# Brakedust removal by Electrostatic precipitator

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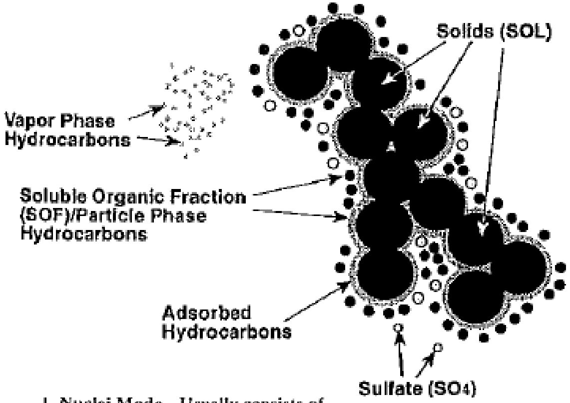
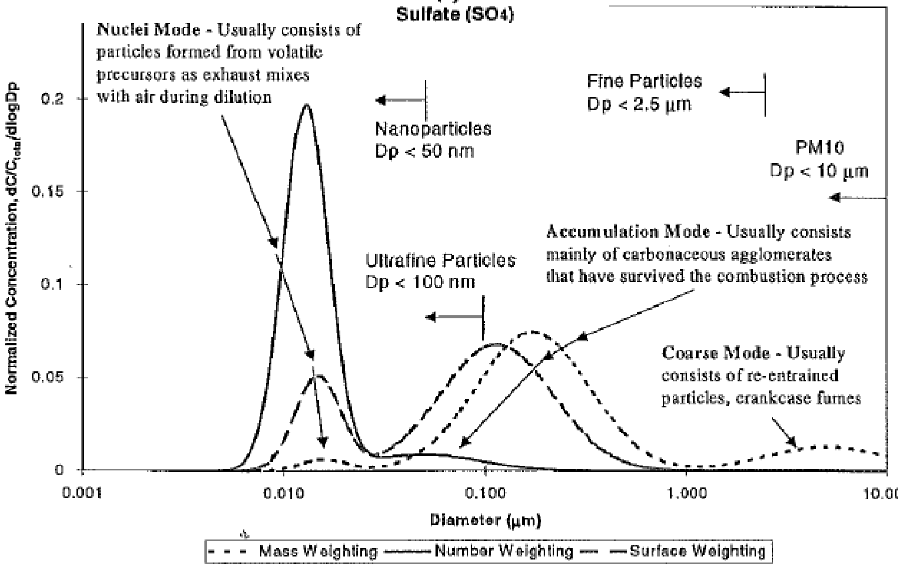
# Particulate matter (PM)

- PM is bad for human health
  - Causes Asthma, COL
  - Cardiovascular problems
  - Development for children
  - Globally 3.7 million deaths (every year) due to air pollution (2012) (same 2019! [1])
  - US: 50.000 premature deaths due to traffic pollution
  - Sweden 2019 6700 deaths from air pollution (~1400 from road traffic) –decreasing [2]

- PM influences climate change
  - Increased reflection and cloud effects (- -)
  - Carbon black absorption (+)
  - Increased ice melting

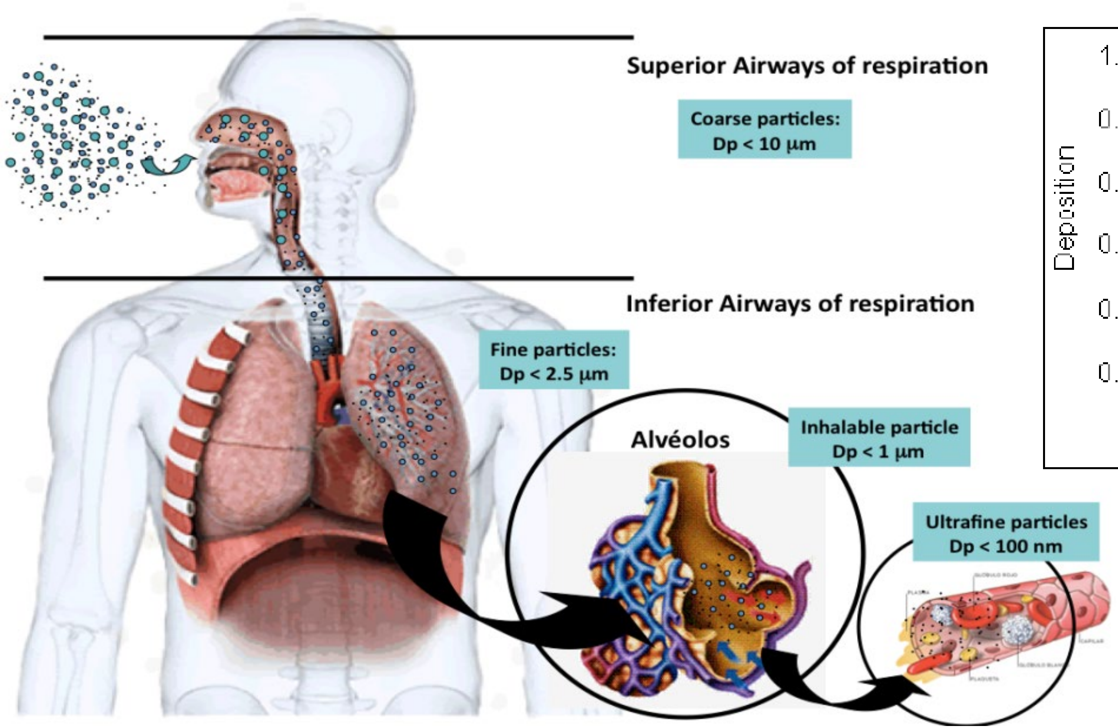


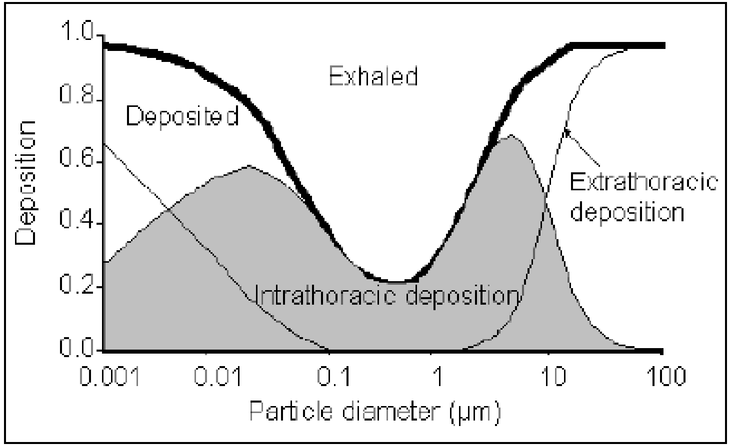





[1] Global Burden of Disease 2020 https://vizhub.healthdata.org/gbd-compare/#
[2] M. Gustafsson *et al.*, "Quantification of population exposure to NO2, PM2.5 and PM10 and estimated health impacts," IVL, 2022

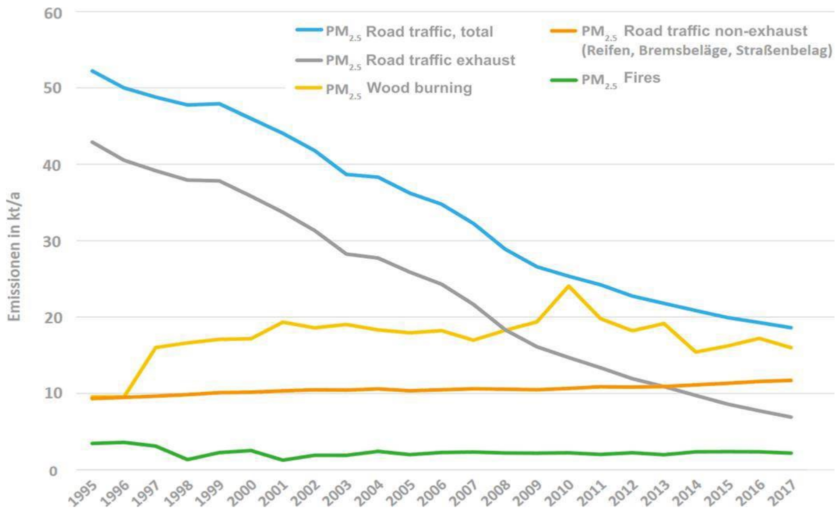
# Why are Particle emissions a Health issue?



# Evolution of Particle emissions

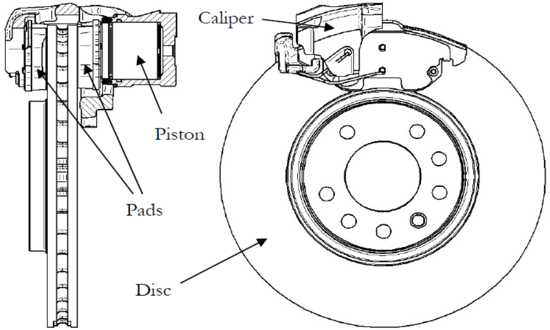
- Tailpipe emissions (from combustion engines) is decreasing
  - Improved exhaust aftertreatment (+ electrification)
- Non-exhaust emissions increase
  - More transport demand!
  - EV contribute too (heavier, high torque)

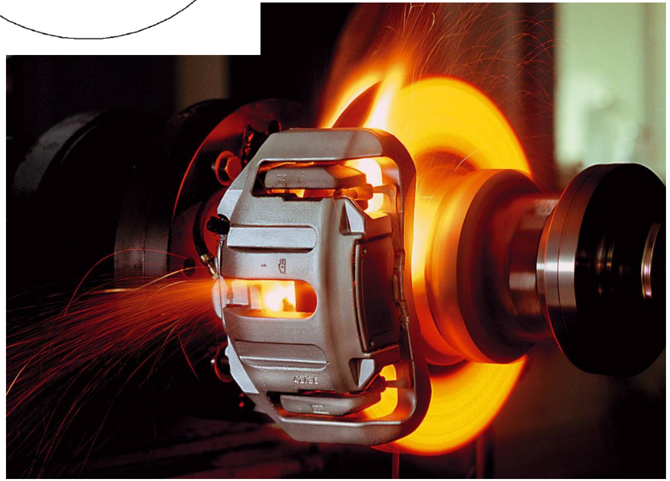


# Wear emissions from brakes

## Car brakes

- Components
  - Disc (cast iron)
  - Pads (composite)
    - Binder, fibers, filler, lubricant, grinder
- Power distribution: 70% (front) 30% (rear)
- Important for safety (!)
- Performance depends on
  - Wear status
  - Temperature
  - Speed/force



## PM composition

- Cu, Fe, Zn, Zr, Sn, Sb

# Non-Exhaust Emission regulations

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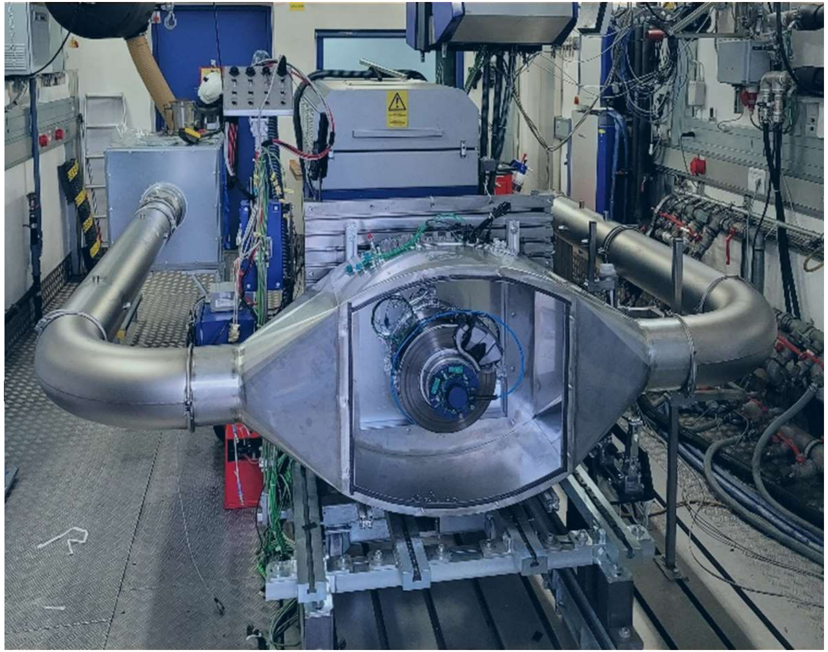
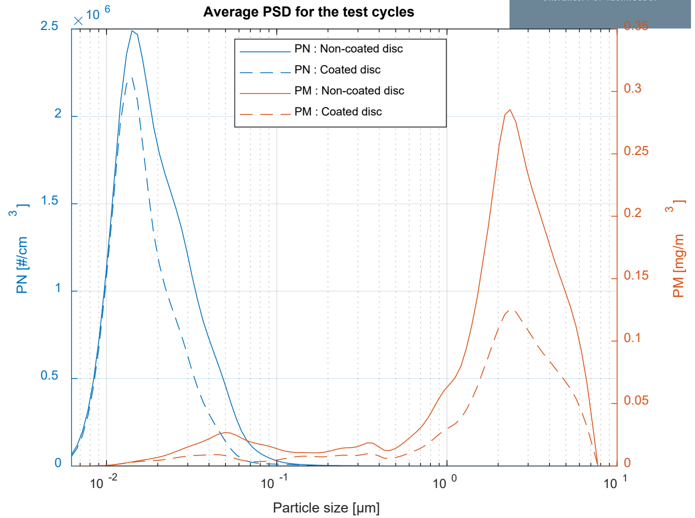
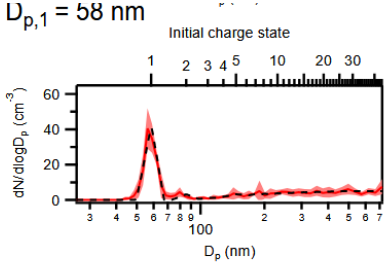
- Brake material legislation
  - Asbestos – forbidden, Cu – regulated in US
- Air quality guidelines
  - $PM_{10}$, $PM_{2.5}$
  - WHO => EU => MKN
- Working environment
  - Respirable, inhalable, NOT $PM_{10}$ and $PM_{2.5}$
  - AFS 2018:1 $CO/NO_X$ used as “proxy” for PM
  - AFS 2020:6 Diesel exhaust (from feb-2023) 50µ
- Euro 7 legislation
  - Brake wear emissions Light-duty:
    - $PM_{10}$: <7mg/km -2035, <3mg/km 2035-
    - $PN_{10}$ (number, <10nm): tbd…
  - Tyre wear emissions: Tbd… (unit: g/1000km)
  - Heavy duty: test protocol proposed 2025, and limits: tbd…

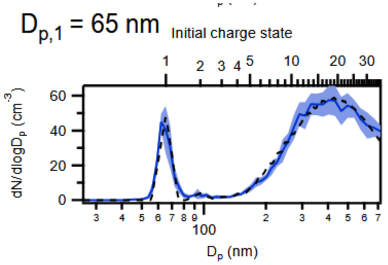


# Brake wear particle size distribution

- Bimodal distribution
  - Large / “coarse” mode (metals, fibres)
  - Small / nucleation mode (condensed resin)
- Coated disc reduces wear
  - Not completely reduced, more “to do” ...
- Brake particles are “naturally” charged!

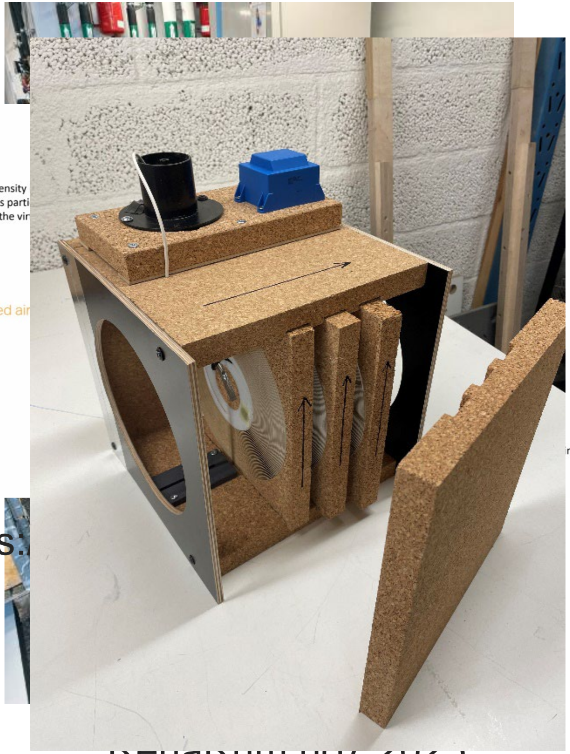


# Innovative Electrostatic particle filter

- Formas project 2023-2025
  - Company: LigthAir (https://lightair.com/en/)
  - (www.cleansurgeair.se)
- Different forces in a channel (drag, diffusion, electrostatic)
- Capture is increased by small channels combined with a small pressure drop
- Challenges when applied to a vehicle
  - Rain/splash will clog and risk of sparks
  - Turbulent, variable flow conditions

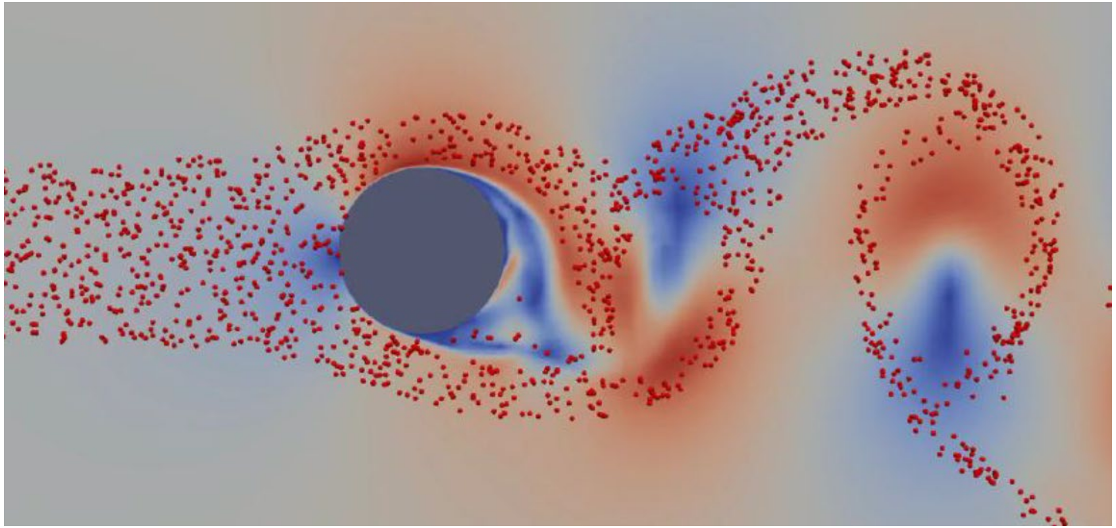


# Particle motion and deposition - a multiscale problem in modelling

- Particles deposition from a fluid flow is governed by a wide range of *recurrent* flow structures that may never repeat exactly → computationally expensive to simulate
- History effects in the development of the boundary layer around an individual particle renders the force that determines the particle motion *non-local* → computationally expensive to simulate

# Recurrence Computational Fluid Dynamics (rCFD)

- rCFD enables computationally efficient time extrapolation to infinity using a limited database of detailed flow field data
- Proven accurate for particle deposition on bluff bodies
- Computational speed-up is several orders of magnitude



Phys. Fluids 37, 093320 (2025); doi: 10.1063/5.0283431

# Recurrence Computational Fluid Dynamics (rCFD)

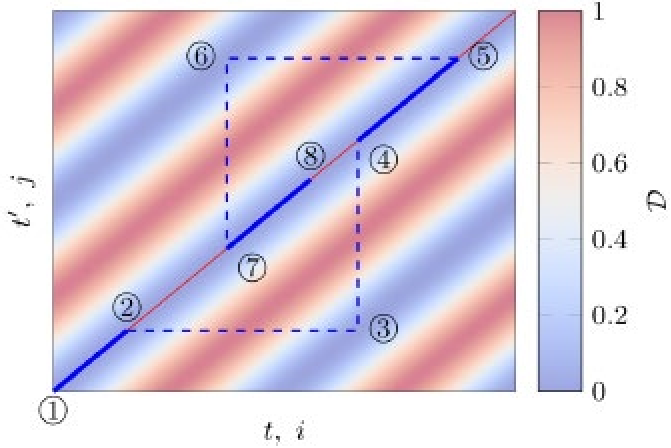
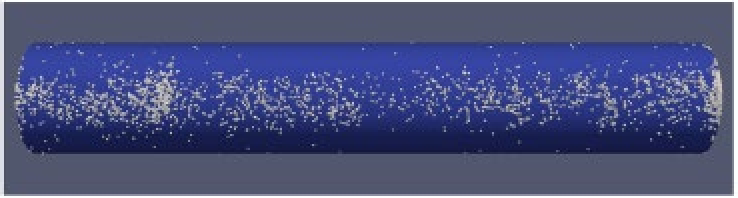



FIG. 1. Schematic illustration of a recurrence matrix. The value of each matrix element $\mathcal{D}_{ij}$ represents the dissimilarity between states $i$ and $j$ in a CFD database according to the chosen difference metric.



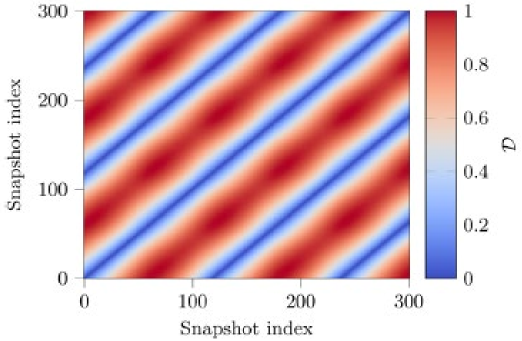



FIG. 5. Recurrence matrix for the CFD database at Re = 100. Plotted are the matrix elements $\mathcal{D}_{ij}$ for the distance metric as defined in Eq. (15).

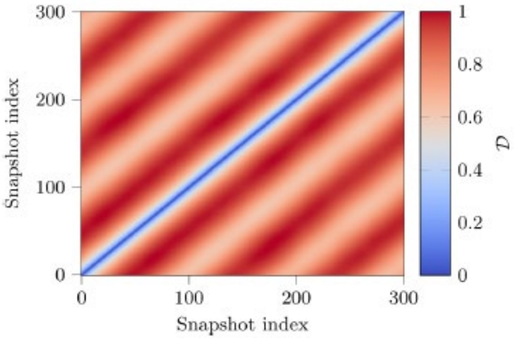



FIG. 6. Recurrence matrix for the CFD database at Re = 10 000.

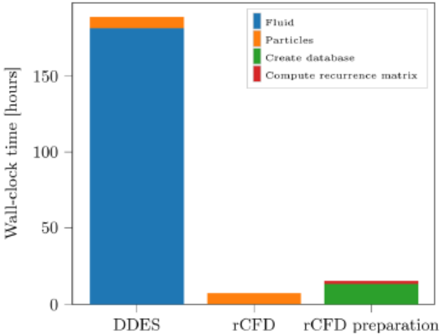


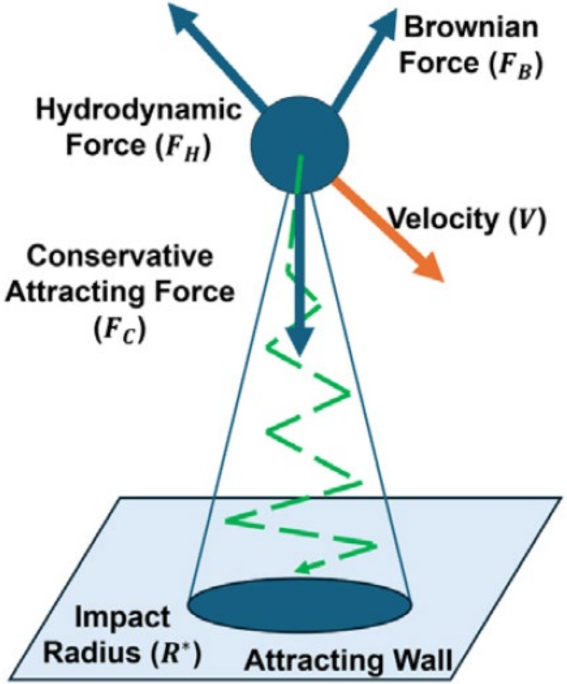

FIG. 14. Computational performance of the DDES and rCFD methods, categorized by type of calculation. The latter method is divided into two phases, "rCFD preparation" and "rCFD." The rCFD preparation phase is only run once for each flow system; the rCFD phase can be run once or several times for parametric studies. Time is measured in wall-clock time.

# Brownian deposition in narrow channels under the influence of an external field

- The total force on a particle is described using a convolution integral between the velocity history and a *memory kernel* (a second order tensor):

$$m_p \frac{d\mathbf{V}(t)}{dt} = \mathbf{F_H}(t) + \mathbf{F_B}(t) + \mathbf{F_C}(t)$$
$$= -\int_0^t \mathbf{K}(t,\tau)\cdot\mathbf{V}(t-\tau)d\tau + \mathbf{F_B}(t) + \mathbf{F_C}(t)$$

- The memory kernel is mapped in several places inside the geometry and can thereafter be reconstructed *on-the-fly*
- No need for (instantaneous) correlations



# Brownian deposition in narrow channels under the influence of an external field

- Computational speed-up of several orders of magnitude →
- rCFD + non-local multiscale model = accurate numerical predictions of particle deposition in complex geometries with fluid flow at high computational efficiency
- The electrostatic precipitator is a perfect real-world application to validate and further develop these simulation tools!

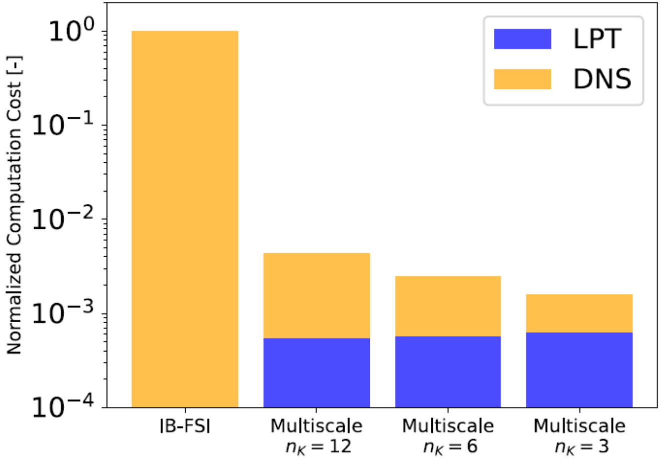



**Fig. 13.** Comparison between computational costs associated with running a pure DNS based on IB-FSI framework and the corresponding multiscale simulation using the memory kernel-based LPT framework. Here, $n_K$ refers to the number of memory kernels used to characterize the hydrodynamic effects the fluid in this particular domain has on the particle.

*A.J. Michael et al.* *International Journal of Multiphase Flow 193 (2025) 105421*

# Brake rig at Chalmers

- Building on new FFI project
  - Transient rig for both LD and HD brake systems
- Measurements of wear particles before/after precipitator (filter)
  - dependency of flow, temperature, brake conditions
  - dependency of filter conditions

# Summary and outlook

- Novel technology in an emerging research field
- Highly relevant and needed to decrease health impact
- Construction of a prototype enabling precise assessment done
  - To be evaluated during spring 2026

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