3 = 5 \times \frac{4}{3}\pi \times \left(\frac{90 \times 10^{-6}}{2}\right)^3 \quad , \; V_p\big|_{90} = V_p\big|_{60} \quad \rightarrow \quad N_p\big|_{60} = 16.8$$

dp	20µm	30µm	40µm	50µm	60µm	70µm	80µm	90µm	100µm
Parcel Type	NFM	NFM	NFM	NFM	NFM/VFM	VFM	VFM	VFM	VFM
Np	15	15	15	15	15	9	6	4	3

Comparing no-parcel, VFM, NFM-VFM:

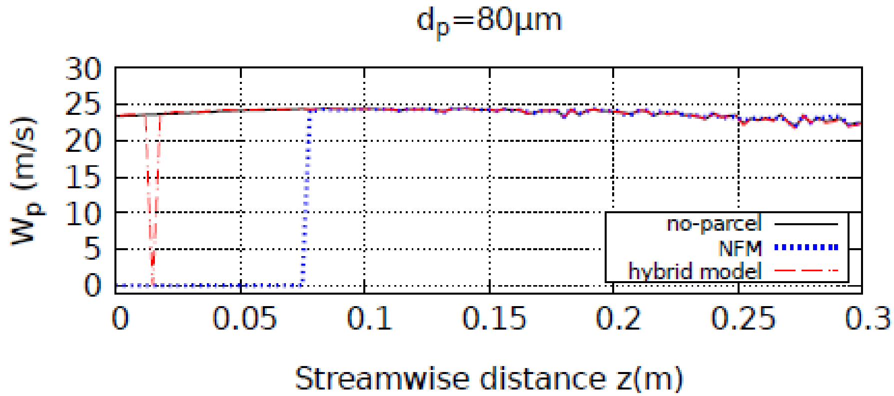
- In comparision with the no-parcel model, for the **particles diameters below the SMD**, the hybrid model shows better parcel dispersion and fewer discrepancies in **the mean and the RMS velocity** profiles of the dispersed phase than **the VFM**

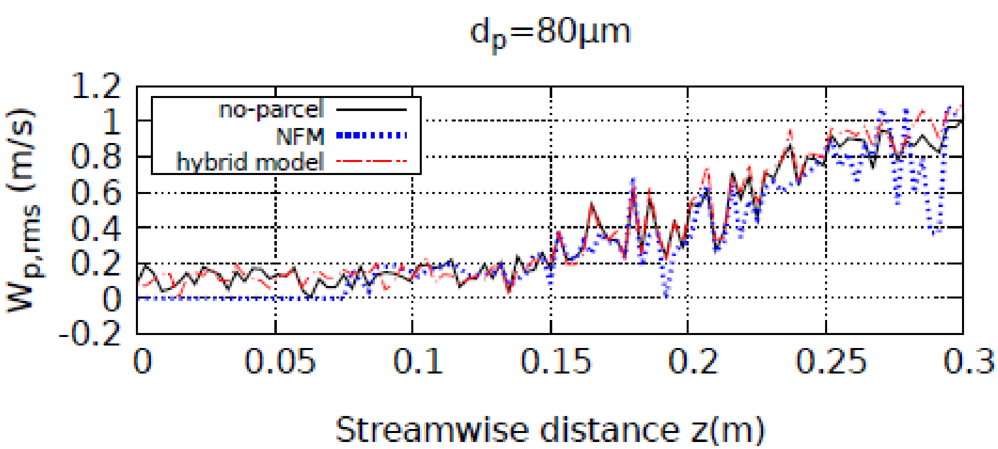




Comparing no-parcel, NFM, NFM-VFM:

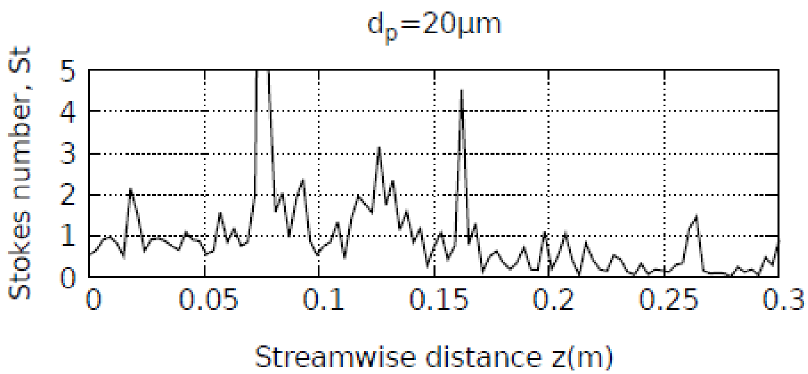
- Observing the results of the no-parcel model, for the **particle diameters above the SMD**, this hybrid model presents better parcel dispersion and fewer discrepancies in **the mean and the RMS velocity** profiles of the dispersed phase than **the NFM.**

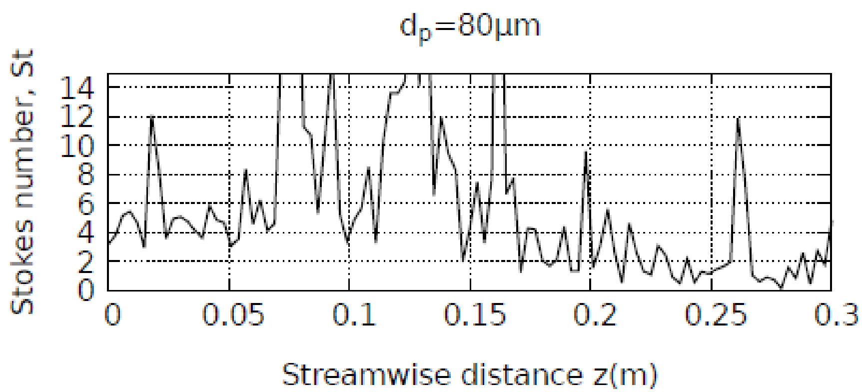




Particles subgrid Stokes number:

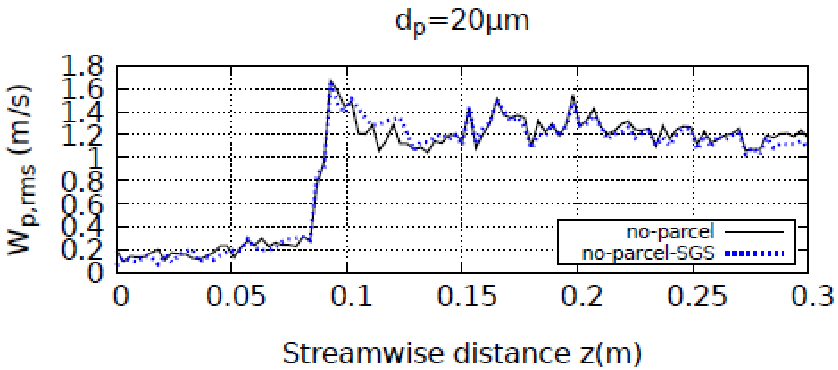
$$St = \tau_p / T_{SGS}$$

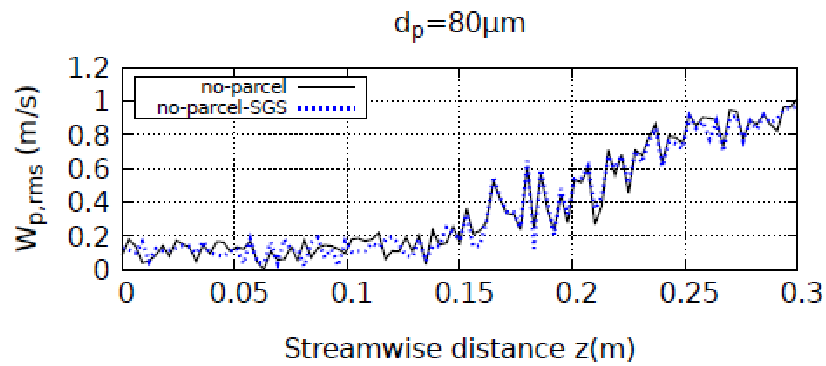


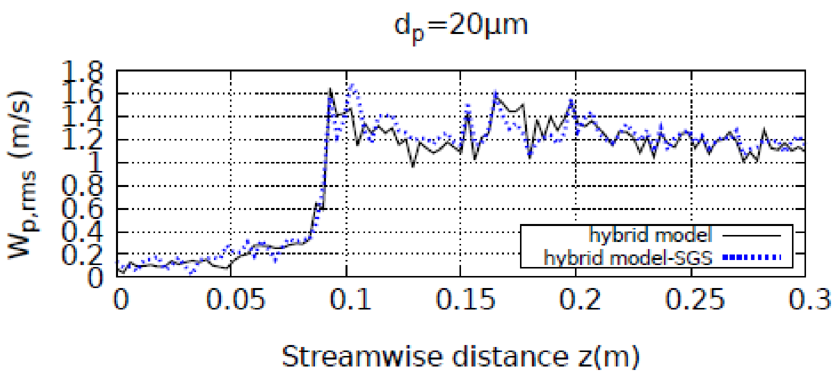


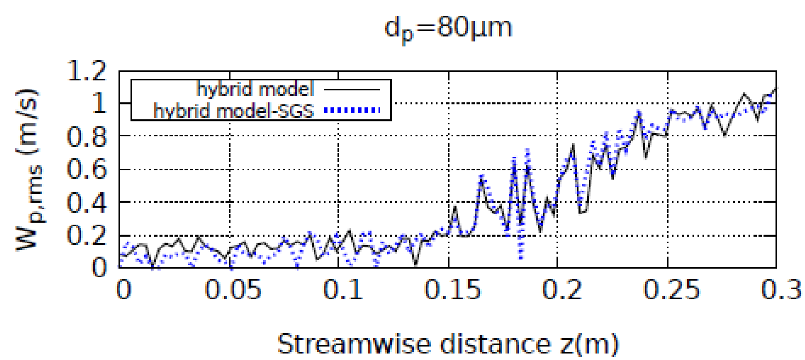
- The values of **the subgrid Stokes numbers** of two different classes of particles (one small and one large particle class diameter) are **above one** in the majority of the streamwise direction.
- It leads to the conclusion that almost all particle classes **can sense the majority of turbulence** in the streamwise direction.

Stochastic Subgrid-Scales effect (Bini and Jones (BJ)):









- Upon implementing **the stochastic subgrid model** of Bini and Jones (BJ), only minor differences are observed in **the RMS velocities** of the particles both in no-parcel and the hybrid model.

Conclusion:

- The **hybrid model** which was a combination of the NFM and the VFM was able to enhance the velocity profiles of the particles compared to the NFM and VFM for different range of particles.
- The effects of the Bini and Jones(BJ) stochastic subgrid model with **this particle size distribution and density** through this **mesh configuration** can be negligible on **the RMS velocities** of the dispersed phase in the streamwise direction.

Future work:

- Quantitative comparison of time-averaged distribution of **particle dispersion**, **particle volume fraction** and **computational cost** for different parcel models.
- Further in-depth analyses of the particle **subgrid Stokes number**, different **stochastic subgrid models**, and **mesh sensibility** will be required to draw more comprehensive conclusions for the stochastic subgrid effects on different particle characteristics.

Thanks For your attention!

Any question?

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