Stochastic modeling of primary atomization : application to Diesel spray.

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Introduction.

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Atomization: main phenomena:

Turbulence in liquid and gaz phase, cavitation, cycle by cycle variations

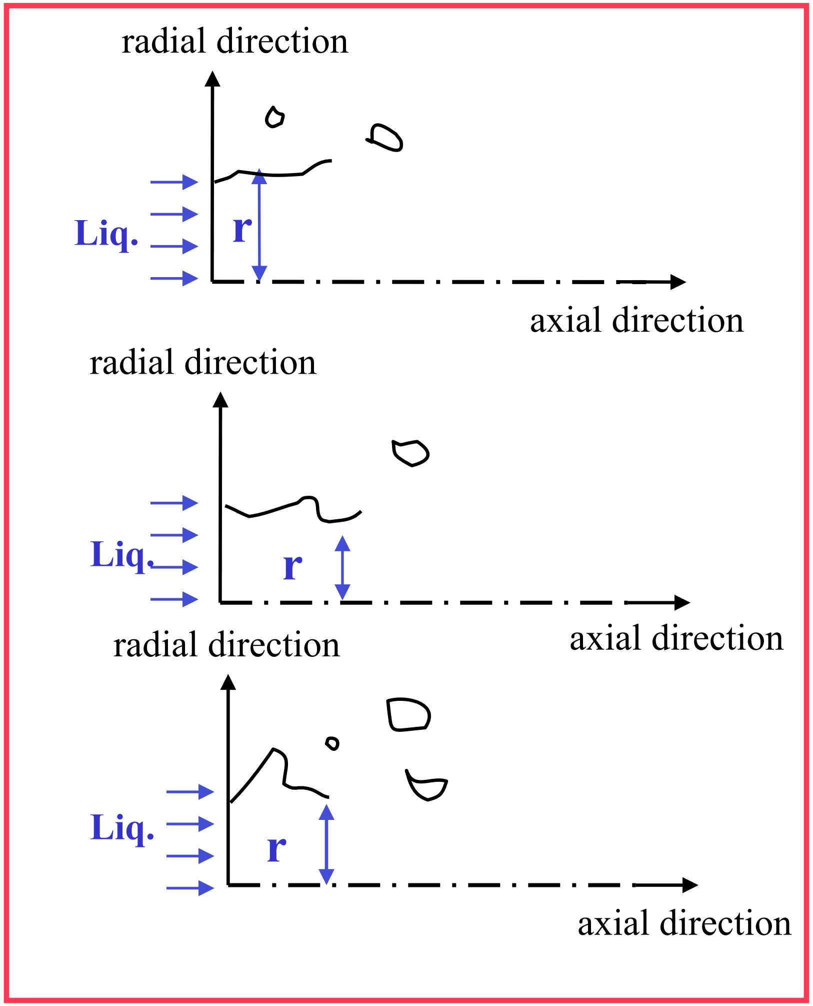
⇒ Deterministic description of such atomization is very diffcult task.

⇒ Stochastic approach

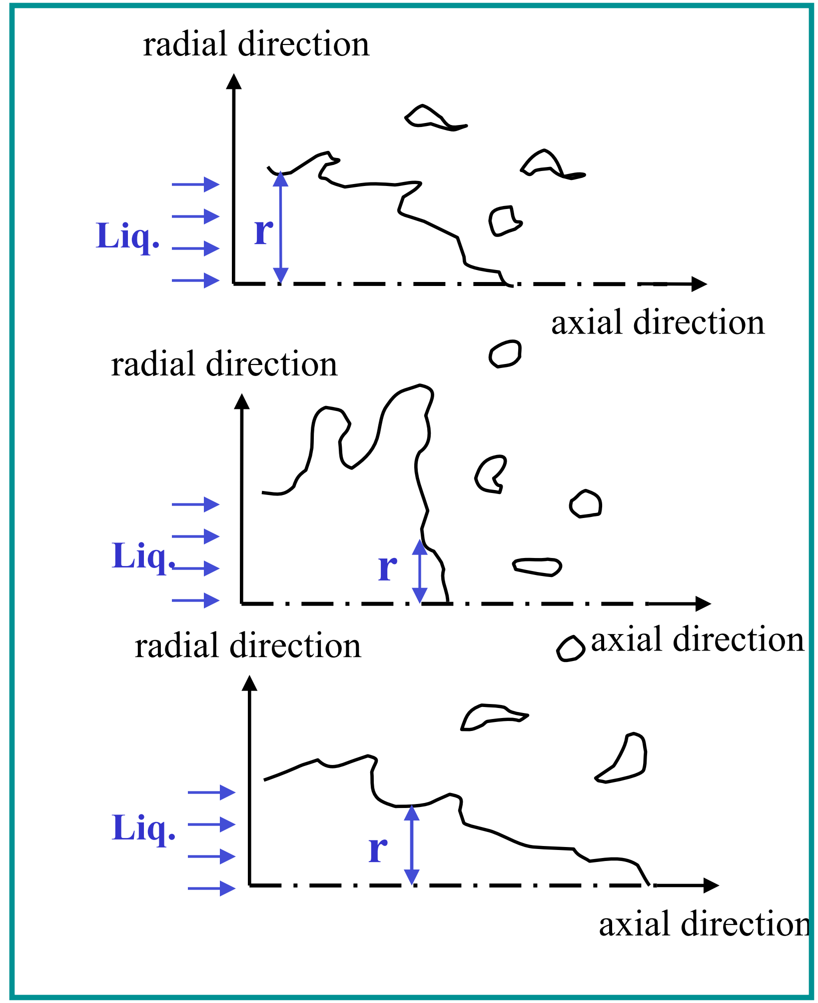
=> Application to primary atomization.

Floating cutter particles.

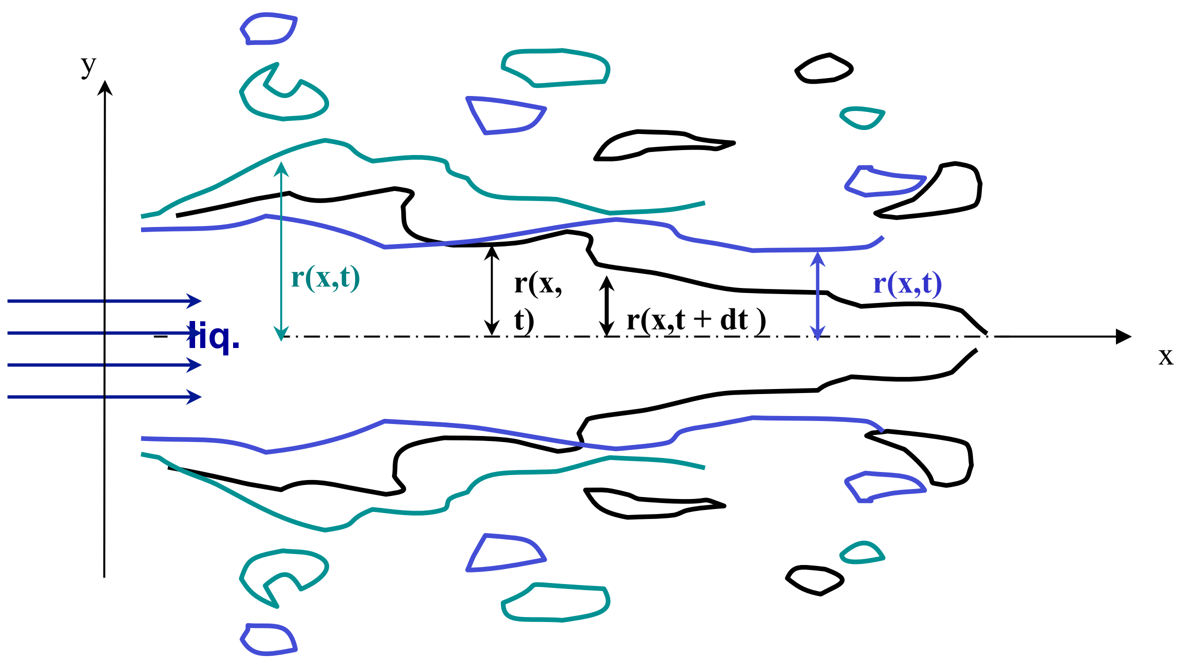
Time t1



Time t2



The main asumption: scaling symetry for thickness.



1. Scaling symetry for thickness of liquid core.

$$r(x,t+dt) = \alpha\, r(x,t)$$

$$0 \prec \alpha \prec 1$$

$$\downarrow$$

$$q(\alpha)$$

Fragmentation intensity spectrum

2. Life time.

3. Ensemble of n particles.

Theory of Fragmentation under Scaling symetry (Gorokhovski & Saveliev 2003, Phys. Fluids).

Evolution equation

$$\frac{\partial f(r,t)}{\partial t} = \nu \int_0^1 f\left(\frac{r}{\alpha}, t\right) q(\alpha) \frac{d\alpha}{\alpha} - \nu f(r,t) \longrightarrow \text{Knowledge of } q(\alpha)$$

Fokker Planck type equation

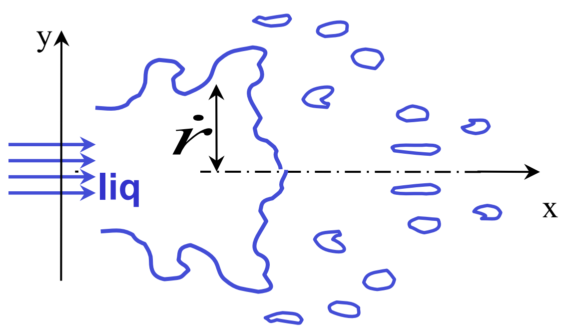
$$\frac{1}{\nu}\frac{\partial f(r,t)}{\partial t} = -\langle \ln \alpha \rangle \frac{\partial}{\partial r}\left(r f(r,t)\right) + \frac{\langle \ln^2 \alpha \rangle}{2} \frac{\partial}{\partial r} r \frac{\partial}{\partial r}\left(r f(r,t)\right) \longrightarrow \text{Knowledge of } \langle \ln\alpha \rangle \text{ and } \langle \ln^2\alpha \rangle$$

→ Equation for the distribution function

→ Log brownian stochastic process

Langevin type equation → Equation for one realisation

$$\dot{r} = \nu \langle \ln \alpha \rangle r + \sqrt{\nu \langle \ln^2 \alpha \rangle / 2}\; r \Gamma(t)$$



$$\frac{\langle \ln^2\alpha \rangle}{\langle \ln\alpha \rangle} = \ln\left(\frac{r_c}{r_*}\right)$$

$$\langle \ln\alpha \rangle = CONST \cdot \ln\left(\frac{r_c}{r_*}\right)$$

$r_c =$ critical length scale

$r_* =$ typical length scale

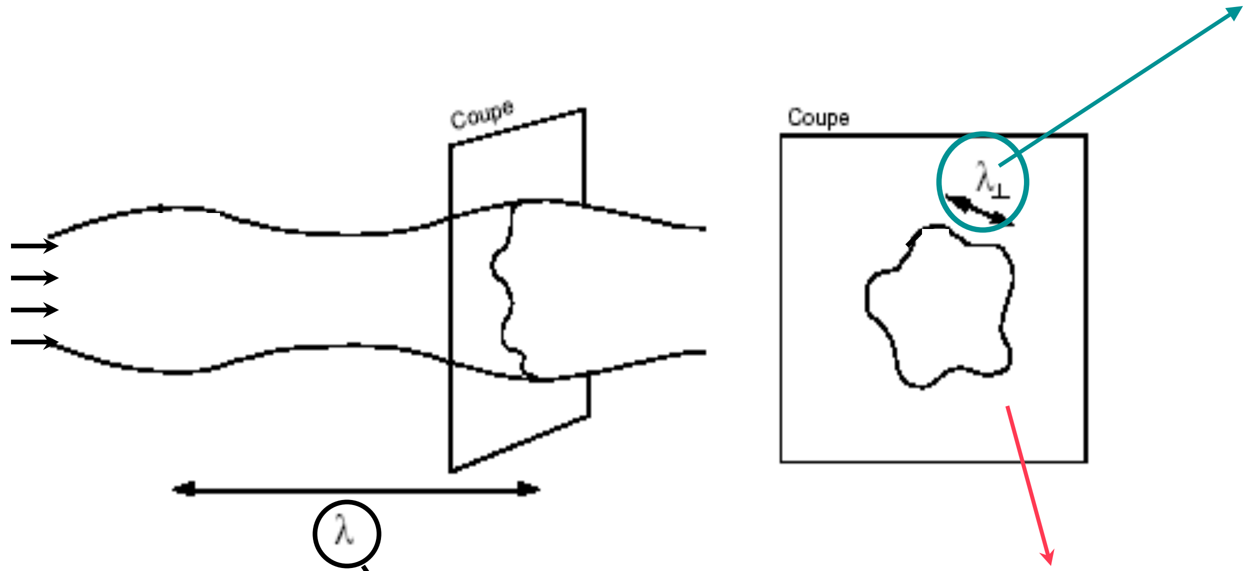
Identifiction of main parameters.

Transverse instability

=

Rayleigh Taylor instability

Liquid



Shearing instability

Formation of droplets through a minimal size r_{cr}

=> $\boldsymbol{r}_c$ = critical radius $\boldsymbol{r}_{cr}$ $\longrightarrow We_{cr} = \dfrac{\rho_g (u_g - u_l)^2 r_{cr}}{\sigma}$

$\boldsymbol{r}_*$ = Rayleigh Taylor scale λ_{RT}

Time scale $\nu = \nu_{RT}$

$$\lambda_{RT} = 9.02 \frac{(1+9.45 Z^{0.5})(1+0.4 T^{0.7})}{(1+0.87 We_2^{1.67})^{0.6}} r_0$$

$$\nu_{RT} = \left[\frac{\rho_l r_0^3}{\sigma}\right]^{-0.5} \frac{(0.34+0.38 We_2^{1.5})}{(1+Z)(1+1.4 T^{0.6})}$$

$$We_1 = \rho_l (u_{g0} - u_{l0})^2 r_0 / \sigma$$

$$We_2 = \rho_g (u_{g0} - u_{l0})^2 r_0 / \sigma$$

$$\mathrm{Re}_1 = (u_{g0} - u_{l0}) r_0 / \nu_l$$

$$Z = We_1^{0.5} / \mathrm{Re}_1$$

$$T = Z We_2^{0.5}$$

(Reitz 1987)

Realization of stochastic process; « Stochastic floating cutter particles ».

Motion of particules

In the radial direction:

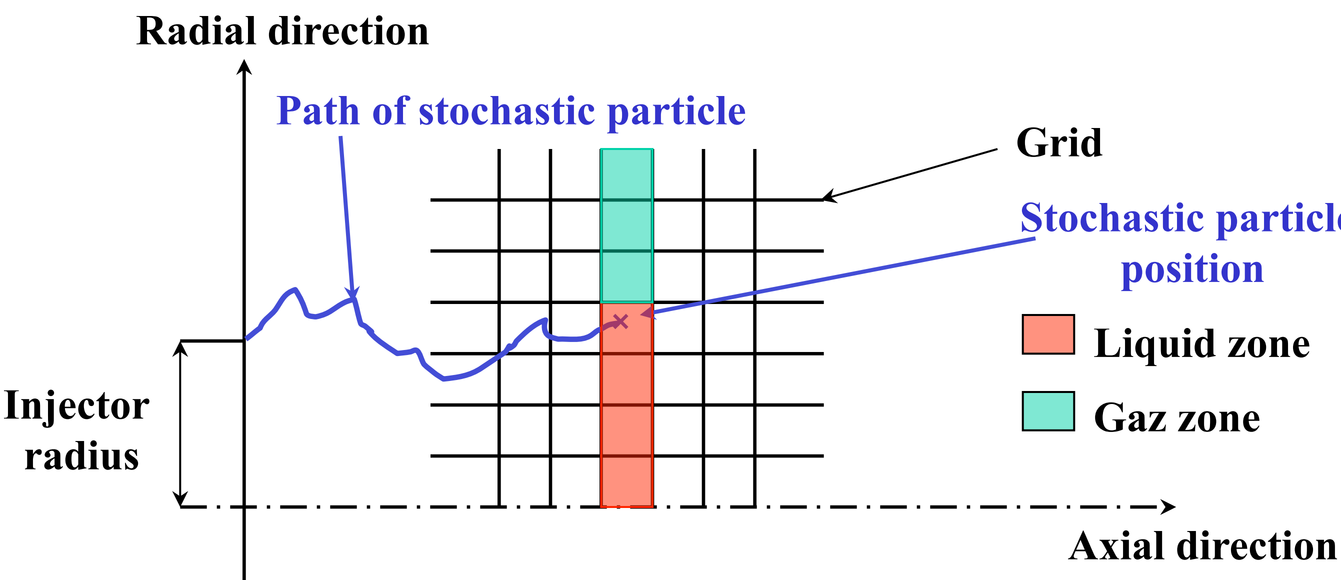
$$V_{ip} = \nu \langle \ln \alpha \rangle r + \sqrt{\nu \langle \ln^2 \alpha \rangle / 2}\; r \Gamma(t)$$

$$\frac{dr}{dt} = V_{ip}$$

In the axial direction:

$$\frac{dU_{ip}}{dt} = \frac{1}{2} \frac{\rho_g}{\rho_l} \left| u_g - u_{ip} \right| \frac{\left| u_g - u_{ip} \right|}{r}$$

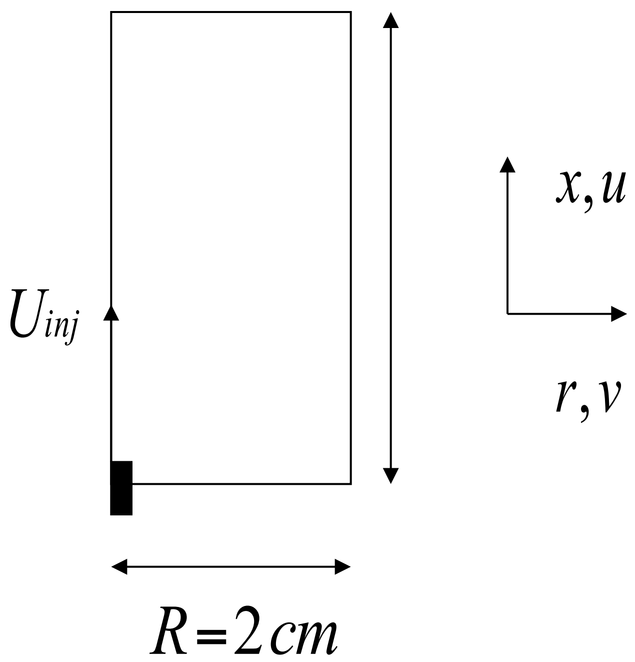
$$\frac{dx_{ip}}{dt} = U_{ip}$$



=> Staitistics of liquid core boundary

Experimental setup.

C. Arcoumanis, M. Gavaises, B. French SAE Technical Paper Series, 970799 (1997).



Gaz initial conditions:

Atmospheric conditions

$$T = 300°K$$

$$p = 1bar$$

Liquid initial conditions:

$$\rho_p = 0.8g/cm^3$$

$$R_{inj} = 0.009cm$$

$$t_{inj} = 0.85ms$$

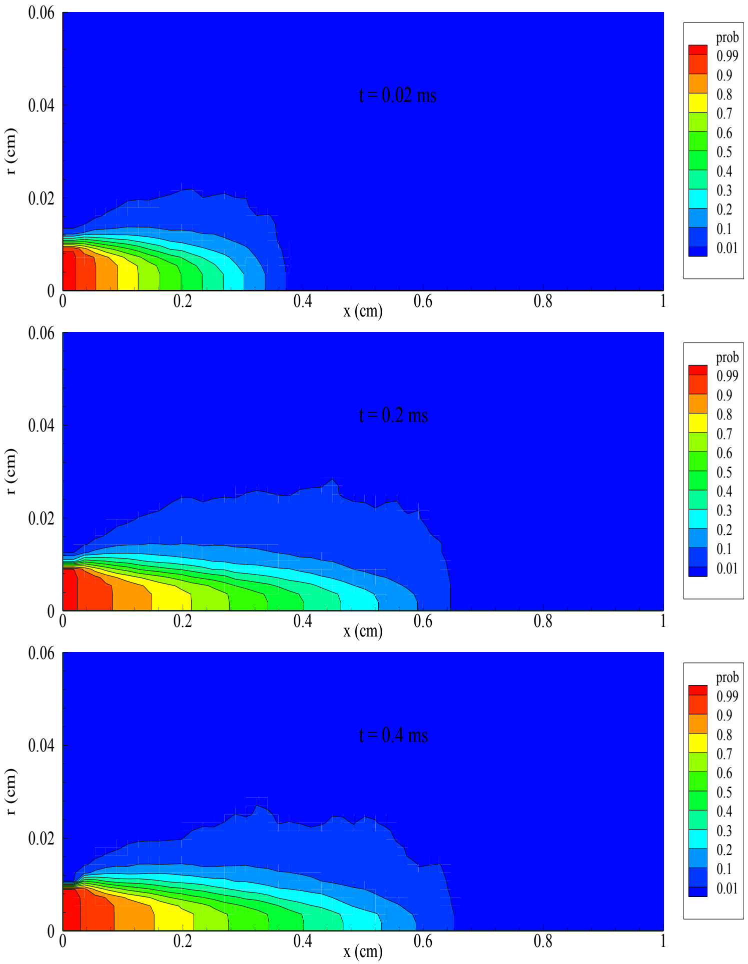
$$m_{inj} = 3.2mg$$

$$T_{inj} = 300°K$$

$$U_{inj} = U_{inj}(t) = 0 \div 260 m/s$$

Probability to get liquid core; formation of discret blobs using presumed distribution:

Statistics of liquid core boundary



Injection of droplets

Radius:

$$f(r) = \frac{1}{r_{typ}} \exp\left(-\frac{r}{r_{typ}}\right)$$

$r_{typ} \rightarrow$ Radius of the injector

Mass flow rate conservation

Motion of droplets

=> Standard KIVA procedure with velocity conditionned on the presence of liquid

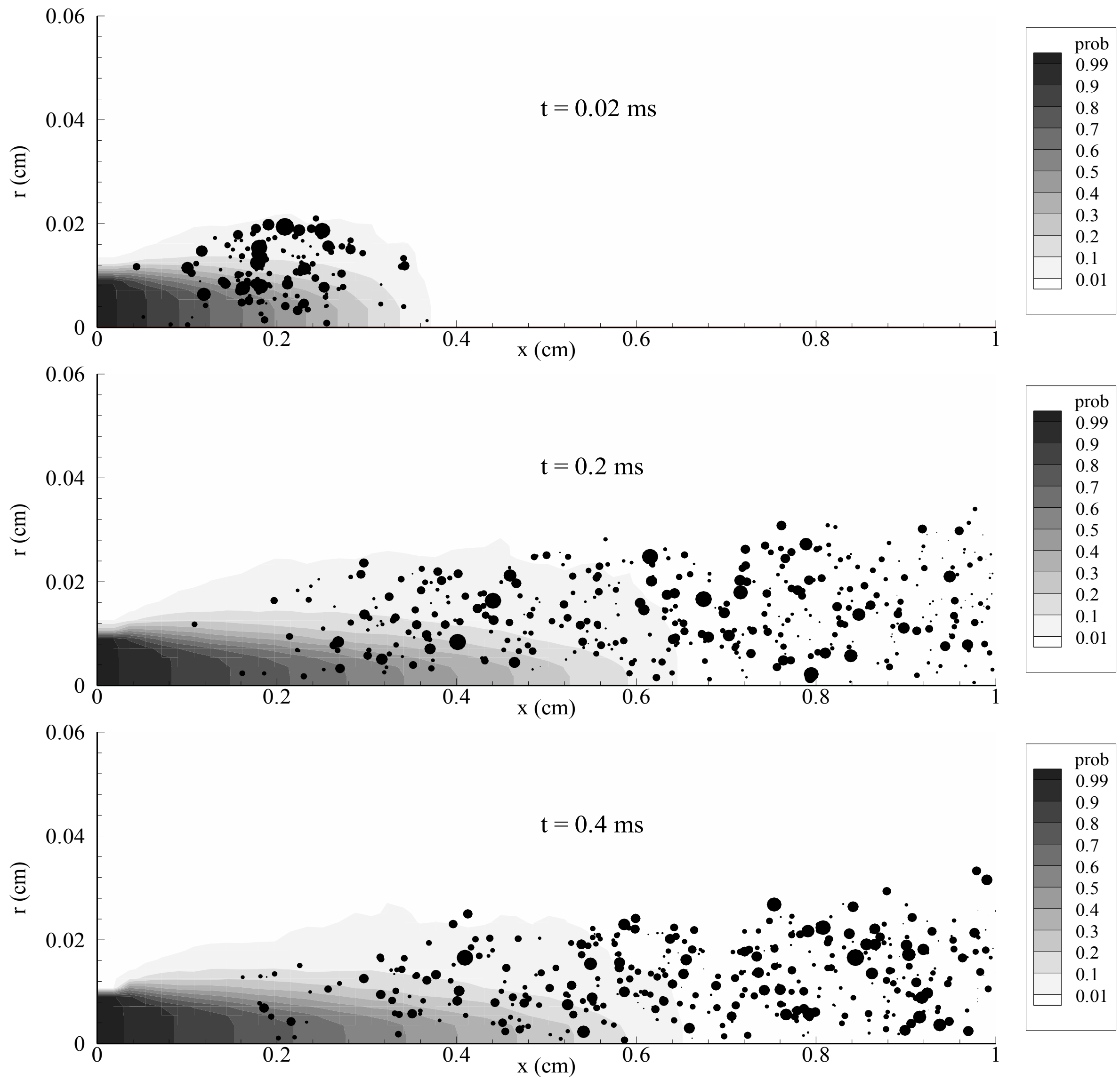
Initial conditions

$$u_p = U_{inj}(t)$$

$\rightarrow$ Injection velocity

$$v_p = \frac{rad_p}{\tau} = \sqrt{K_{liquid}} \sqrt{\frac{\rho_g}{\rho_p}}$$

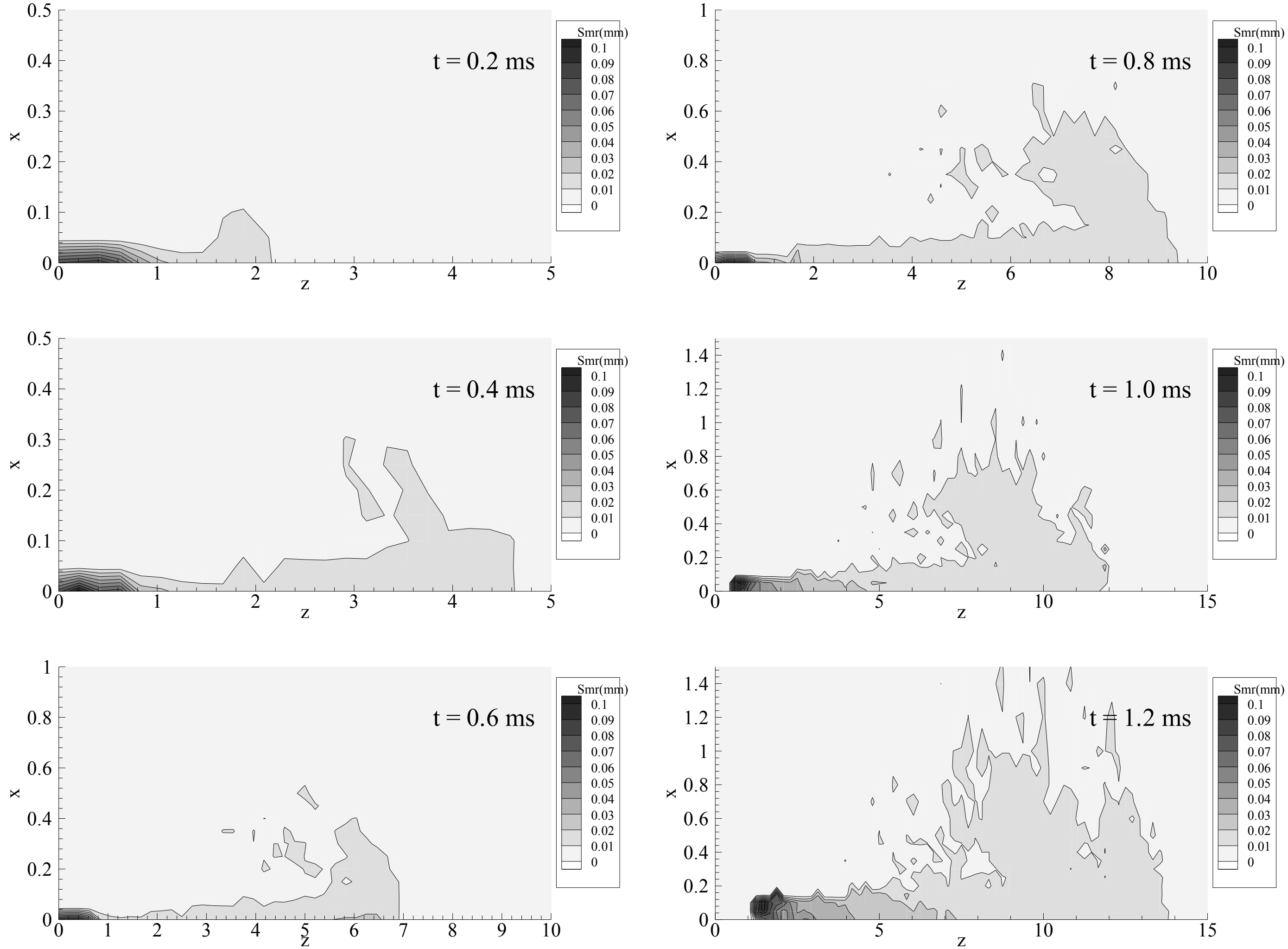
Example of distribution of formed blobs.



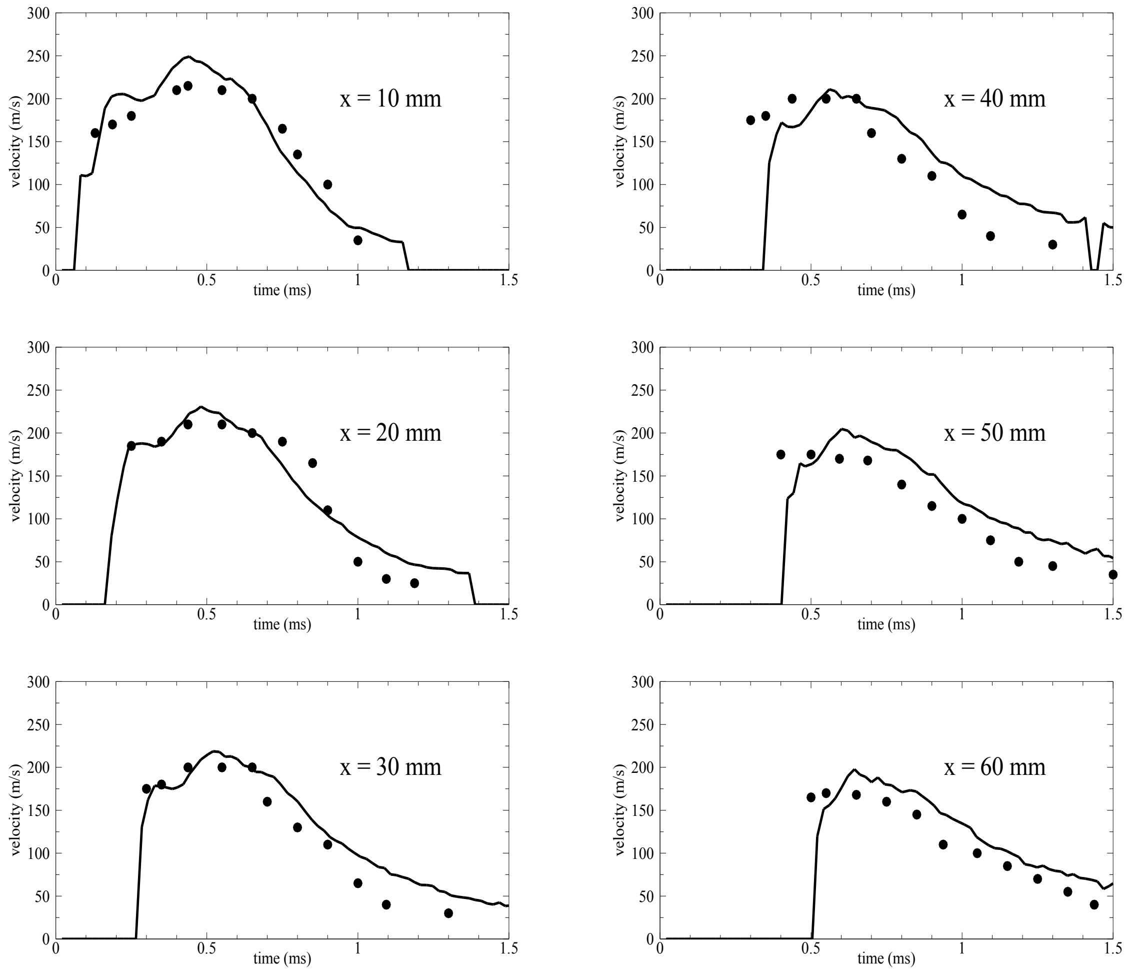
Computed mean sauter diameter.

Sauter Mean Diameter

$$D_{32} = \frac{\int_{D_{min}}^{D_{max}} D^3 f(D)\, dD}{\int_{D_{min}}^{D_{max}} D^2 f(D)\, dD}$$



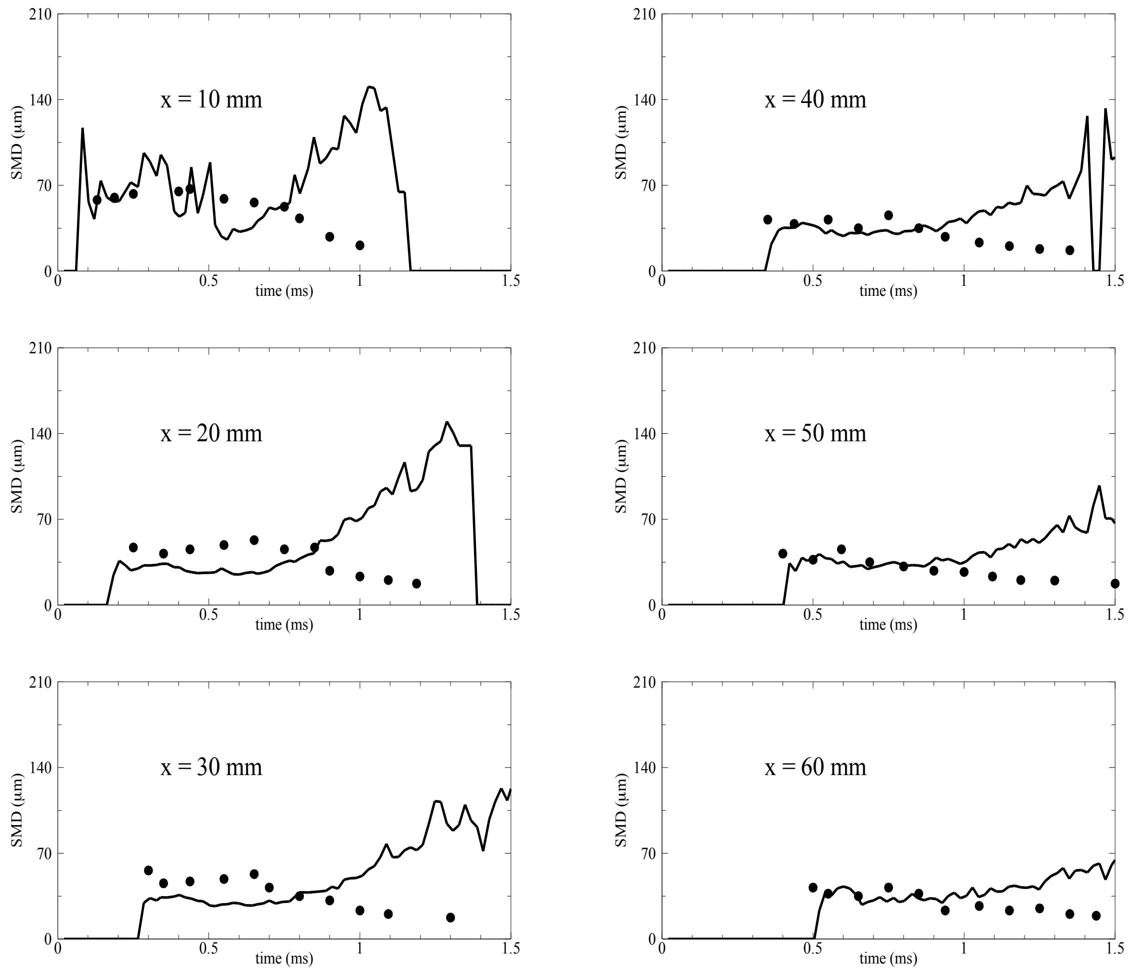
Centerline droplet mean axial velocity.



Symbols = experiment

Line = simulation

Centerline Sauter Mean Diameter (SMD).



Symbols = experiment

Line = simulation

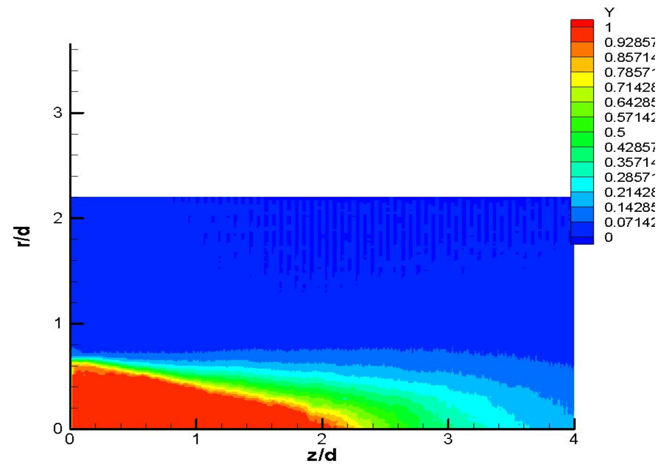
Application to Air-Blast atomization.

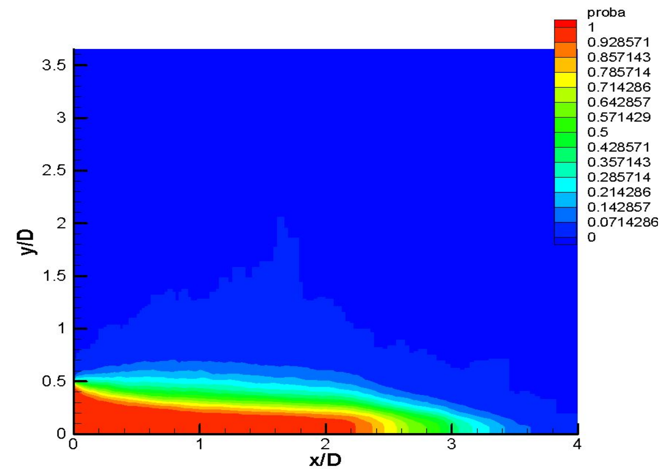
Experiment => mean liquid volume fraction (Stepowski & Werquin 2001)

Simulation => statistics of liquid core boundary

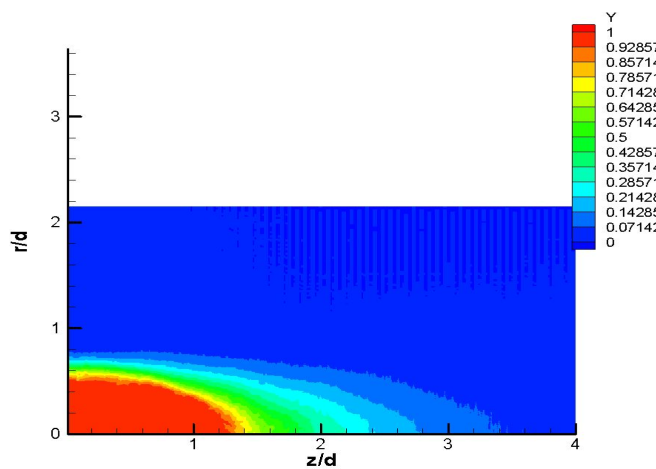
Key parameter: $M = \dfrac{\rho_g u_g^2}{\rho_l u_l^2}$

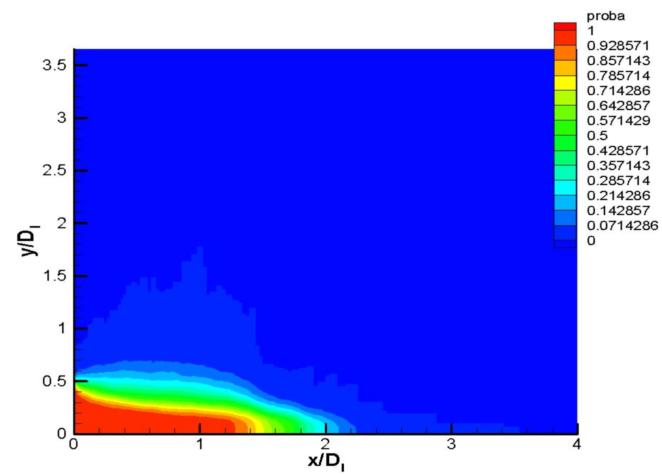
Ug = 60 m/s, Ul = 1.36 m/s





Ug = 60 m/s, Ul = 0.68 m/s





Drop injection and lagrangian tracking.

Typical size resulting from primary atomization

$$r_{typ} = \frac{1}{2}\left(\frac{\sigma}{\rho_g} We_{cr}\right)^{\frac{3}{5}} \varepsilon^{-2/5}$$

Motion of the drops injected.

Lagrangian tracking :

$$\frac{dx_p}{dt} = u_p$$

$$\frac{du_p}{dt} = \frac{f}{St_p}\left(\langle u_g \rangle_l - u_p\right)$$

$f \rightarrow$ Drag coefficient , Stp $\longrightarrow$ particle Stokes number

Modification of the gas velocity field:

$$\langle u_g \rangle_l = u_g (1 - P_l) + u_l P_l$$

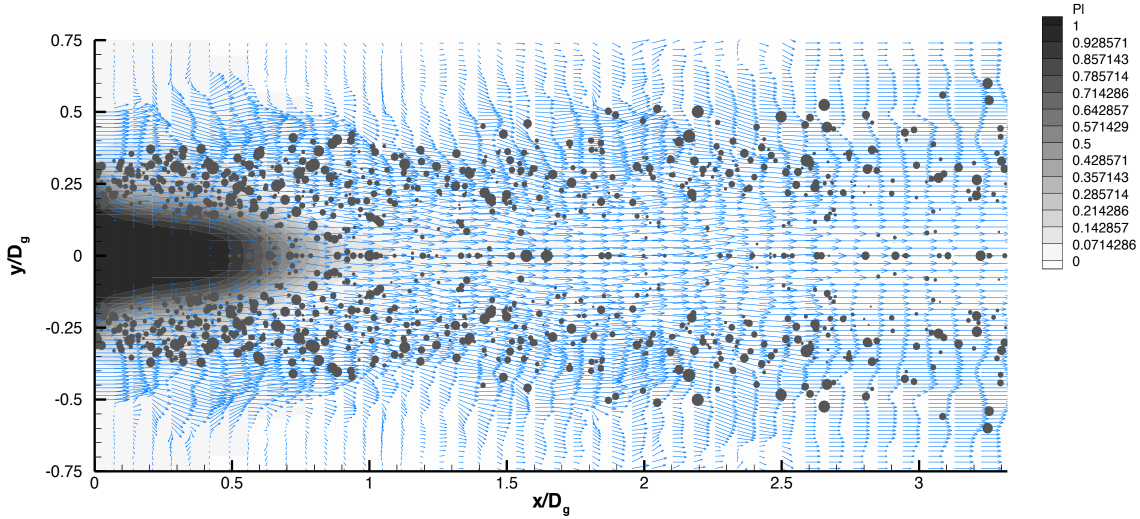
$P_l \longrightarrow$ probability of presence of liquid

Distribution of formed blobs.

Experiments (Lasheras & al 1998)

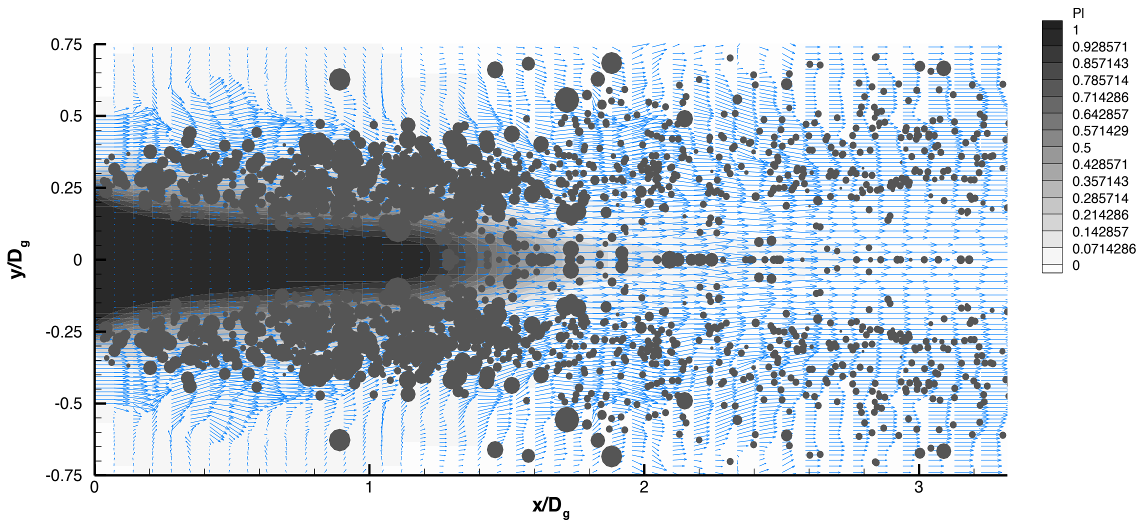
Ug = 140 m/s

Ul = 0.13 m/s



Examples of instantaneous distribution of formed droplets with instantaneous conditionned velocity of gaz and liquid core

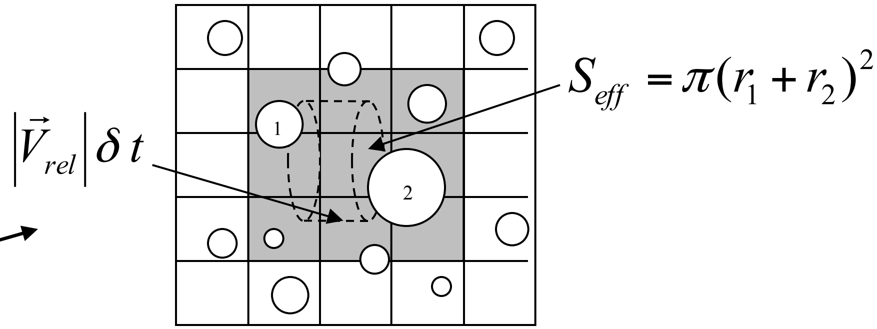
Ul = 2.8 m/s



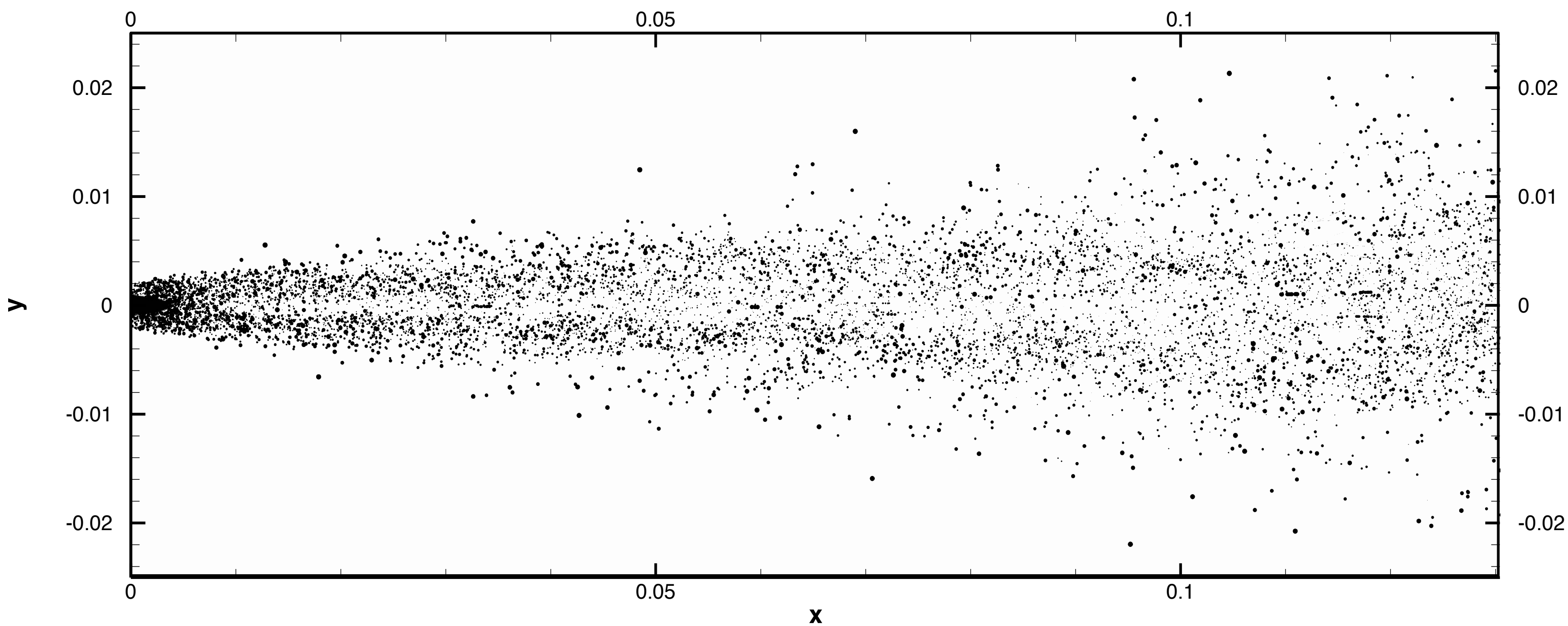
Computation in the far field.

=> Secondary processes:

- → Shearing
- → Turbulence
- → Collisions



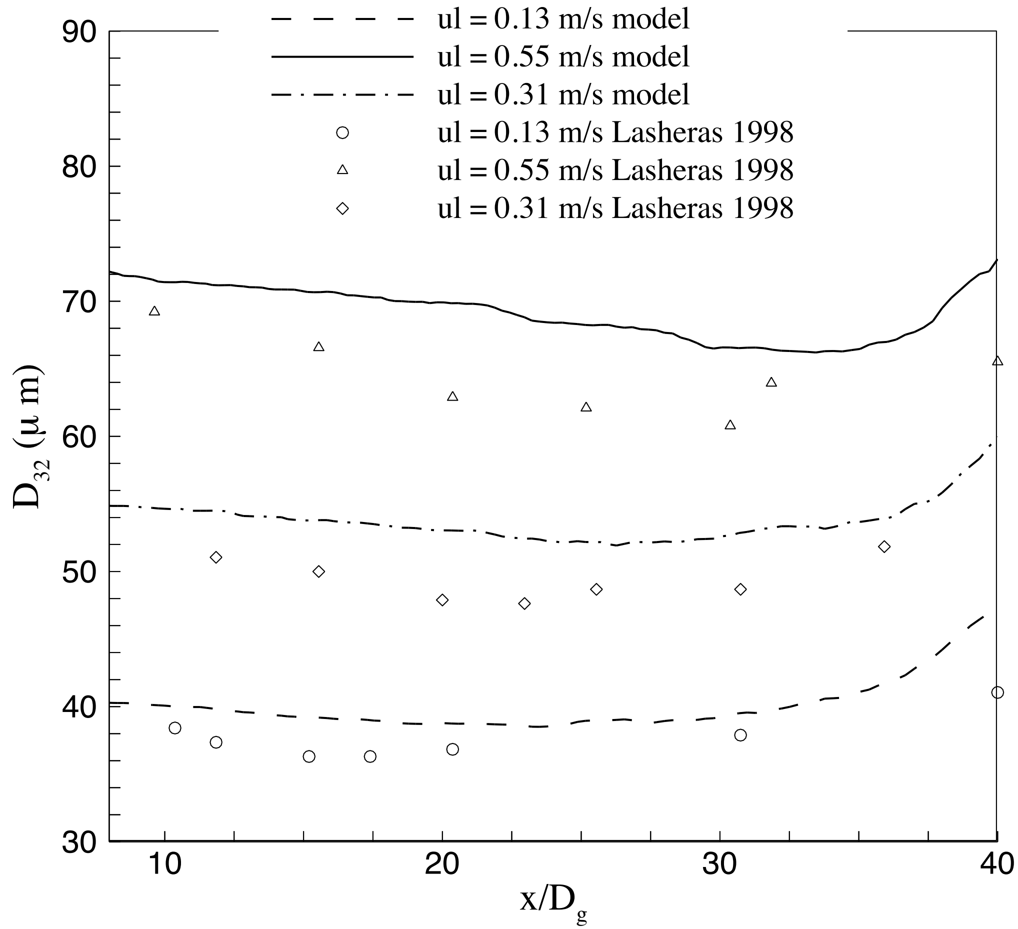
→ Fragmentation or coalescence



Example of instantaneous distribution of formed droplets

ug = 140 m/s , ul = 0.55 m/s

Comparison in the far field. Ug = 140 m/s



Conclusion.

⇒ Simple enginering model for primary atomization is proposed.

⇒ This allows to form the blobs in the near-injector region.

Future work.

⇒ Comparison with experiments in Brighton (trying different main mechanisms for fragmentation).