Numerical Assessment of Parcel Modeling in Large Eddy Simulation for Dispersed Multiphase Flows

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Abstract. Tracking millions of particles in an Eulerian-Lagrangian two-phase turbulent flow within Large Eddy simulations is computationally expensive. In order to achieve less computational cost besides sufficient accuracy using parcel modeling is recommended. Therefore for validation purposes, a benchmark case of a confined jet by Hishida [1] is selected. Then, the effect of different particle turbulent inlet boundary conditions on the dispersion and accuracy of the dispersed phase is carried out. Later on, the different parcel models are presented and the effect of turbulent subgrid-scale (SGS), accuracy and computational costs of each model are studied. The purpose behind presenting a new hybrid parcel model is to optimize the computational cost of the simulation versus the accuracy.

1 Introduction

Dispersed multiphase flow is playing an important role in a wide range of applications such as aircraft icing, fuel injection in the combustion chamber, dispersion of pollutants, evaporative cooling, cyclone separators, inertial particle separators, etc. One of the approaches to deal with the numerical simulation of dispersed multiphase flows is the Eulerian-Lagrangian approach where thousands or millions of particles are present in the domain. The Eulerian part is used for the fluid simulation and the Lagrangian method is for tracking the dispersed phase.

For industrial applications where a large domain is applied, tracking millions of particles needs huge computational resources. One approach for decreasing the computational cost besides having reasonable accuracy is using the parcel method. Parcel is a group of particles with similar characteristics such as diameter and velocity. The two common models used for parcel modeling are the Number Fixed Model (NFM) and the Volume Fixed Model (VFM) which is presented in the work of Watanabe et al. [2]. In order to enhance the computational cost versus accuracy in a wide range of particle diameter distribution, a combined model can be presented which is explained in detail in the work of Bahramian et al. [3]. The goal here is to dig into more detail about the parcel models and study their behaviors through different simulation conditions using the polydispersed two-phase flows.

2 Methodology

In this section, the essential equations that have been applied is summarized. The dispersed phase motion in a continuous phase using a Lagrangian method can be defined by Newton's law. Therefore the governing equations for determining the nth particle position and momentum are:

$$\frac{\mathrm{d}\mathbf{x_p^n}}{\mathrm{d}t} = \mathbf{v_p^n} \tag{1}$$

$$m_\mathrm{p}^n \frac{\mathrm{d}\mathbf{v_p^n}}{\mathrm{d}t} = \sum_i \mathbf{F_i} \tag{2}$$

where $\mathbf{x_p^n}$, $\mathbf{v_p^n}$, and m_p^n are the nth particle's center location, velocity, and mass. The sum of forces appearing on the right-hand side of Eq. (2) accounts for all the relevant forces acting over the particles, e.g., drag, gravity, added mass, pressure gradient force, etc. It is assuming that particles are large enough that any Brownian or non-continuum motion of the particles may be neglected.

The drag force is assumed the only significant fluid-particle interaction force in the particle-fluid two-way coupling. The equations of a viscous incompressible continuous fluid are governed by the Navier-Stokes (NS) equations. It can be approximated by:

$$\nabla \cdot \mathbf{u} = 0 \tag{3}$$

$$\rho_\mathrm{c}\left[\frac{\partial \mathbf{u}}{\partial t} + \nabla \cdot (\mathbf{uu})\right] = -\nabla p + \mu \nabla^2 \mathbf{u} + \mathbf{S_u} \quad , \quad \mathbf{S_u} = -\sum_{n=1}^{N_\mathrm{p}} \frac{m_\mathrm{p}^n \mathbf{f_{cp}^n}}{V_\mathrm{cell}} \tag{4}$$

where p, μ, and $\mathbf{S_u}$ are the pressure, the dynamic viscosity, and the momentum source term. $\mathbf{f_{cp}^n}$, V_cell, and N_p are the fluid-particle interaction force per unit mass of the particle, the volume of the computational cell, and the number of particles occupying in a computational cell.

3 Preliminary Results and Conclusions

The selected benchmark test case is the confined jet of Hishida [1]. All the numerical simulations have been carried out through an in-house parallel C++/MPI CFD code called TermoFluids [4] based on the finite volume method (FVM) and symmetry-preserving discretization of the momentum equation. In Fig. 1, the instantaneous velocity distributed in the desired domain is shown. Fig. 2 shows the streamwise velocity profile of two different particle diameters. The results obtained for the new proposed hybrid model compared with the NFM and the VFM for the previous benchmark case used in the work of Bahramian et al. [3]. The objective here was to see if the hybrid model can present better behavior than the VFM for the particles with diameters smaller than the Sauter mean diameter (SMD), along with showing fewer discrepancies than the NFM for the particles with diameters above the SMD. Here the particles are ordered with the mean diameter class of 20, 30, 40, 50, 60, 70, 80, 90, 100μm and the SMD is 60 μm.

As can be seen, the hybrid model is showing more convenient results compared to NFM and VFM parcel models. The goal of the present work is to enhance the presented parcel hybrid model using a simpler benchmark case and consider the effect of the SGS on the dispersion of the polydispersed phase. We expect that the effect of turbulent subgrid-scale varies with particle Stokes number.

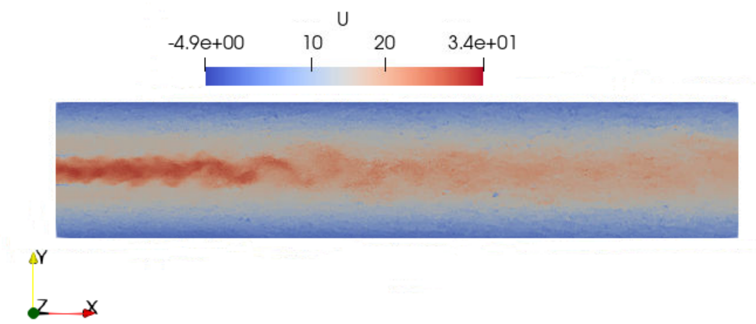

Figure 1: Longitudinal section of instantaneous velocity field in the direction of the flow.

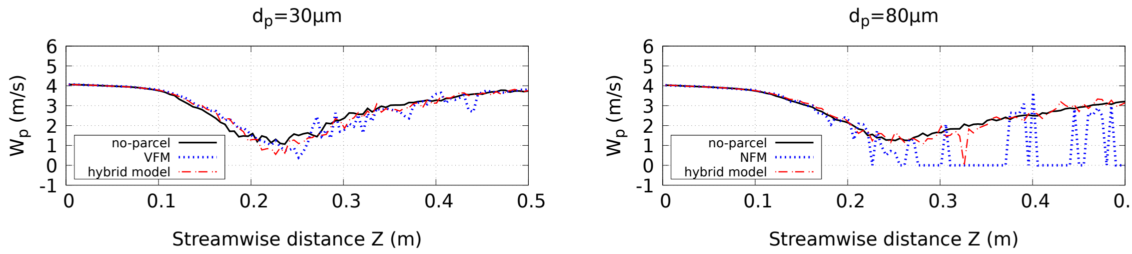

Figure 2: Streamwise profiles of particle ($dp = 30\mu m$ and $dp = 80\mu m$) for the particle-laden configuration comparing no-parcel, NFM, VFM and hybrid model [3].

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