Imperial College London

UKCTRF meeting

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Electrostatic fields for the control of evaporating fuel droplets in a charged electrospray

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Objectives

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II. Increase the effective time available for droplet evaporation over a finite-length mixing region.

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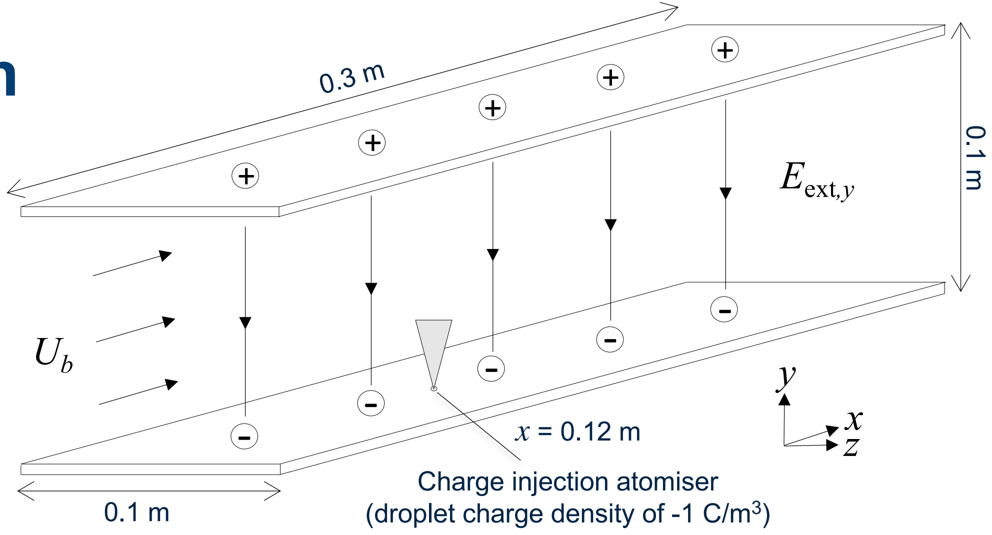
II. Increase the effective time available for droplet evaporation over a finite-length mixing region.
III. Control the location of fuel vapour release – a concept introduced here as *'targeted evaporation'*.

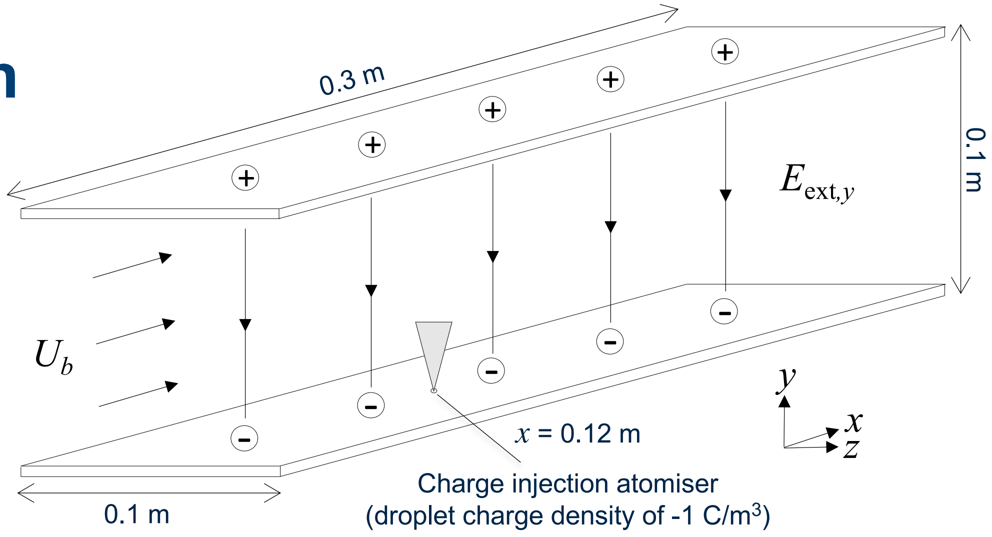
Hypothetical configuration



[1]E_{ref} = 1×10^6 V/m < Electrical breakdown of air (~ 3×10^6 V/m)

Hypothetical configuration

- 'Electrospray in cross-flow'
- Air at atmospheric pressure
- Charged kerosene droplets w/ initial temperature of 300 K
- 3×10^6 mesh points



Case	$T_{g,0}$ [K]	U_b [m/s]	$d_{0,i}$ [μm]	$u_{d,y,0}$ [m/s]	θ_d [°]	E_{ext}/E_{ref} [1]	Orientation
A	300	2, 20, 80	{5:95}	30	±9	0, 0.1, 1	$\pm E_{ext,y}$
B	700	10	50	10	0	0, 2	$E_{ext,x}$

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Numerical method

- Large eddy simulation (LES) with Eulerian-Lagrangian formulation
- Based on open-source CFD software package OpenFOAM
- Rapid mixing model[1] for droplet evaporation (secondary breakup neglected)
- Electrostatic forces computed in the Eulerian framework[2]
- Net charge of each droplet considered constant throughout lifetime[3]

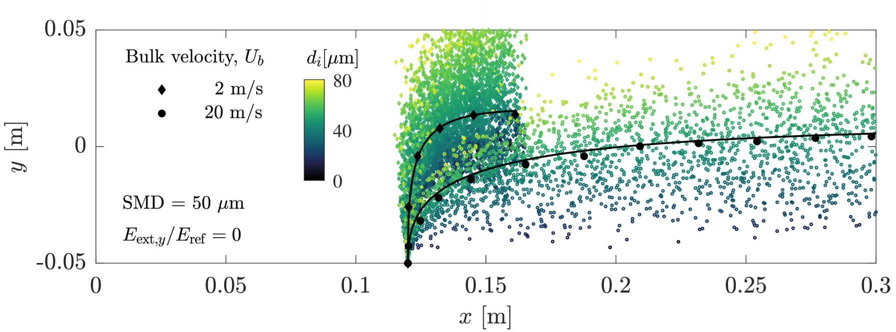
[1]Miller et al., International Journal of Multiphase Flow 24 (1998), 1025-1055.

[2]Weiand and Giusti, International Journal of Spray and Combustion Dynamics (2021), In review.

[3]Doyle et al., Journal of Colloid Science 19 (1964), 136-143.

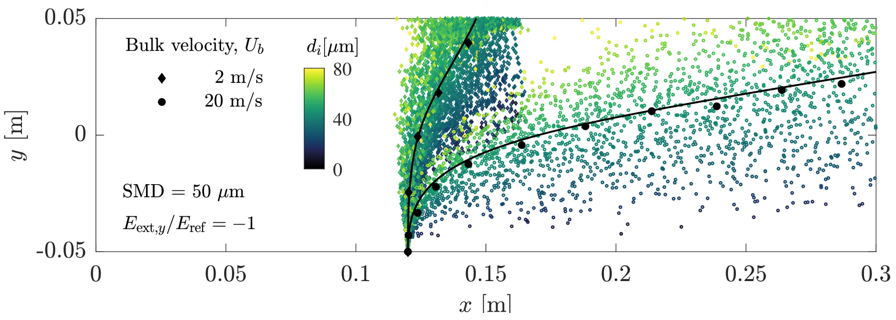
Case A – Droplet trajectories

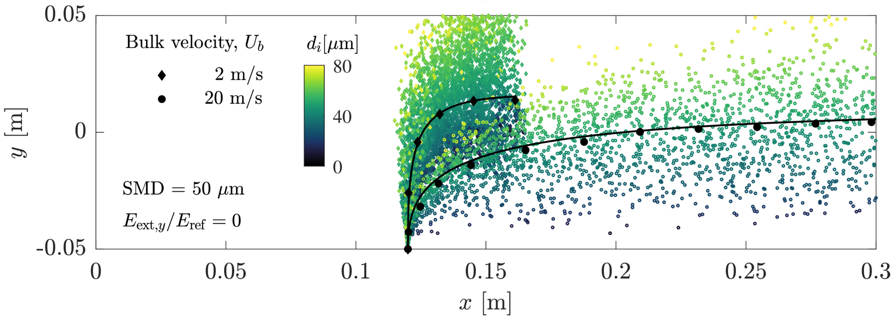
- *Symbols:* droplet bin-averages
- *Lines:* 2D analytical model based on drag and electrostatic forces



Case A – Droplet trajectories

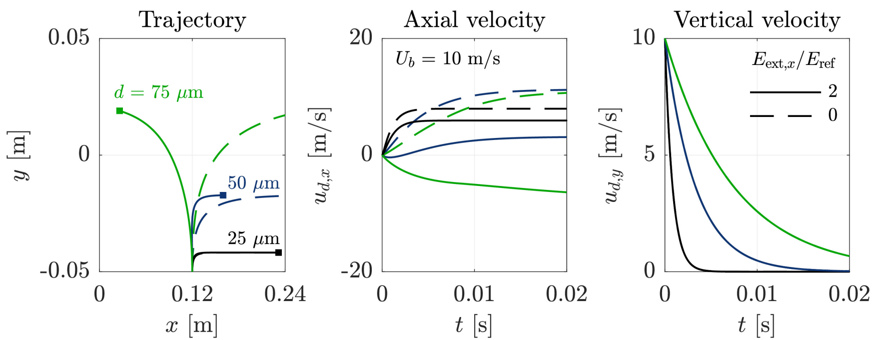
- *Symbols:* droplet bin-averages
- *Lines:* 2D analytical model based on drag and electrostatic forces
- *Setup:* el. field in the negative vertical direction (top figure only)
- *Conclusion:* mean droplet trajectories affected by el. forces





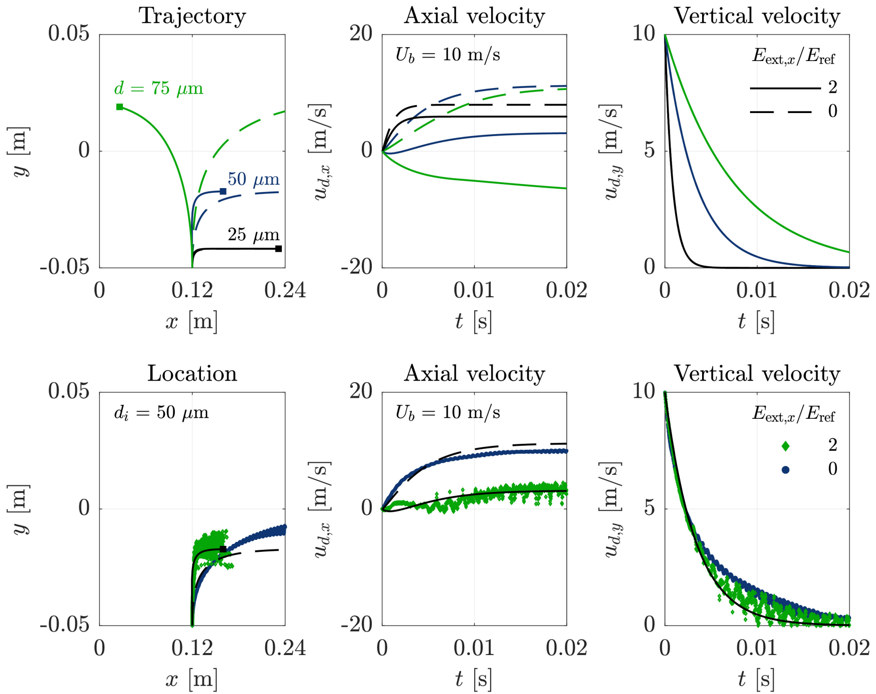
Case B – Residence time

- *Setup:* el. field in the positive horiz. direction (no evaporation)
- *Top - 2D model:* promising balance for 50 μm droplet



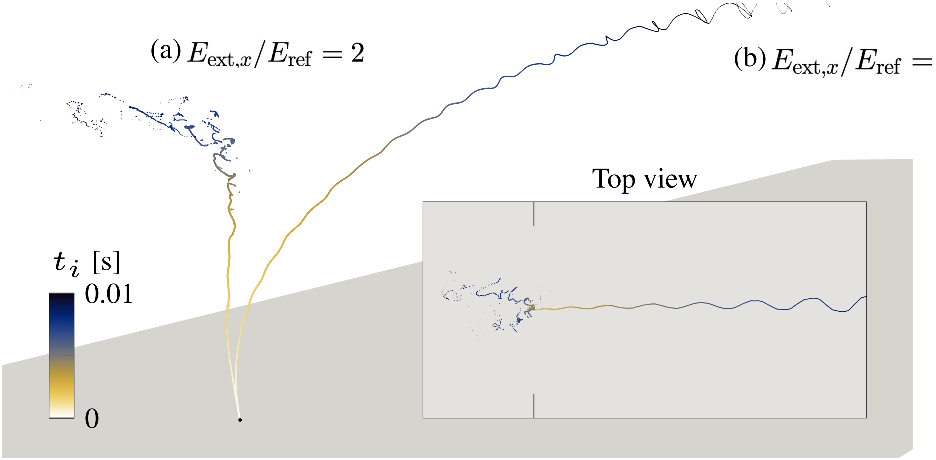
Case B – Residence time

- *Setup:* el. field in the positive horiz. direction (no evaporation)
- *Top - 2D model:* promising balance for 50 μm droplet
- *Bottom - CFD:* quasi-infinite droplet residence time achieved



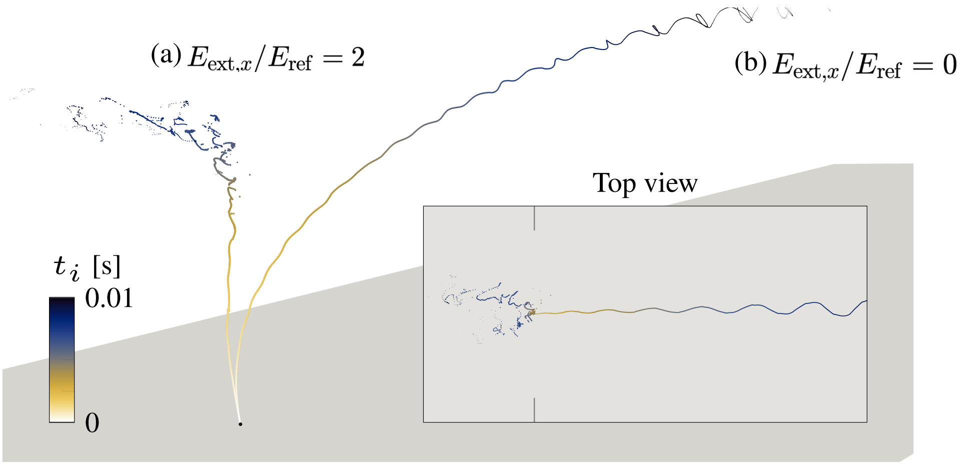
Case B – ‘*Targeted evaporation*’

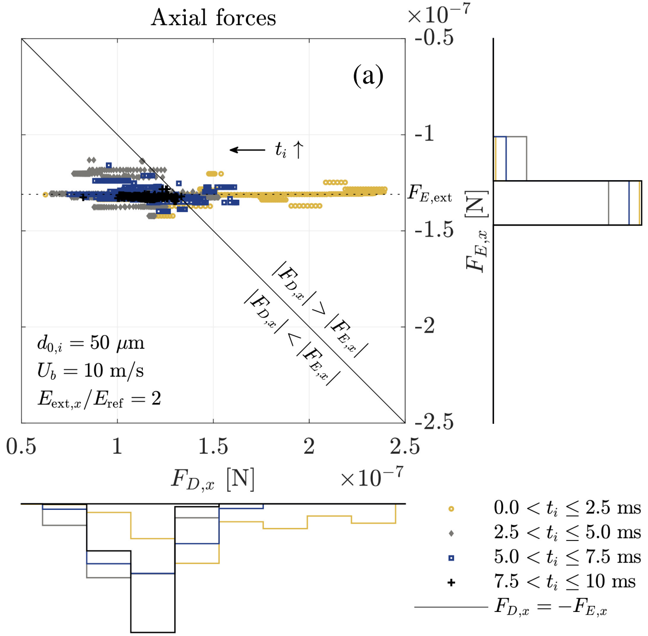
- *Setup:* el. field in the positive horiz. direction



Case B – '*Targeted evaporation*'

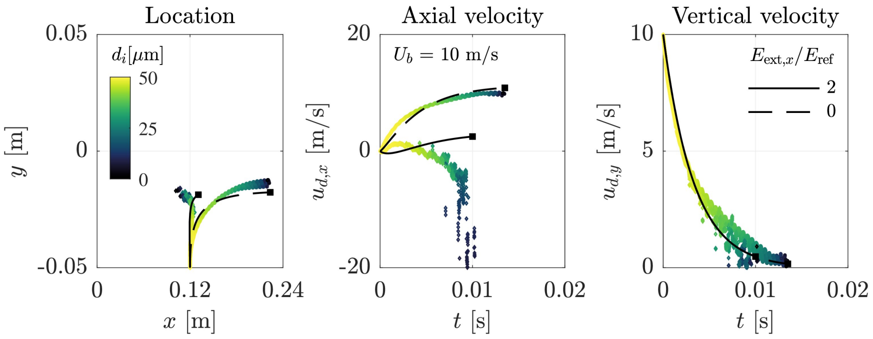
- *Setup:* el. field in the positive horiz. direction





‘*Targeted evaporation*’ (2)

- Localised fuel vapour release
- Repulsion forces promote droplet separation and dispersion



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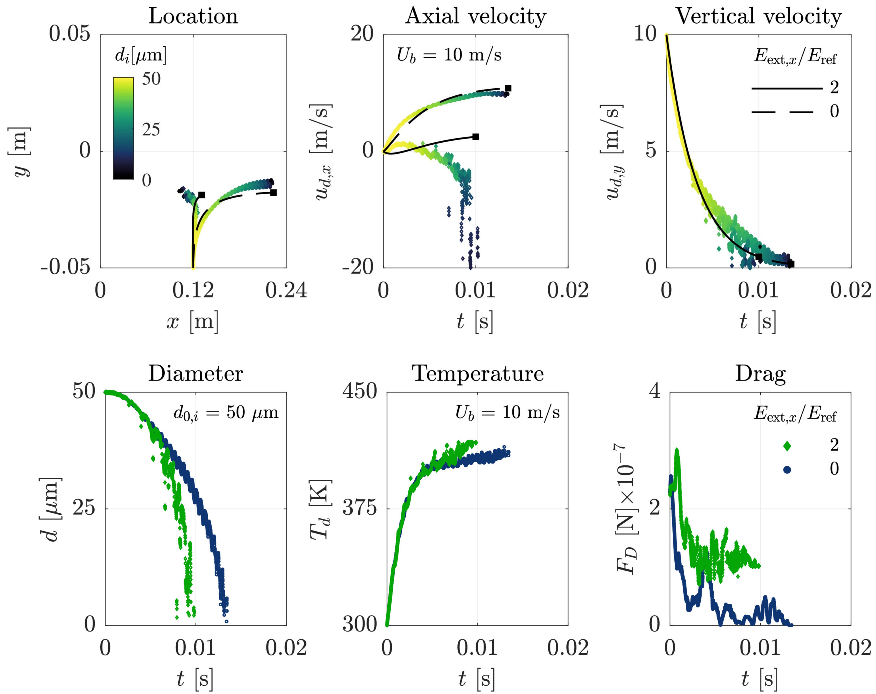
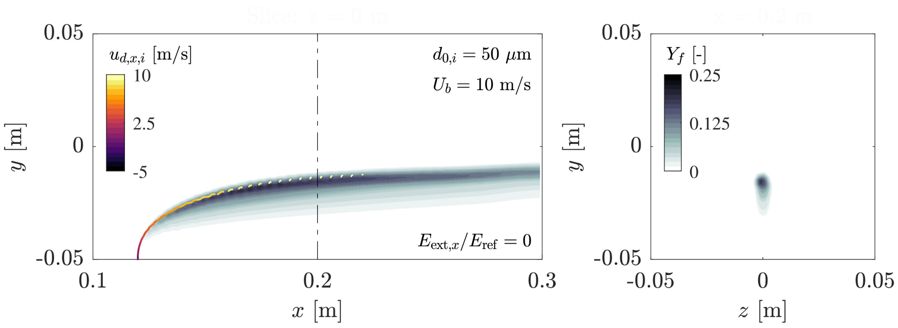
- Localised fuel vapour release
- Repulsion forces promote droplet separation and dispersion
- Quicker evaporation (-30%) due to higher droplet *Re* number (increased relative velocity)

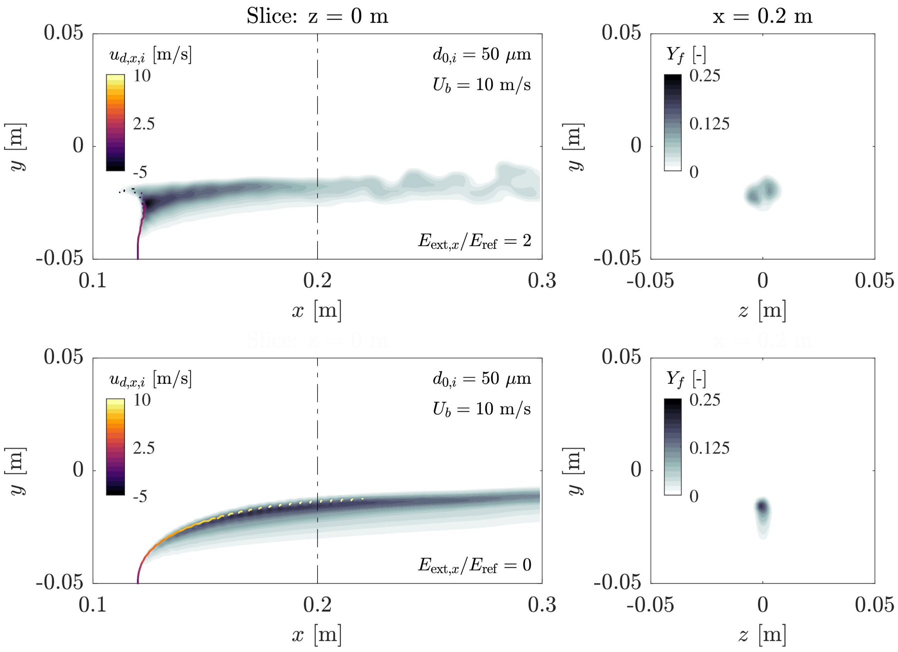


‘*Targeted evaporation*’ (3)



‘*Targeted evaporation*’ (3)

- Enhanced mixing due to higher turbulence intensity in the continuous phase
- Smaller fuel vapour gradients downstream (more homogeneous mixture)



Conclusions

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II. Increased the effective time available for droplet evaporation over a finite-length mixing region.

III. Demonstrated *'targeted* evaporation' by controlling the location of fuel vapour release.

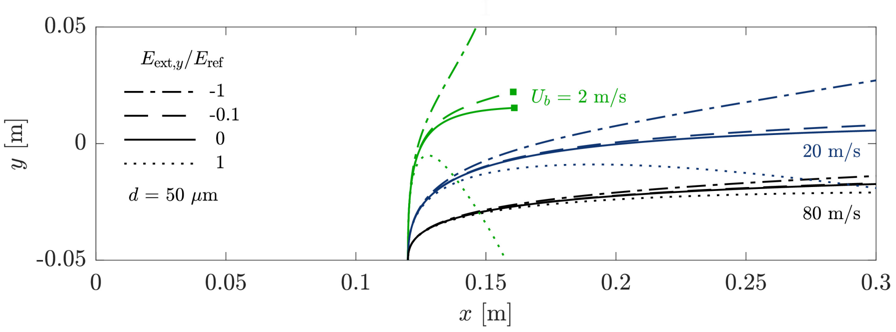
Future work

- Conceptualise and investigate practical configuration
- Include break-up model based on Coulomb explosion
- Consider benefits of nanoparticle addition (e.g. shell formation)
- Simulate influence on subsequent combustion process

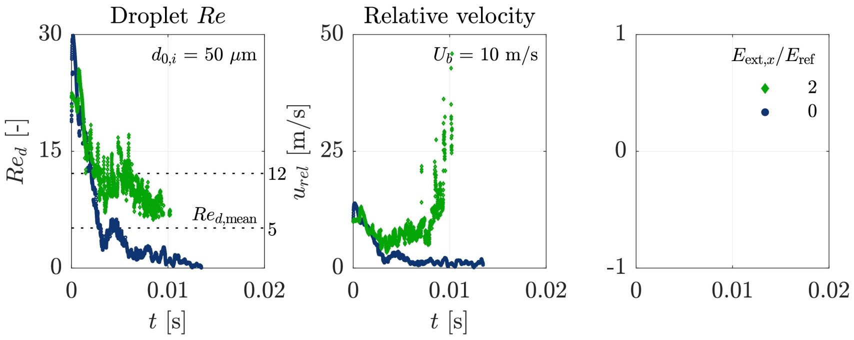
Acknowledgements

- This project is funded by the European Commission through the Clean Sky 2 Joint Undertaking under the European Union's Horizon 2020 Research and Innovation Program, project LEAFINNOX (Grant Agreement \#831804).
- The work is also supported by the UK Consortium on Turbulent Reacting Flow (UKCTRF) and uses the ARCHER UK National Supercomputing Service (http://www.archer.ac.uk).

Appendix A: Parameter variation



Appendix B: Droplet statistics



Appendix C: Mathematical formulation

$$\nabla^2 \varphi = -\frac{\rho_q}{\varepsilon_0}, \tag{1}$$

$$\boldsymbol{E} = -\nabla \varphi. \tag{2}$$

$$\boldsymbol{F}_{E,i} = q_{d,i}\, \boldsymbol{E}. \tag{3}$$

$$q_{d,i} = \rho_{q,d,i}\, V_{d,i}, \tag{4}$$

Appendix D: Analytical model

$$\frac{\mathrm{d}\boldsymbol{u}_d}{\mathrm{d}t} = \frac{1}{m_d}(\boldsymbol{F}_D + \boldsymbol{F}_E), \tag{5}$$

$$\boldsymbol{F}_D = 0.125\,\rho_g\,\boldsymbol{u}_{\mathrm{rel}}^2\,C_D\,\pi\,d^2, \tag{6}$$

$$C_D = \begin{cases} 0.424, & \text{if } \mathrm{Re}_d > 1000, \\ \frac{24}{\mathrm{Re}_d}\left(1 + \frac{\mathrm{Re}_d^{2/3}}{6}\right), & \text{otherwise}, \end{cases} \tag{7}$$

$$\mathrm{Re}_d = \frac{\rho_g\,|\boldsymbol{u}_{\mathrm{rel}}|\,d^2}{\mu_g}, \tag{8}$$

$$\boldsymbol{u}_{\mathrm{rel}} = \begin{bmatrix} U_x \\ 0 \end{bmatrix} - \begin{bmatrix} u_{d,x} \\ u_{d,y} \end{bmatrix} \tag{9}$$

$$U_x(y) = \frac{U_b}{0.8}\left(1 - 2\,\frac{|\,y\,|}{h}\right)^{1/4}, \tag{10}$$

$$\boldsymbol{F}_E = q_d\,\frac{\Delta\varphi_{\mathrm{ext}}}{|\boldsymbol{L}|}\,\hat{\boldsymbol{e}}_L, \tag{11}$$