A two-way coupled fully Lagrangian model for gas-droplet flows

T.S. Zaripov, O.D. Rybdylova

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Overview

1. What is the problem with simulating clouds of inertial droplets?
2. How can fully Lagrangian approach help us?
3. Making FLA applicable in industrial applications: a two-way coupled fully Lagrangian model for gas-droplet flows

Part 1

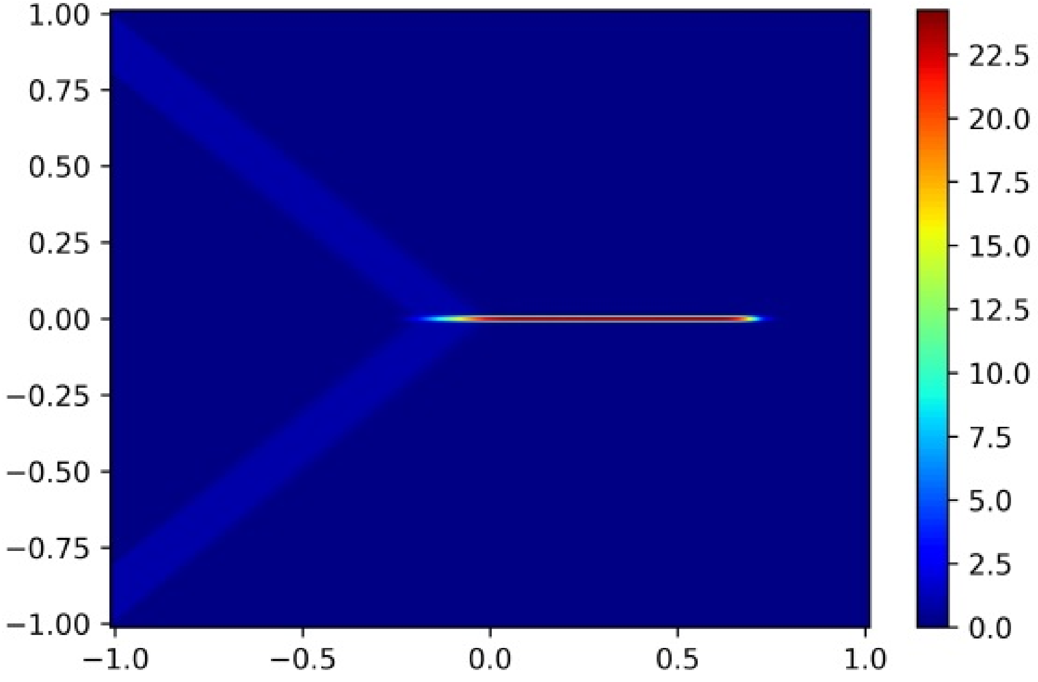
What is the problem with simulating clouds of inertial droplets?

Inertial particles in two-phase flows

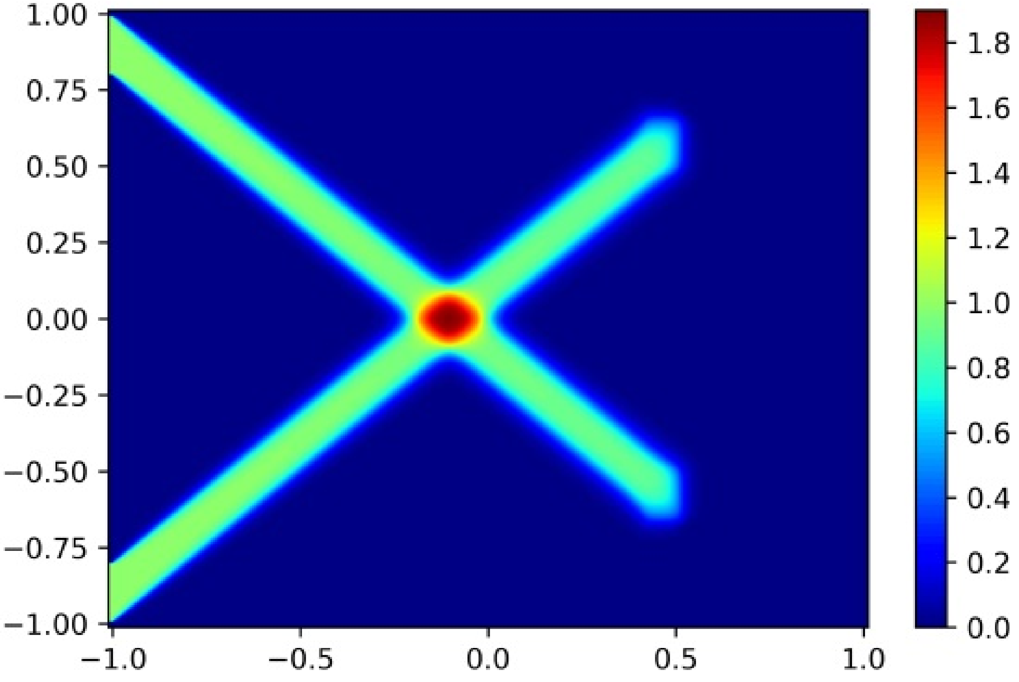
- Want to know particle concentration to estimate momentum, heat and mass transfer between phases.
- Flow and particle velocities are not equal.
- How to model particles in trajectories-crossing region?

Two clouds passing through each other: Eulerian-Eulerian approach

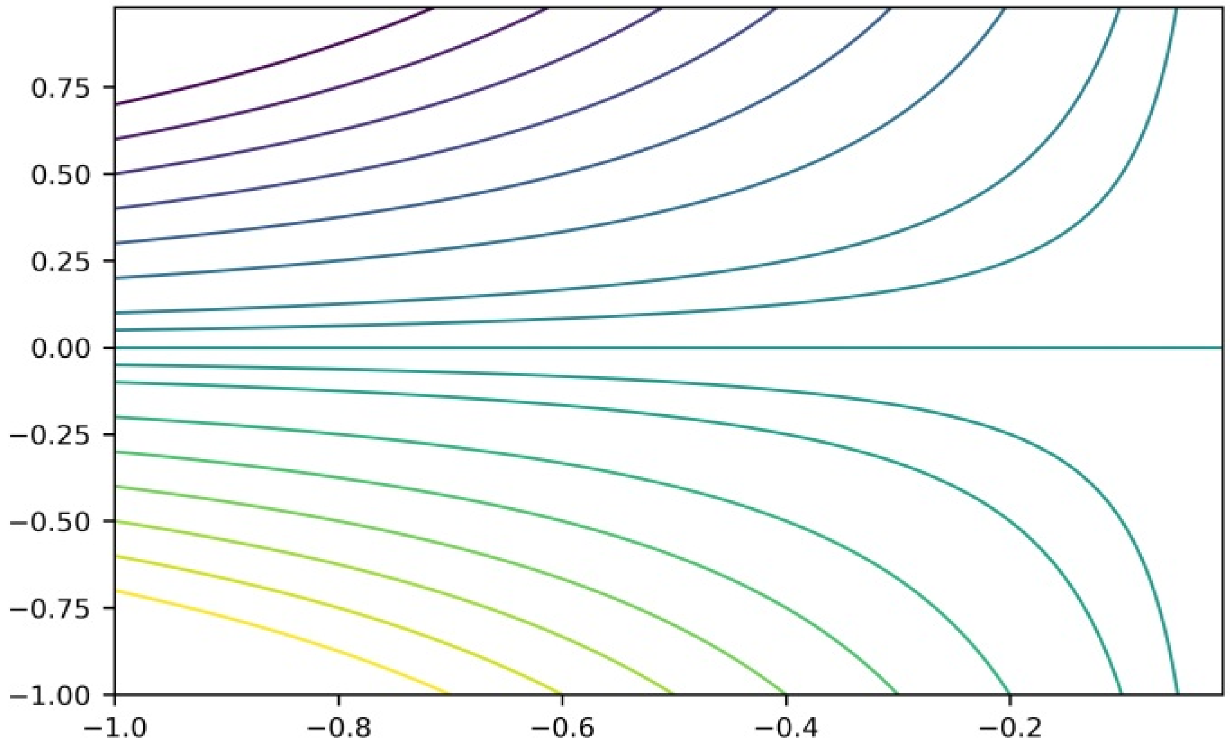
Single velocity at point



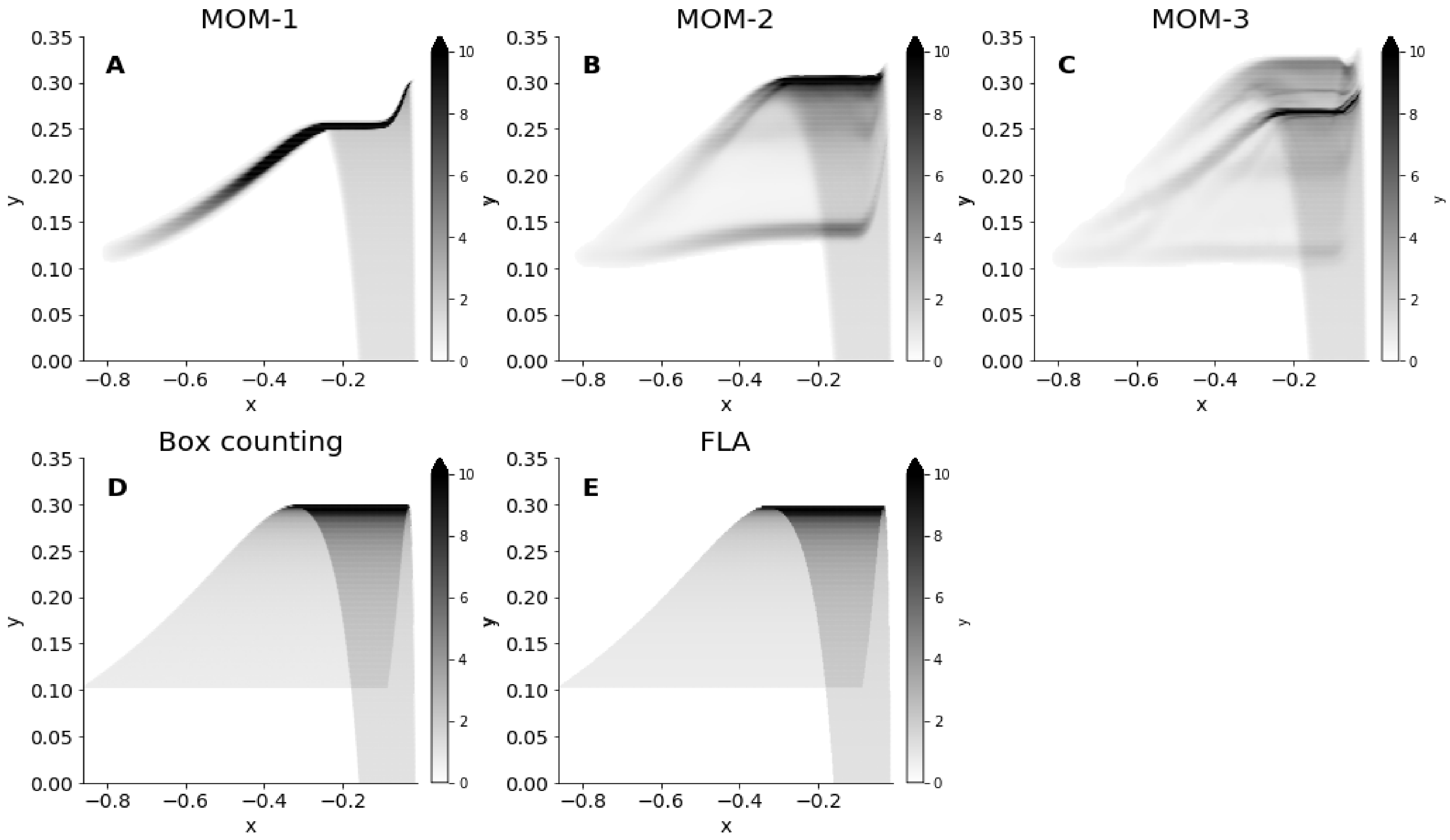
Two-velocities at point



Hyperbolic flow



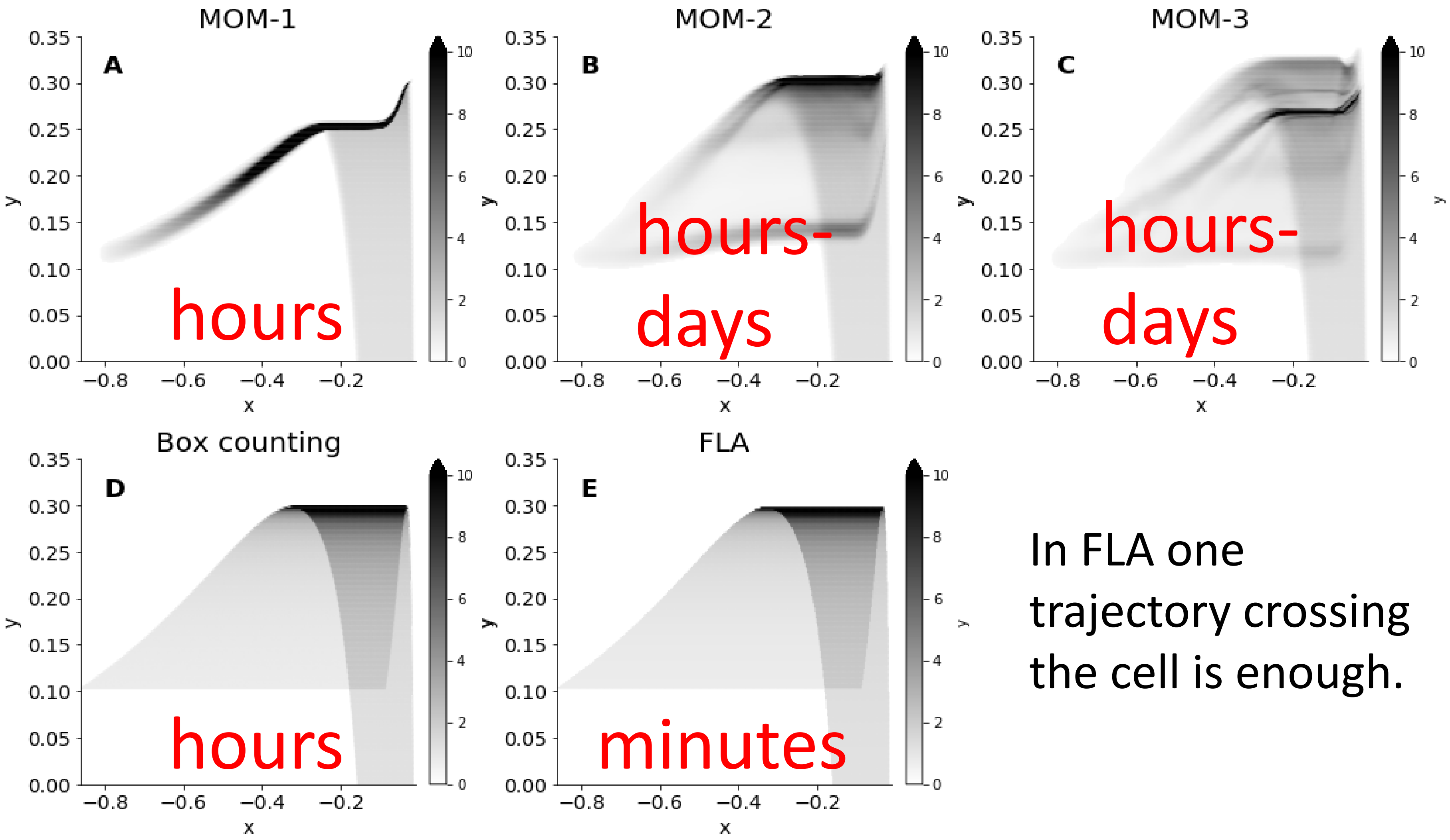
The distributions of number densities of particles with Stk = 1 in the hyperbolic flow



Part 2

How can fully Lagrangian approach help us?

Time to produce result

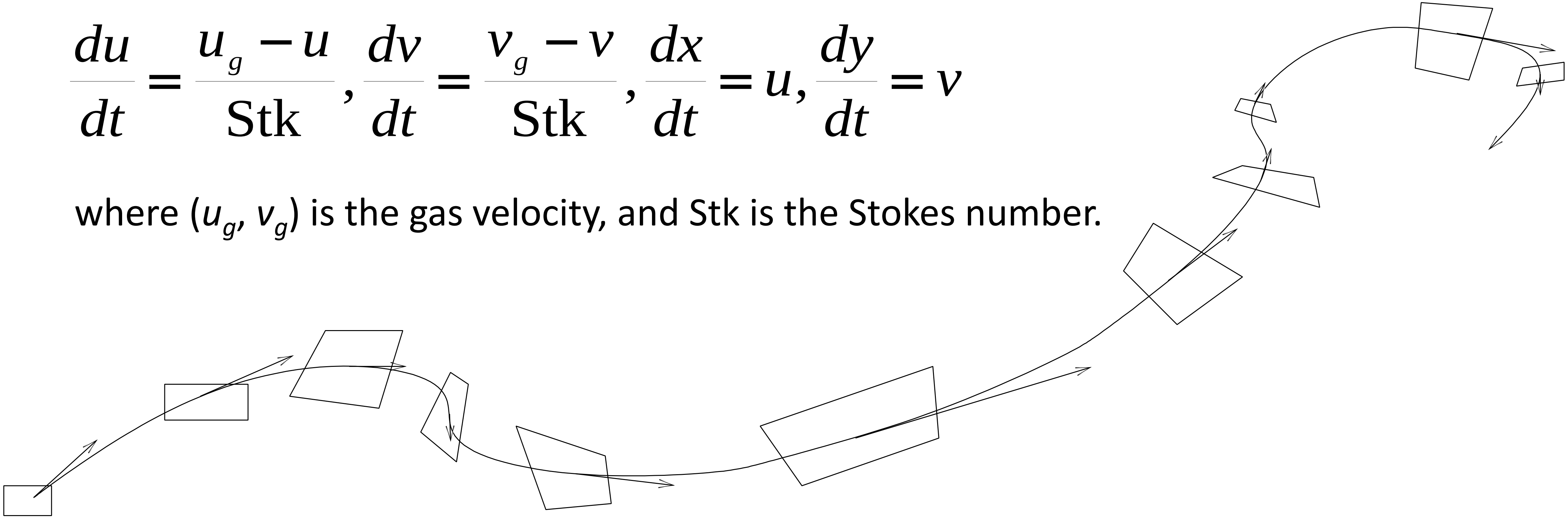


In FLA one trajectory crossing the cell is enough.

Fully Lagrangian approach (FLA)

$$\frac{du}{dt}=\frac{u_g-u}{\mathrm{Stk}},\frac{dv}{dt}=\frac{v_g-v}{\mathrm{Stk}},\frac{dx}{dt}=u,\frac{dy}{dt}=v$$

where (u_g, v_g) is the gas velocity, and Stk is the Stokes number.



$$n_d|J|=n_{d0}$$

Fully Lagrangian approach (FLA)

$$J_{11} = \frac{\partial x}{\partial x_0}, J_{12} = \frac{\partial x}{\partial y_0}, J_{21} = \frac{\partial y}{\partial x_0}, J_{22} = \frac{\partial y}{\partial y_0}$$

$$\frac{dJ_{11}}{dt} = w_{11}, \quad \frac{dJ_{12}}{dt} = w_{12}, \quad \frac{dJ_{21}}{dt} = w_{21}, \quad \frac{dJ_{22}}{dt} = w_{22}$$

$$\frac{dw_{11}}{dt} = \frac{1}{\mathrm{Stk}}\left(J_{11}\frac{\partial u_g}{\partial x} + J_{21}\frac{\partial u_g}{\partial y} - w_{11}\right), \quad \frac{dw_{12}}{dt} = \frac{1}{\mathrm{Stk}}\left(J_{12}\frac{\partial u_g}{\partial x} + J_{22}\frac{\partial u_g}{\partial y} - w_{12}\right),$$

$$\frac{dw_{21}}{dt} = \frac{1}{\mathrm{Stk}}\left(J_{11}\frac{\partial v_g}{\partial x} + J_{21}\frac{\partial v_g}{\partial y} - w_{21}\right), \quad \frac{dw_{22}}{dt} = \frac{1}{\mathrm{Stk}}\left(J_{12}\frac{\partial v_g}{\partial x} + J_{22}\frac{\partial v_g}{\partial y} - w_{22}\right).$$

Part 3
Making FLA applicable in industrial applications.

Challenges

- Implementation beyond in-house codes and analytical flows
- Interpretation
  - “Infinite” number density at trajectory crossing points
  - Integration of particle properties over cell
- Accuracy (numerical calculation of velocity gradient may lead to accumulation of error)

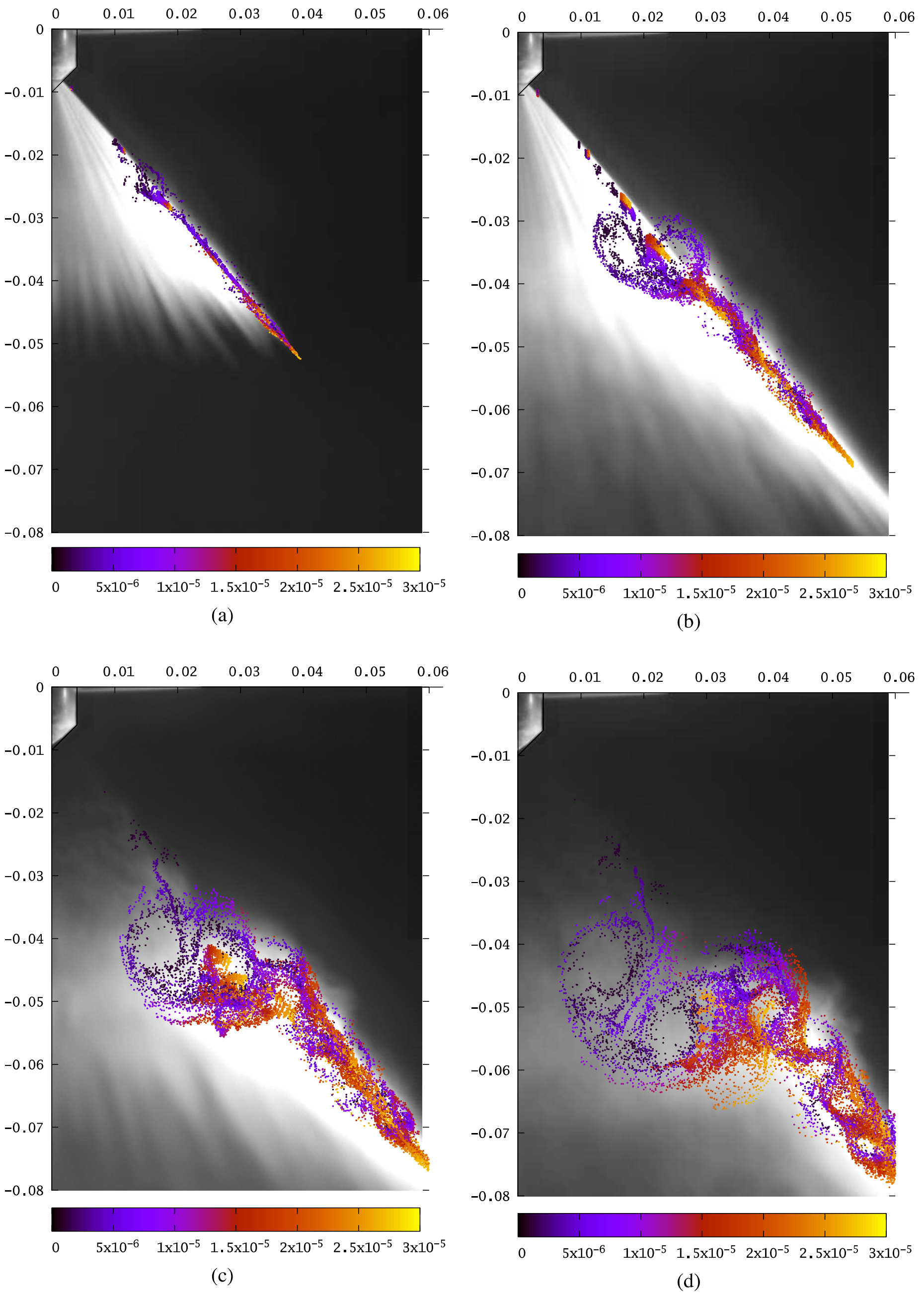


FIG. 10: The time evolution of droplets with diameters between 10^{-6} m and 30×10^{-6} m shown by color/shade of gray, as predicted by the ANSYS Fluent, overlayed on the images of an experimentally observed spray

Evolution of direct-injection-type gasoline spray (Zaripov et al, 2017)

The customized version of ANSYS Fluent, with the fully Lagrangian approach (FLA) implemented into it, has been used to calculate the number densities of droplets in a direct-injection-type gasoline spray. Results, reproduced from Zaripov et al (2017), show good qualitative agreement between the numerical simulation and experimental observations.

Figure: The time evolution of polydisperse droplet cloud shown by colour/shade of gray, as predicted by the ANSYS Fluent, overlayed on the images of an experimentally observed spray

Impact of droplet number density on interphase heat and mass exchange (Zaripov et al, 2018)

A model for heating and evaporation of a cloud of mono-component droplets in air, taking into account the evolution of droplet number densities, is developed and implemented into ANSYS Fluent. Functionality testing of the new customised version of ANSYS Fluent is based on its application to the analysis of a droplet cloud in a two-phase back-step flow. It is shown that the effect of the droplet cloud needs to be taken into account when estimating the heat and mass transfer rates from the carrier phase to the droplets.

Figure: Time evolution of mass transfer rate from evaporating droplets (in kg/s). Solid curves show the values predicted for individual droplets. Dash-dotted curves show the same values scaled by the number densities, predicted by the FLA.

Next step

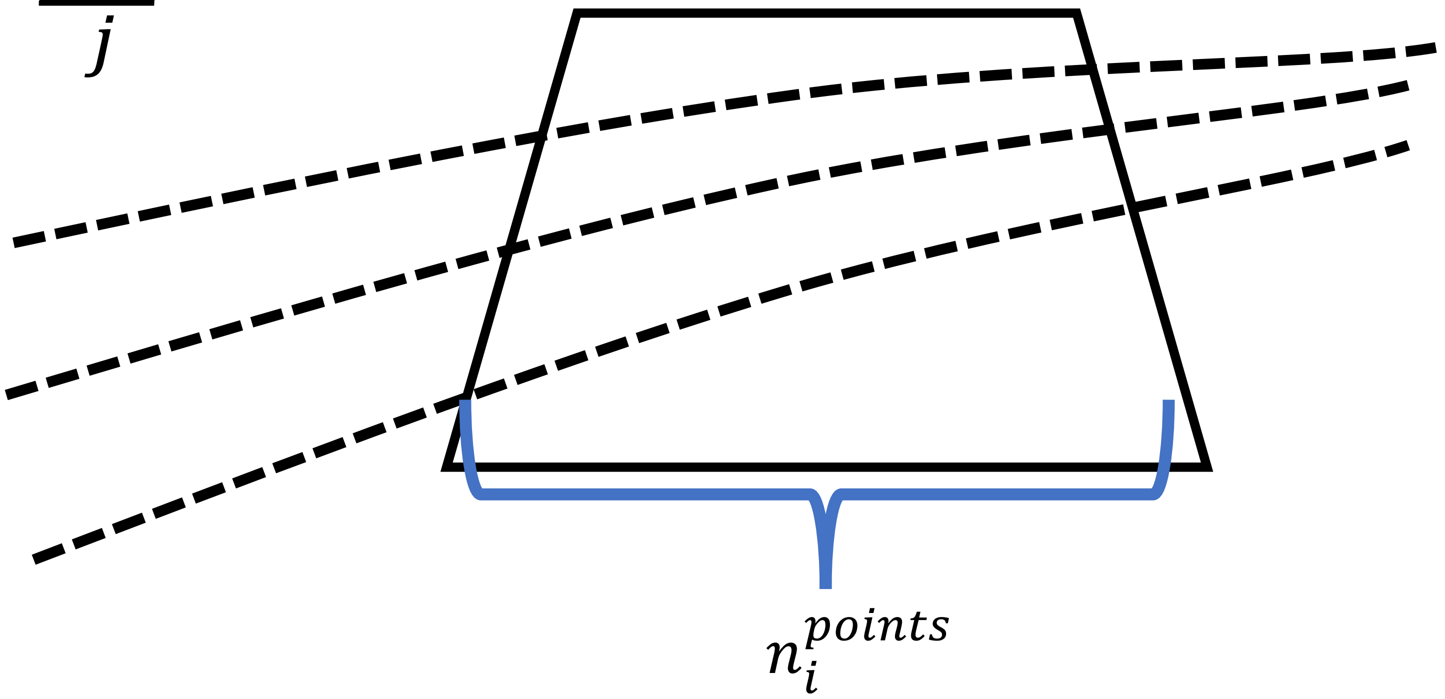
A two-way coupled fully Lagrangian model for gas-droplet flows

- Steady-state
- Two-way momentum exchange
- OpenFOAM (fully integrated)

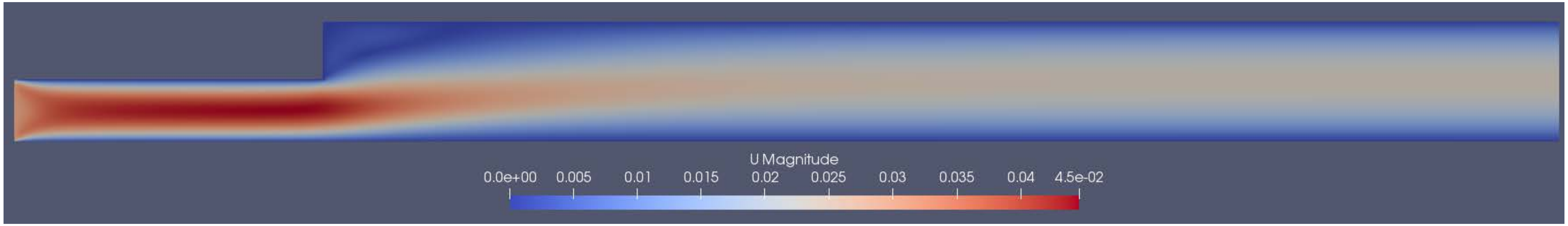
Two-way coupled FLA

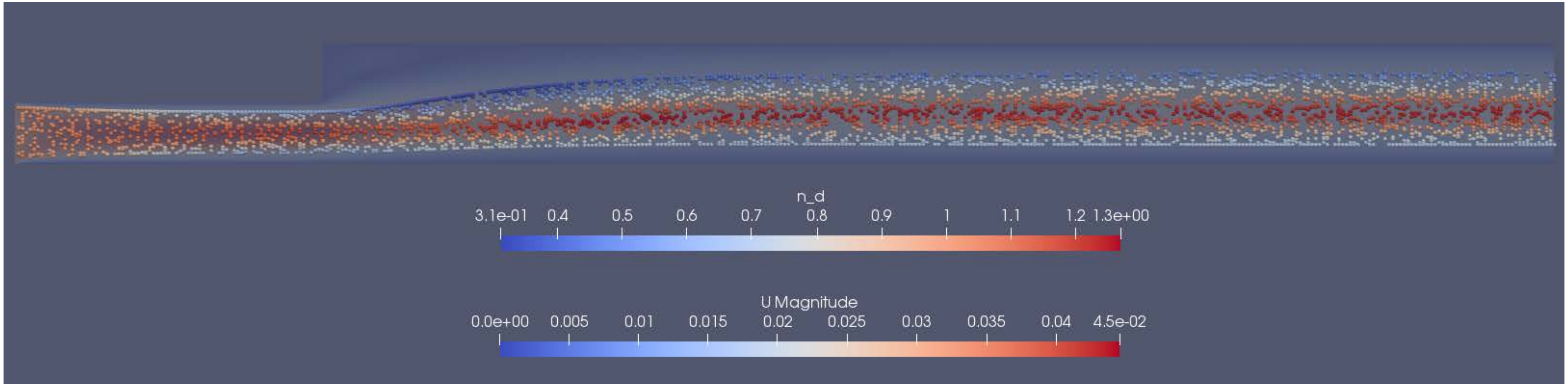
$$S_u^{\ cell} = \frac{1}{n^{traj}} \sum_{i}^{n^{traj}} \sum_{j}^{n_i^{points}} S_{u,ij} \;\; n_{d,ij}$$

Instead of using parcel mass, we relate number density in cell to trajectories' start.

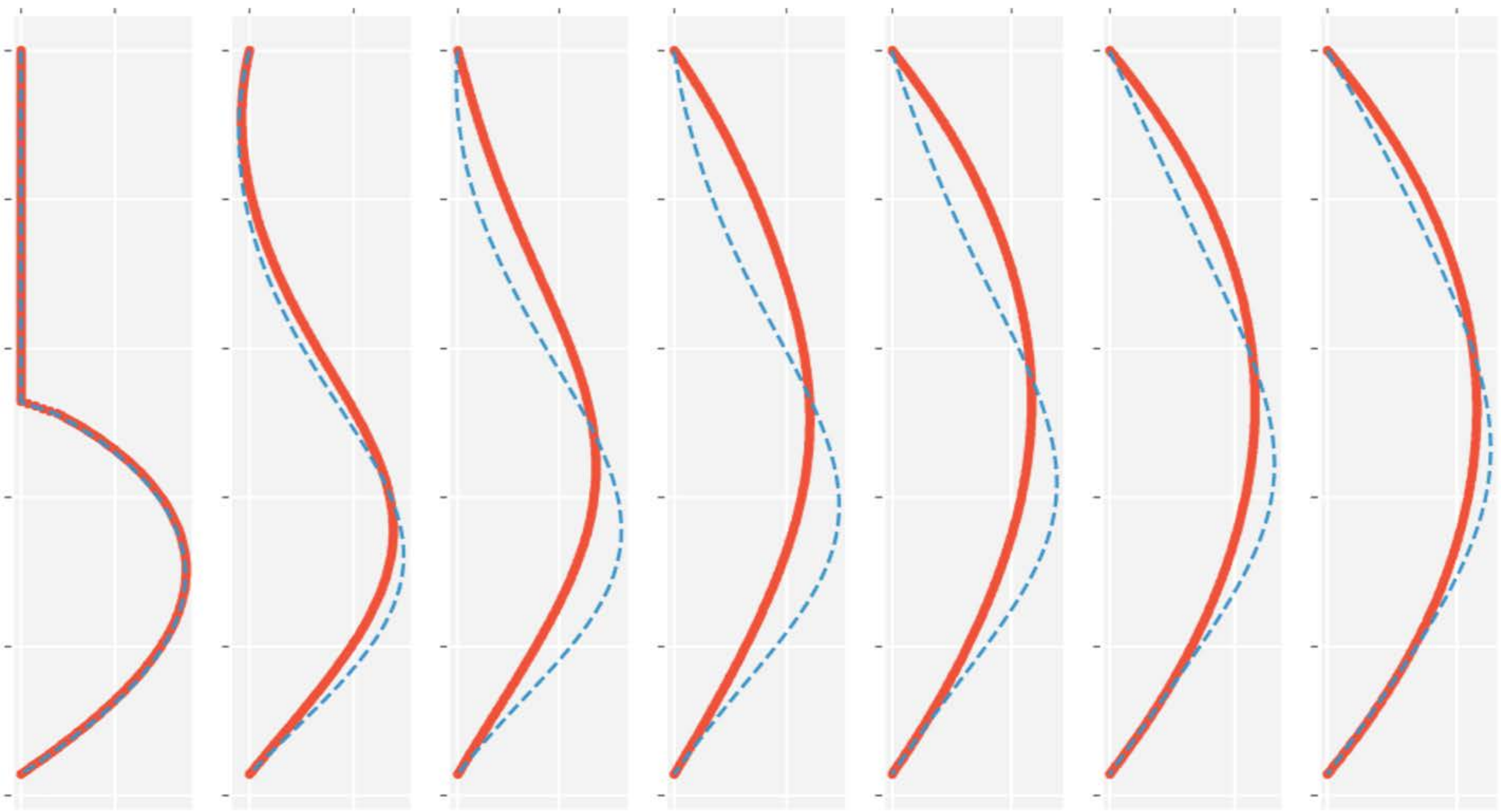


Back-step flow, Re=50, Stk=0.5





Profiles of U_x (coupled/uncoupled)



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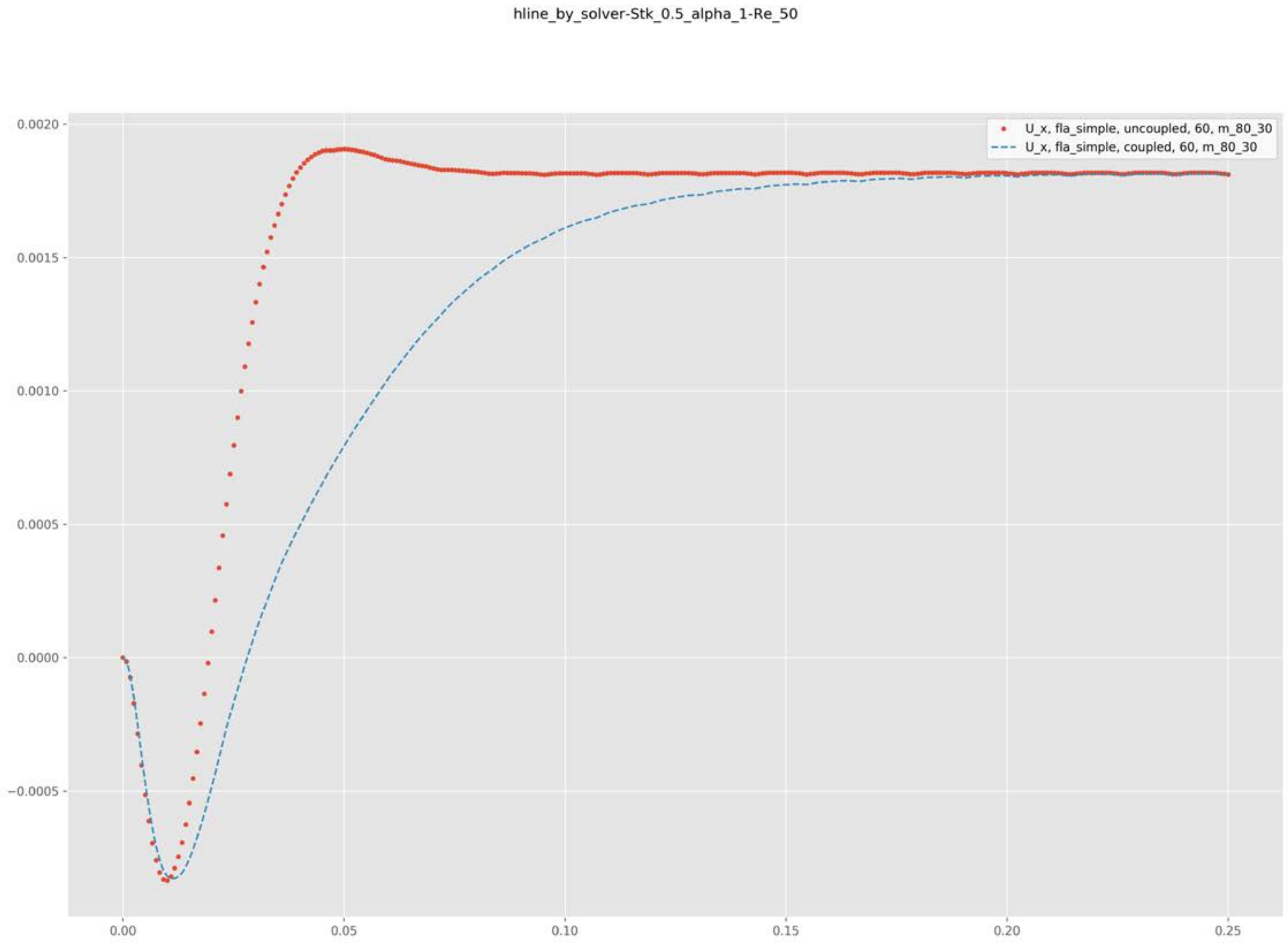

Acknowledgments

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Thank you!