University of Brighton

CAE Workshop
14 July, 2015

Application of the Fully Lagrangian Approach to simulate a two-phase flow with vortex ring

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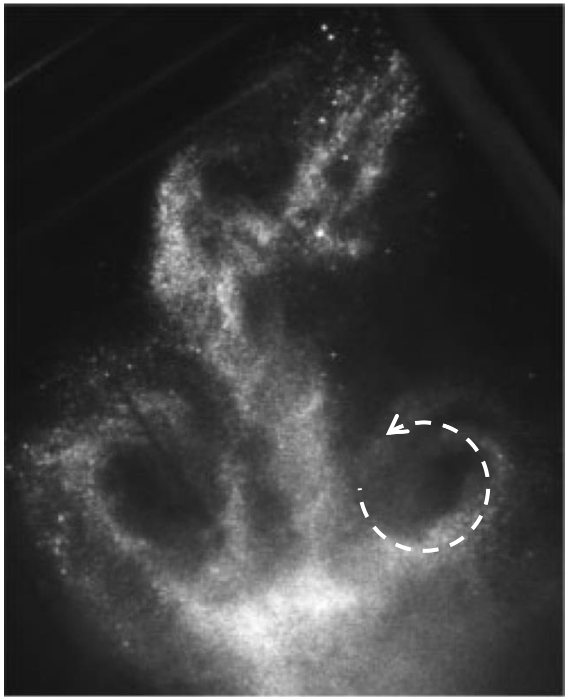
Outline

- Motivation
- FLA. Mathematical formulation
- Preliminary results
- Further work

Previous studies

Fukumoto, Y. & Kaplanski, F. 2008,
Begg, S., Kaplanski, F., Sazhin, S., Hindle, M. & Heikal, M. 2009
Kaplanski, F., Sazhin, S. S., Fukumoto, Y., Begg, S. & Heikal, M. 2009
Kaplanski, F., Sazhin, S. S., Begg, S., Fukumoto, Y. & Heikal, M. 2010
Kaplanski F., Fukumoto, Y. & Rudi, U. 2012
Danaila, I., Kaplanski, F. & Sazhin, S. 2015

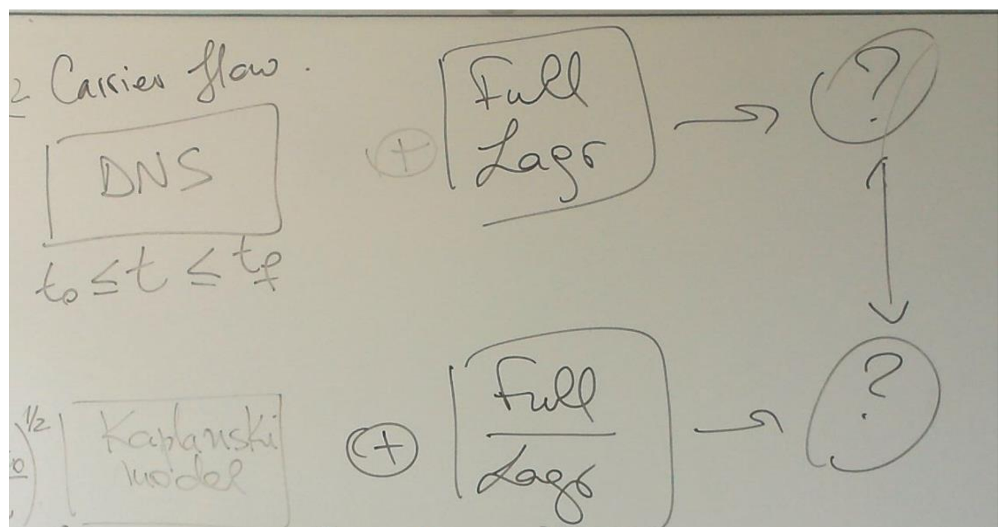
Motivation



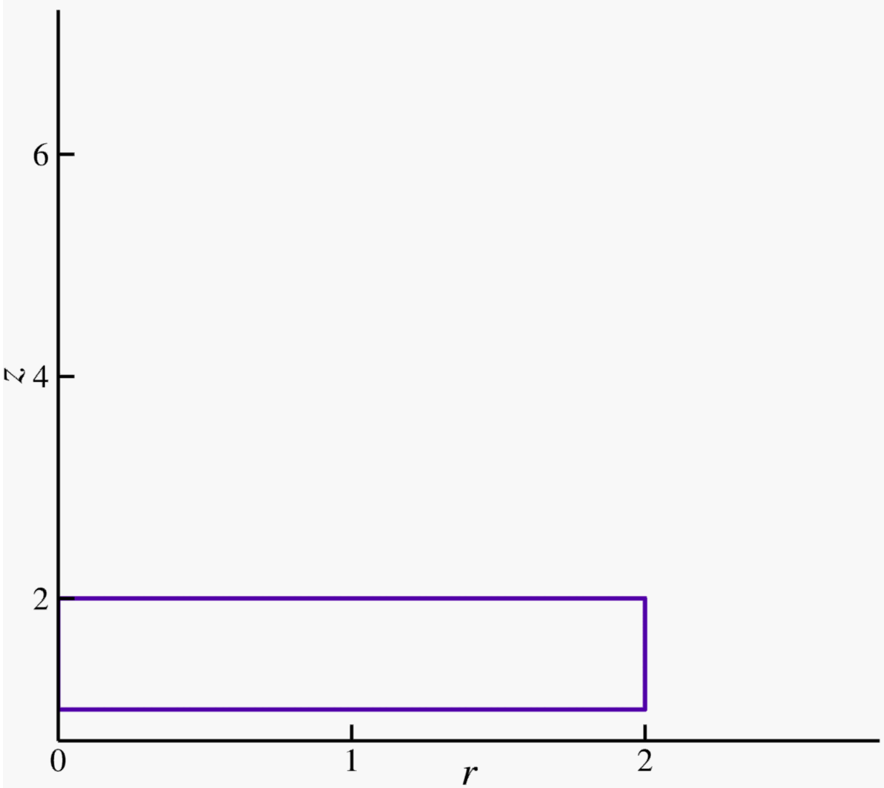
A typical high-speed photograph of a G-DI spray (Begg et al 2009)

<u>EPSRC project</u> “Investigation of vortex ring-like structures in internal combustion engines, taking into account thermal and confinement effects”

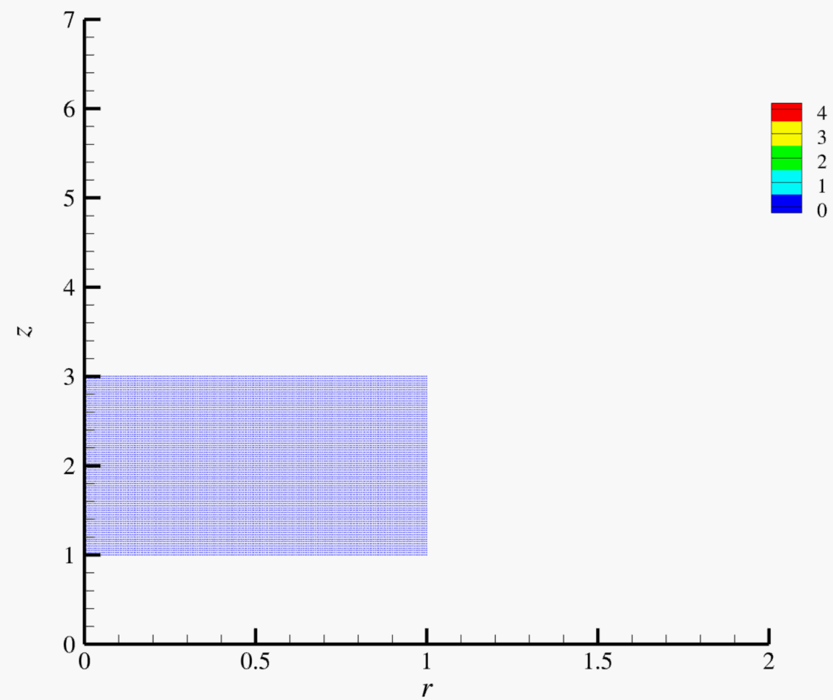
Extract from ‘Aims and objectives’:
“5. To investigate the applicability of the full Lagrangian approach to modelling sprays in the presence of swirl, thermal gradients, and the heating and evaporation of droplets.”



Why FLA?



Lagrangian frame deformation



Number of folds

Mathematical formulation

One-way coupling

Carrier phase: viscous incompressible liquid
(DNS and Kaplanski-Rudi solution)

Dispersed phase: identical spherical particles/droplets, pressureless continuum

Force acting on a particle: aerodynamic drag force

Mathematical formulation

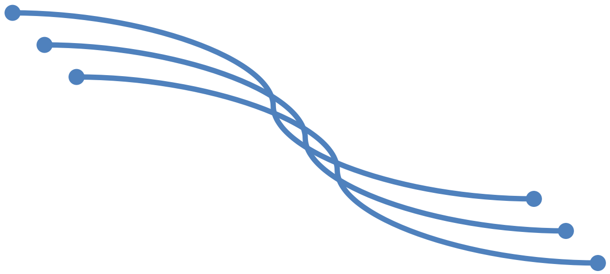
Fully Lagrangian approach:

Lagrangian variables:

Coordinates of trajectory origin

+

Time/parameter along a particle trajectory



$$n_s |J| = n_{s0} |J_0|$$

Mass conservation

$$\frac{d\mathbf{r}}{dt} = \mathbf{v}_s$$

$$m \frac{d\mathbf{v}_s}{dt} = \mathbf{f}_s$$

Momentum balance

+ aux. equations for the Jacobian

$$J_{ij} = \frac{\partial x_i}{\partial x_{0j}}$$

Carrier phase: vortex ring

Incompressible viscous liquid

Cylindrical coordinates

- Kaplanski analytical solution

$$\Psi = -\frac{r\sqrt{\mathrm{Re}}}{4\sqrt{2t}} \int_0^\infty F\left(x, \sqrt{\mathrm{Re}}\frac{z - z_{vc}}{\sqrt{2t}}\right) \mathrm{J}_1\left(\sqrt{\mathrm{Re}}\frac{x}{\sqrt{2t}}\right) \mathrm{J}_1\left(\sqrt{\mathrm{Re}}\frac{rx}{\sqrt{2t}}\right) dx.$$

- DNS (Second order finite difference)

Dispersed phase equations:

$$\beta = \frac{6\pi\sigma\mu R_0^2}{m\Gamma_0}$$

$$n_d r \left| J \right| = n_{d0} r_0$$

$$\frac{d\mathbf{r}_d}{dt} = \mathbf{v}_d$$

$$\frac{d\mathbf{v}_d}{dt} = \beta\left(\mathbf{v} - \mathbf{v}_d\right)$$

$$\frac{\partial J_{ij}}{\partial t} = q_{ij}$$

$$\frac{\partial q_{ij}}{\partial t} = \beta\left(\frac{\partial v_i}{\partial x_1} J_{1j} + \frac{\partial v_i}{\partial x_2} J_{2j} - q_{ij}\right)$$

$$J_{ij} = \frac{\partial x_{id}}{\partial x_{j0}} \qquad q_{ij} = \frac{\partial v_{id}}{\partial x_{j0}}$$

$1 - r$

$2 - z$

Initial conditions:

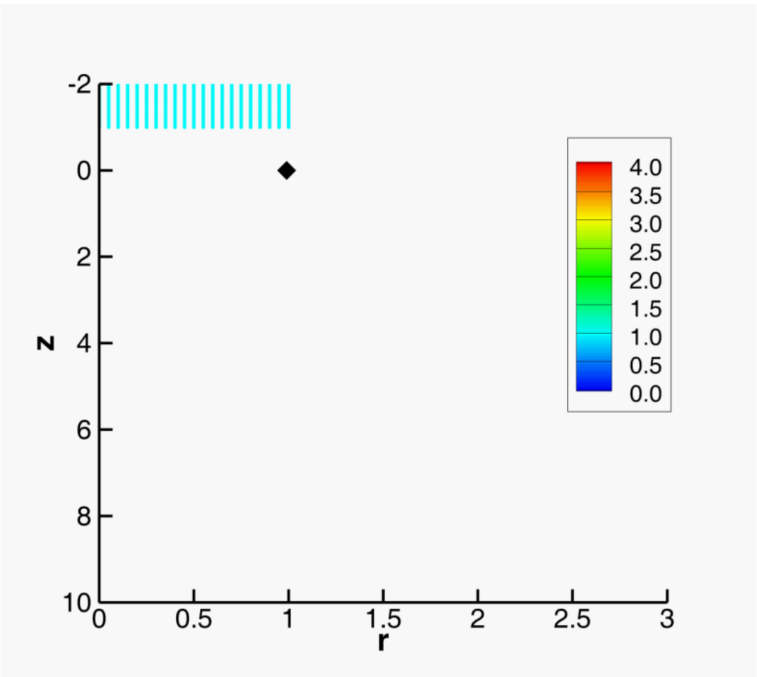
$$r_d = r_{d0},\ z_d = z_{d0},\ u_d = u_{d0},\ v_d = v_{d0},\ n_d = n_{d0}$$

$$q_{ij} = 0, \quad J_{ij} = \delta_{ij}$$

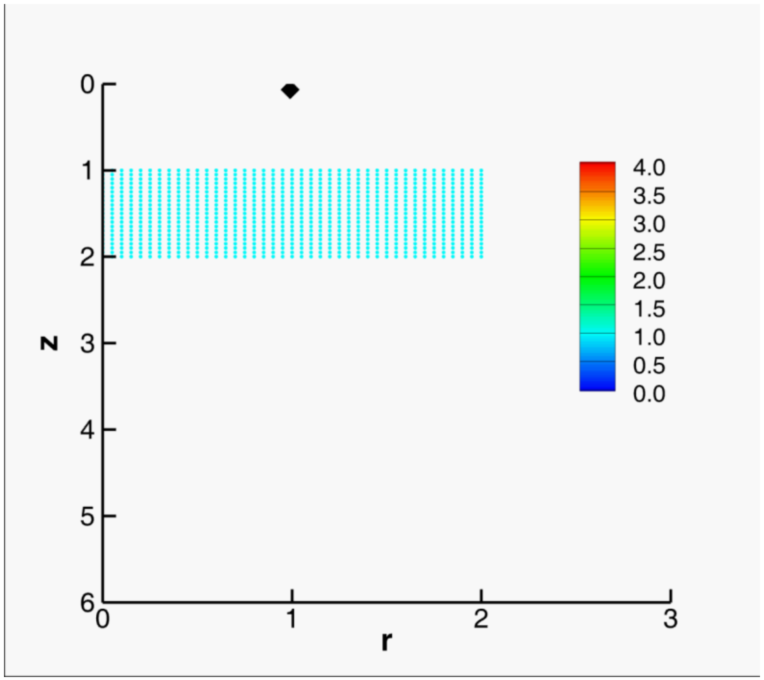
Two-phase flow, number density

Simulations based on Kaplanski solution,

Re = 100



Two-phase jet

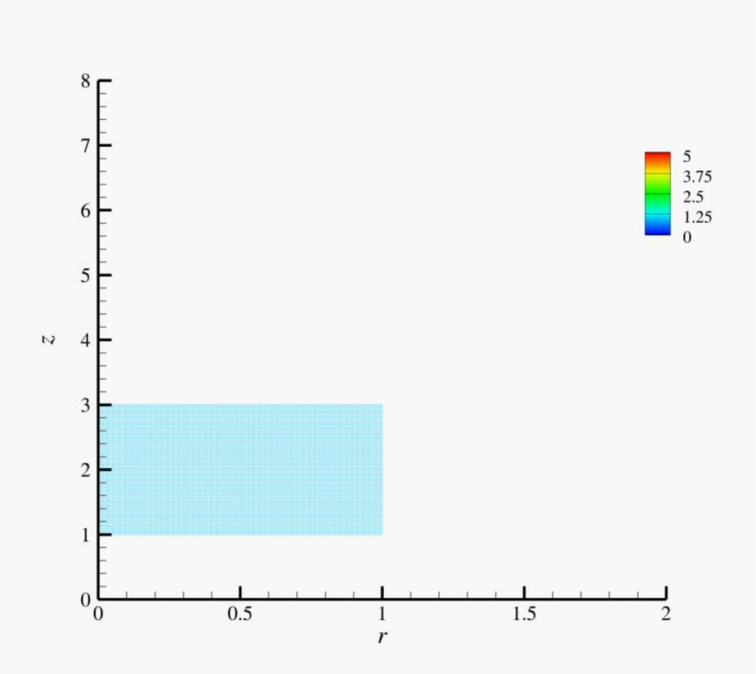


Cloud of particles ahead of the vortex ring

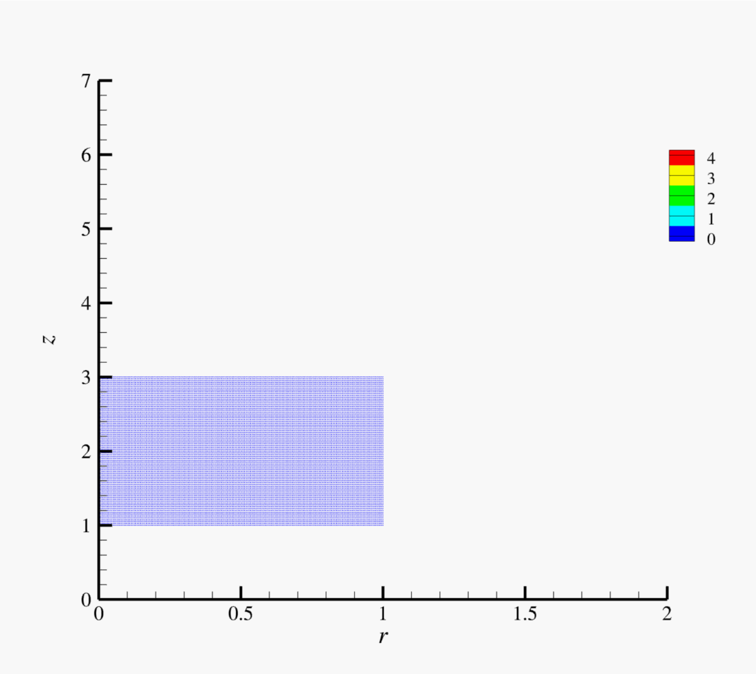
Two-phase flow

Simulations based on DNS

Re = 20 000



Particle number density



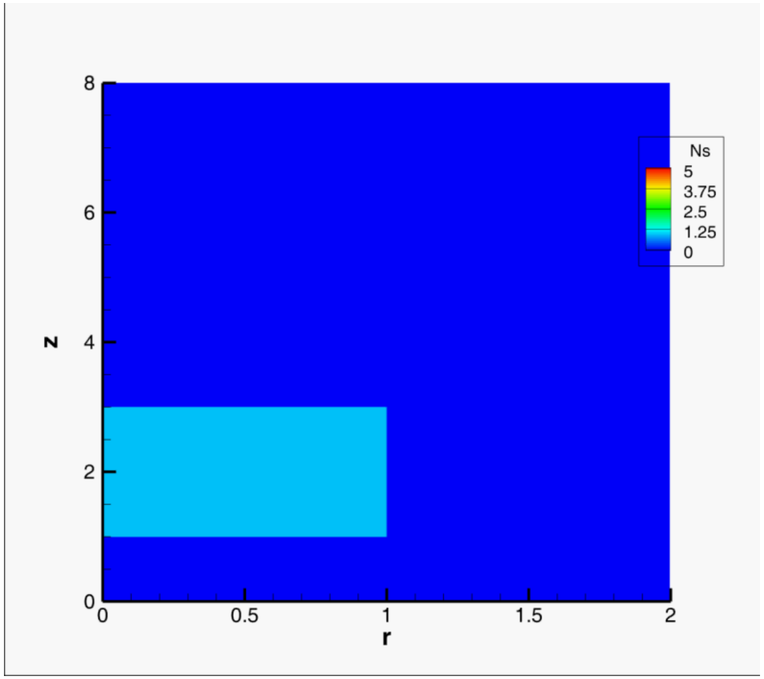
Number of folds

Cloud of particles ahead of the vortex ring

Two-phase flow

Simulations based on DNS,

Re = 20 000



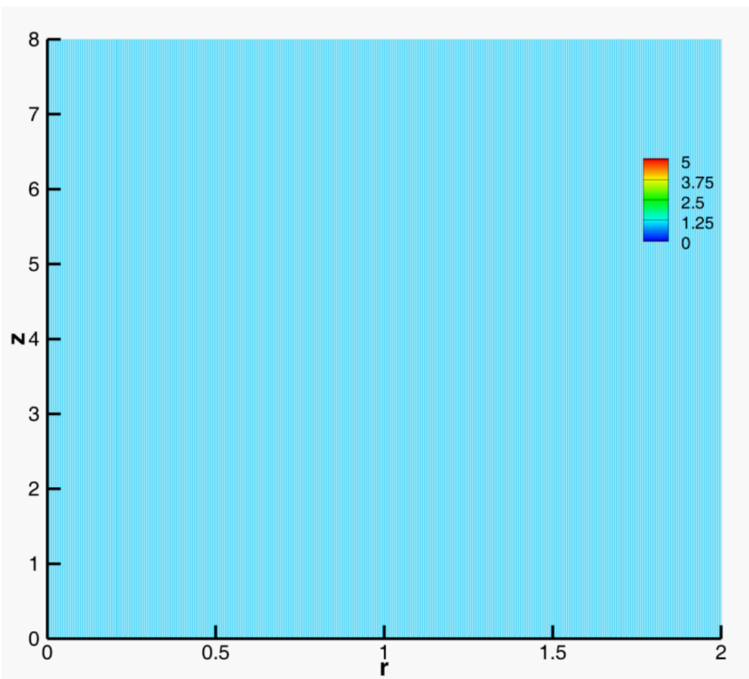
Single-valued particle number density

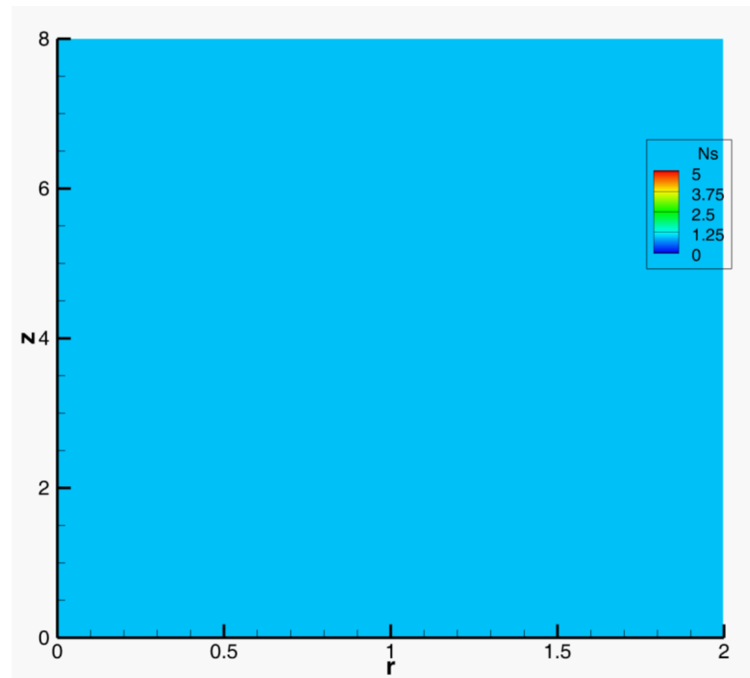
Cloud of particles ahead of the vortex ring

Two-phase flow

Simulations based on DNS

Re = 20 000



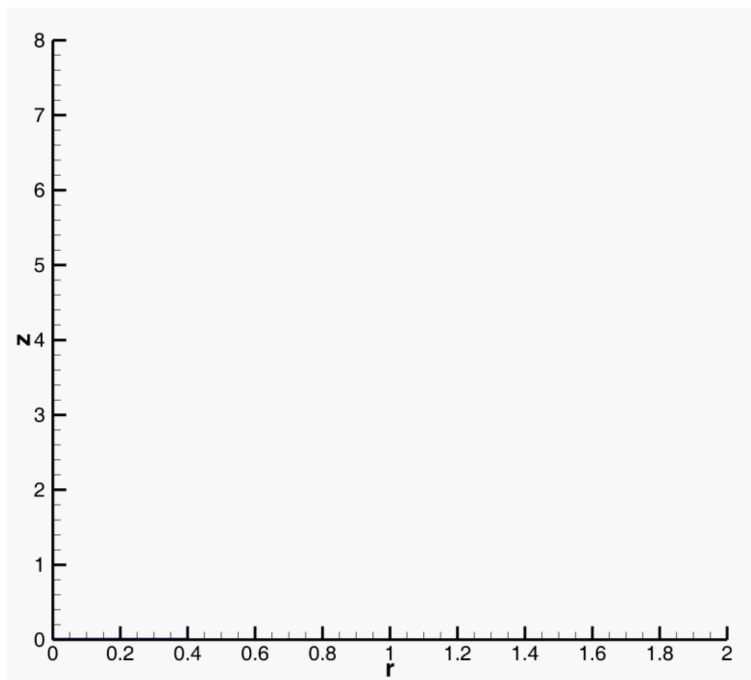


Propagation of vortex ring in a cloud of particles

Two-phase jet

Simulations based on DNS

Re = 20 000



Further work

- Two-phase jet, injection: initial conditions
- Two-phase jet, injection: more time steps
- Comparison between DNS+FLA and Kaplanski+FLA
- Transform Lagrangian to Eulerian concentration fields

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