

# Simulating the Interaction of Particles & Droplets with Road Vehicles

ADRIAN GAYLARD, 11 March 2024

Title: Simulating the Interaction of Particles & Droplets with Road Vehicles  
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# OVERVIEW

Motivation, sources & interactions

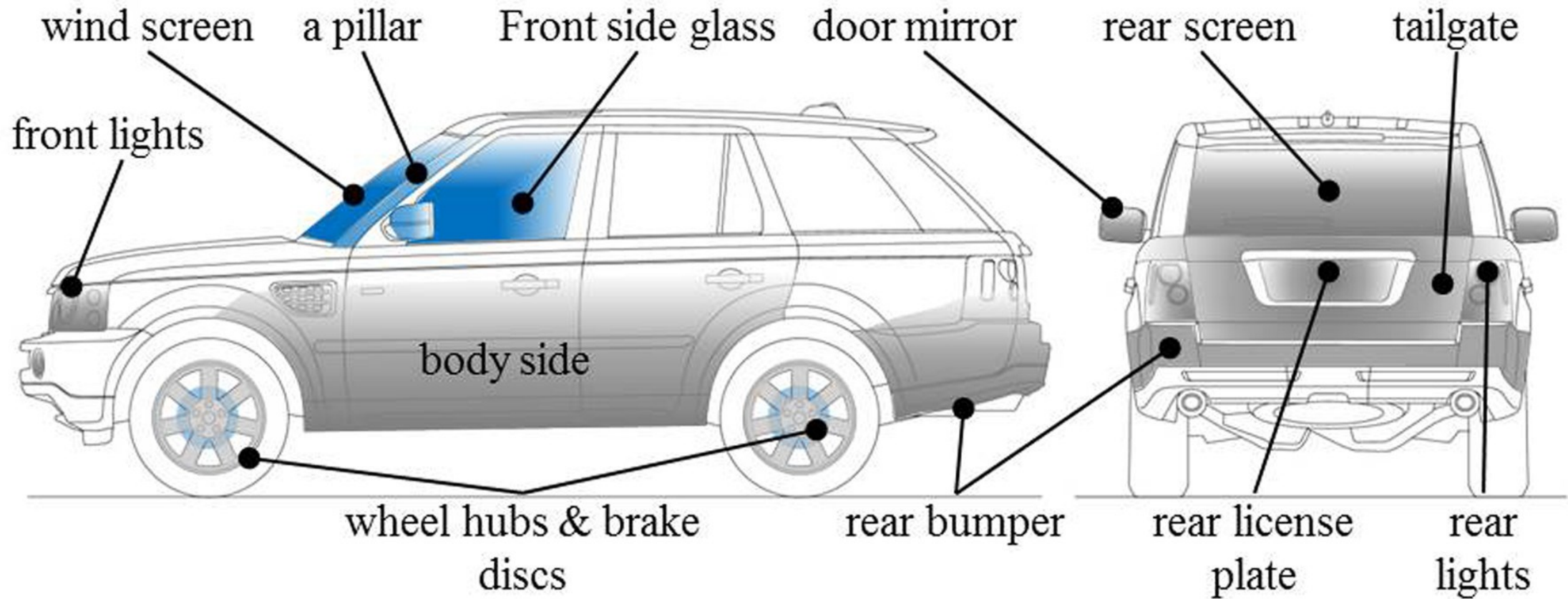
**MY MOTIVATION: LAND ROVER DISCOVERY 3**

“The upper tailgate gets very dirty on the outside and you can't use the handle on the inside to close it successfully, **so you really need to wear gloves ...**” (JLR Probe data, 1MIS UK Verbatim Responses, 2004.)

Gaylard & Duncan (2011). Simulation of Rear Glass and Body Side Vehicle Soiling by Road Sprays. *SAE Int. J. Passeng. Cars – Mech. Syst.*, 4(1):184-196.  
DOI: [10.4271/2011-01-0173](https://doi.org/10.4271/2011-01-0173).



ZONES OF INTEREST



Gaylard, Kirwan & Lockerby (2017). Surface contamination of cars: A review. *Proc. Inst. Mech. Eng. D: J. Automob. Eng.*, 231(9):1160-1176.  
 DOI: [10.1177/0954407017695141](https://doi.org/10.1177/0954407017695141)

## WHAT ARE THE CONTAMINANTS OF INTEREST?

“Any substance .. if it is foreign to a particular vehicle surface and degrades the vision of drivers, the visibility of vehicles, system performance or aesthetic appeal.”

### Natural

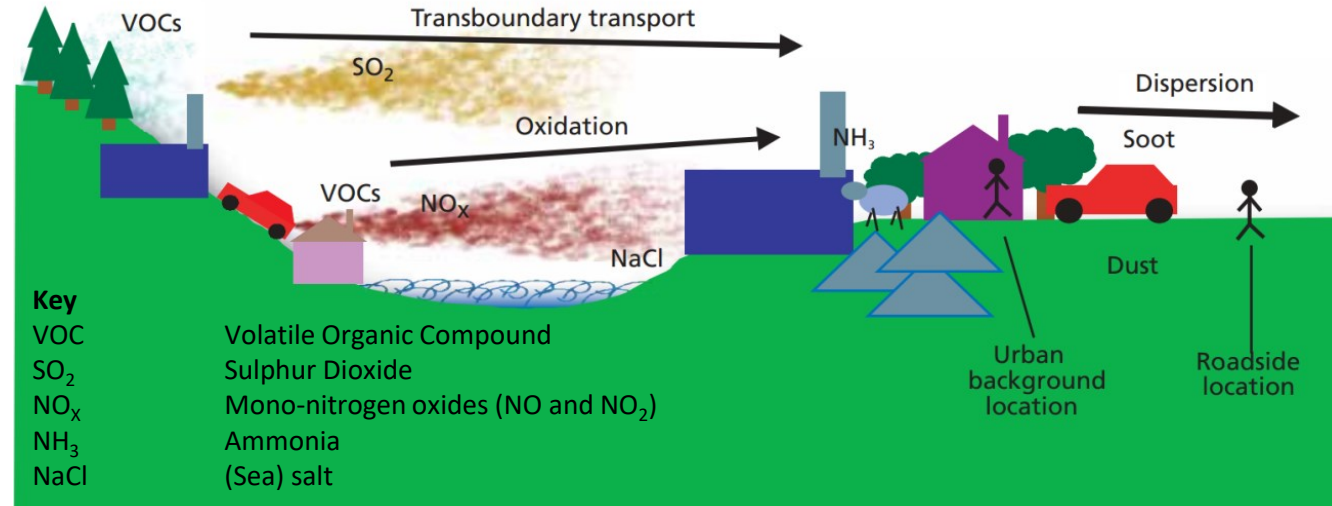
environmental water, with rain the primary source, natural soil, ocean salt, desert sand and biogenic material.

### Man Made

carbon (diesel combustion)  
 components of fuels and motor oils  
 Brake and tyre wear debris  
 Abraded road surface  
 De-icing salt and grit

### From the Car

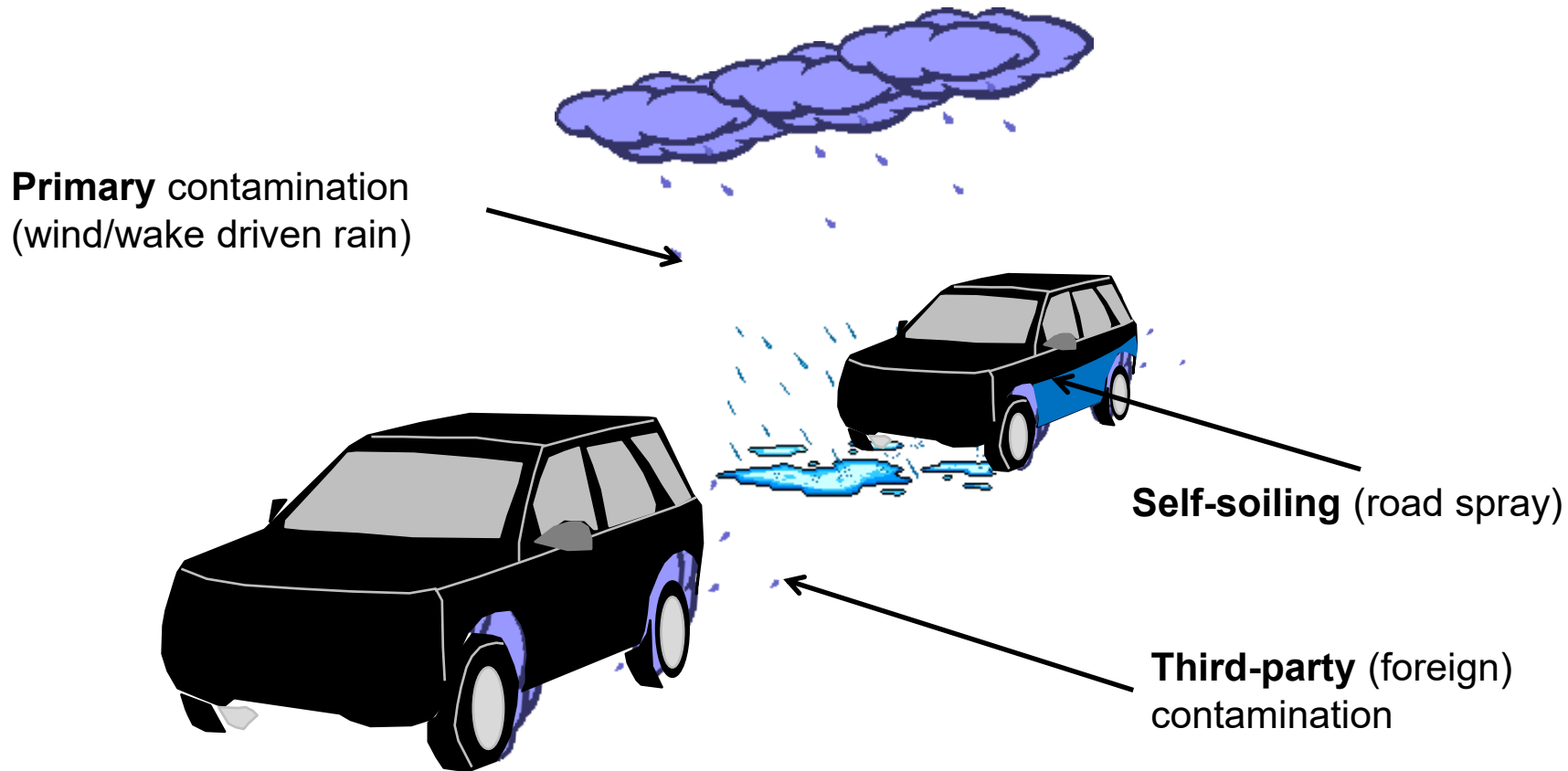
Water mixed with cleaning agents  
 brake dust  
 soot from diesel engine exhausts



AQEG (2005). Particulate matter in the UK: Summary. London: Defra.

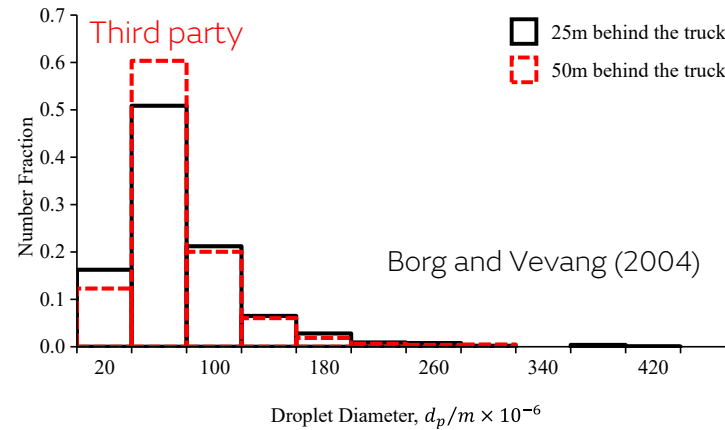
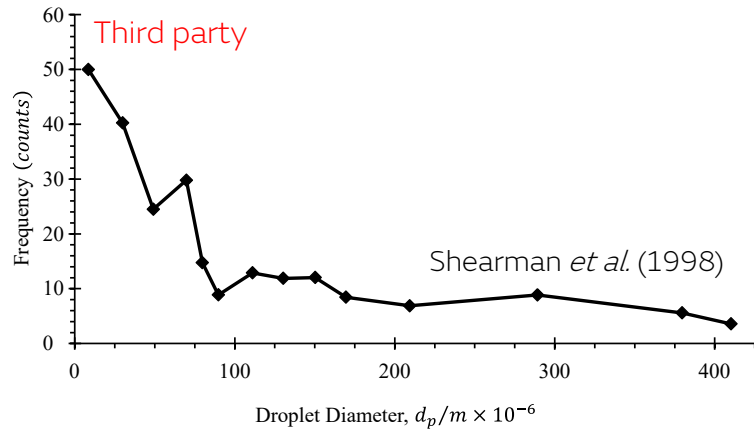
Gaylard, Kirwan & Lockerby (2017). Surface contamination of cars: A review. *Proc. Inst. Mech. Eng. D: J. Automob. Eng.*, 231(9):1160-1176.  
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### SOILING CATEGORISATION BY SOURCE



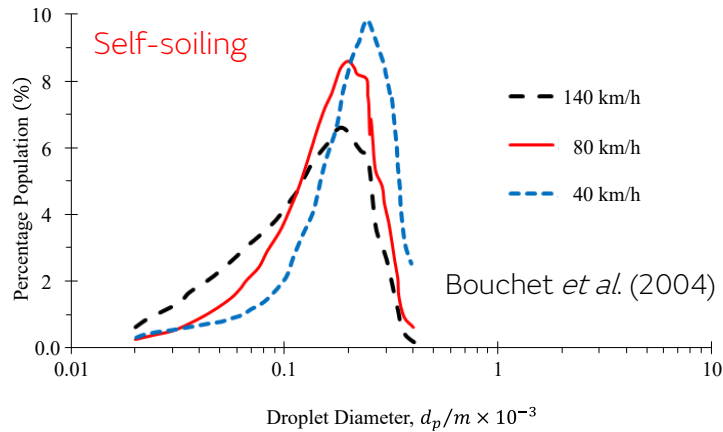
Hagemeier, Hartmann & Thevenin (2011). Practice of vehicle soiling investigations: a review. *Int J Multiphase Flow*, 37(8): 860–875.  
DOI: [10.1016/j.ijmultiphaseflow.2011.05.002](https://doi.org/10.1016/j.ijmultiphaseflow.2011.05.002)

## TYRE SPRAY DROPLET DIAMETER DISTRIBUTIONS



$$\bar{d} = \sum_{i=1}^j n_i d_i / N$$

Borg and Vevang (2004)  $\bar{d} = (75 \pm 10) \times 10^{-6} \text{ m}$   
 Shearman *et al.* (1998)  $\bar{d} = 87 \times 10^{-6} \text{ m}$



Gaylard, Kirwan & Lockerby (2017). Surface contamination of cars: A review. *Proc. Inst. Mech. Eng. D: J. Automob. Eng.*, **231**(9):1160-1176.  
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# APPLICATIONS

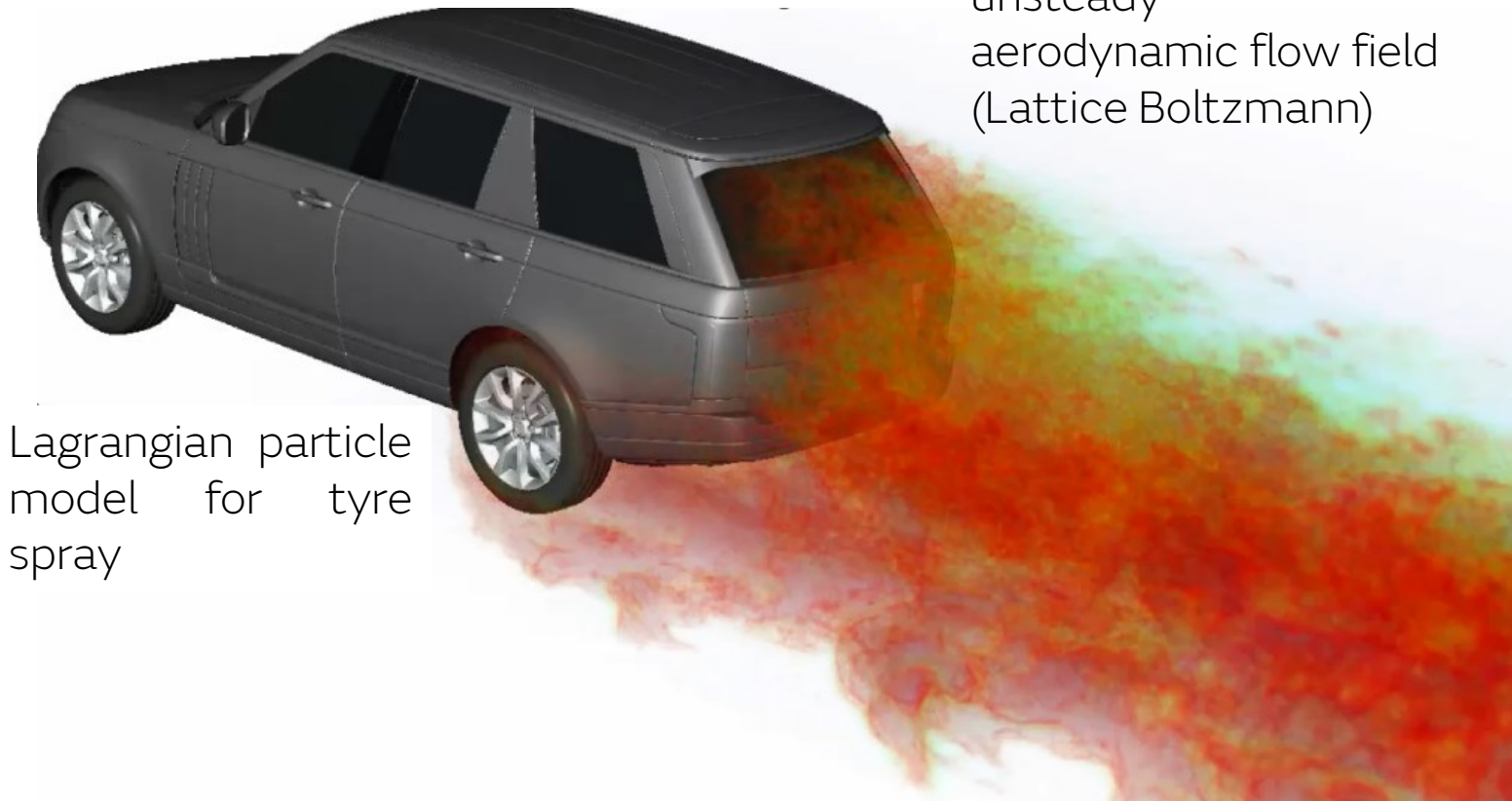
Rear Soiling, Brake Dust, Water Management



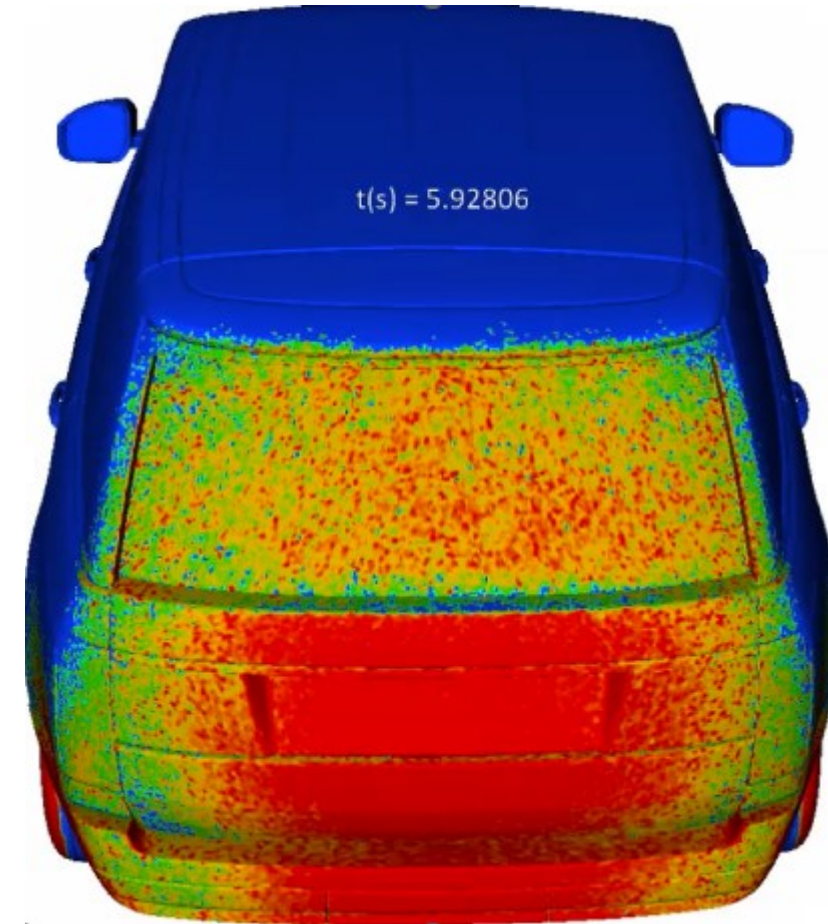
### REAR SOILING

Scale resolved  
unsteady  
aerodynamic flow field  
(Lattice Boltzmann)

Thin film solver to capture deposition

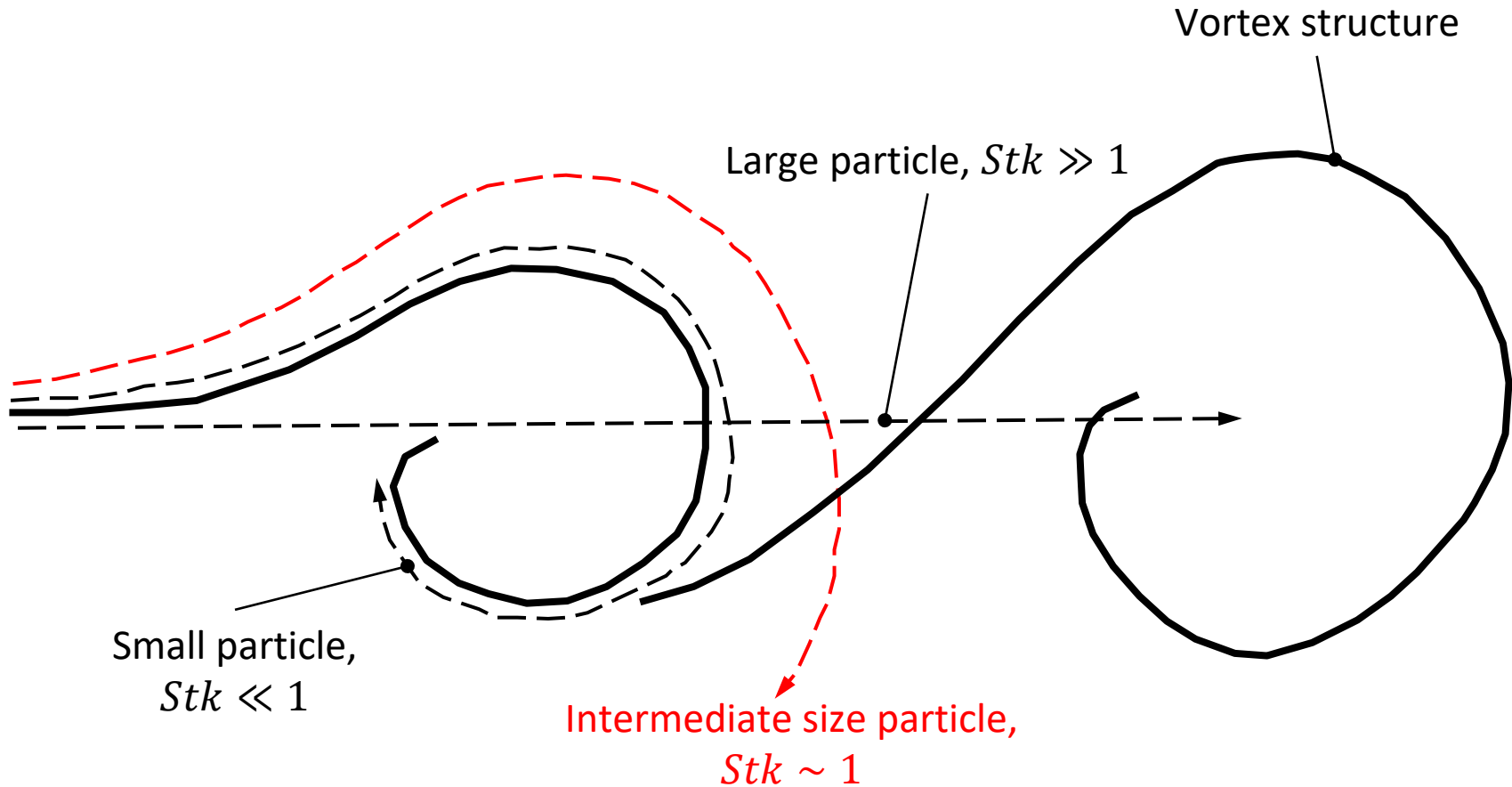


Lagrangian particle  
model for tyre  
spray



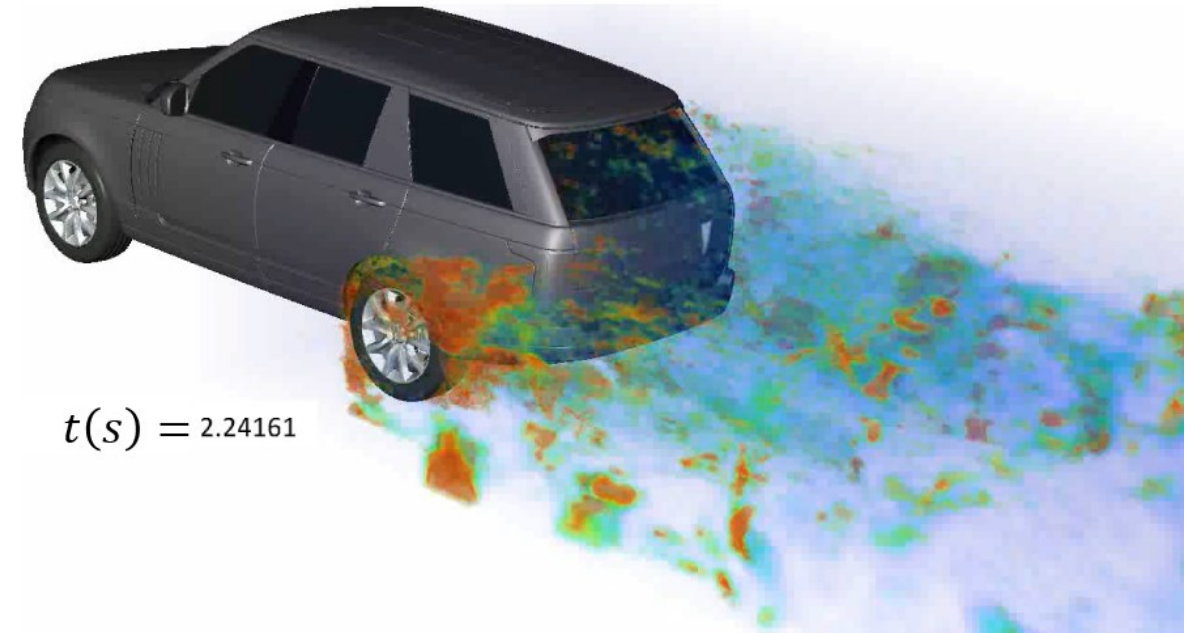
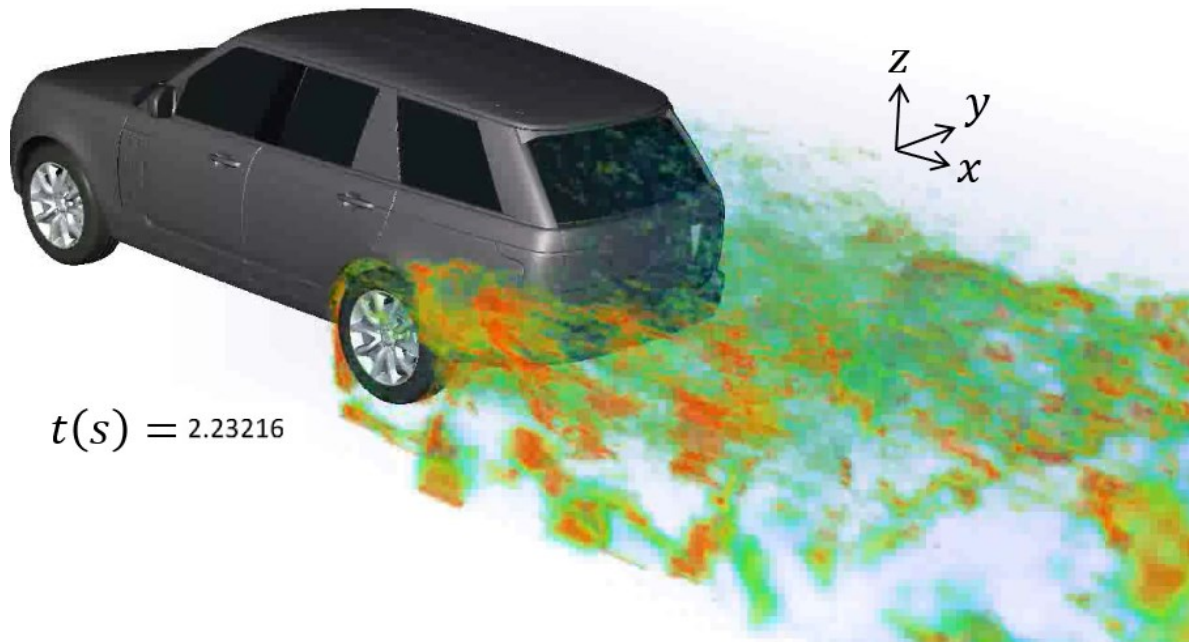
Gaylard (2019) Vehicle surface contamination, unsteady flow and aerodynamic drag. EngD Thesis, University of Warwick.  
<https://webcat.warwick.ac.uk/record=b3473824~S15>

REAR SOILING

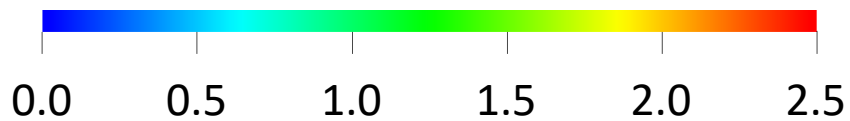


Crowe, Chung & Troutt (1988). Particle Mixing In Free Shear Flows. *Prog. Energy Combust. Sci.*, **14**: 171-194.

REAR SOILING



Stokes number,  $Stk$

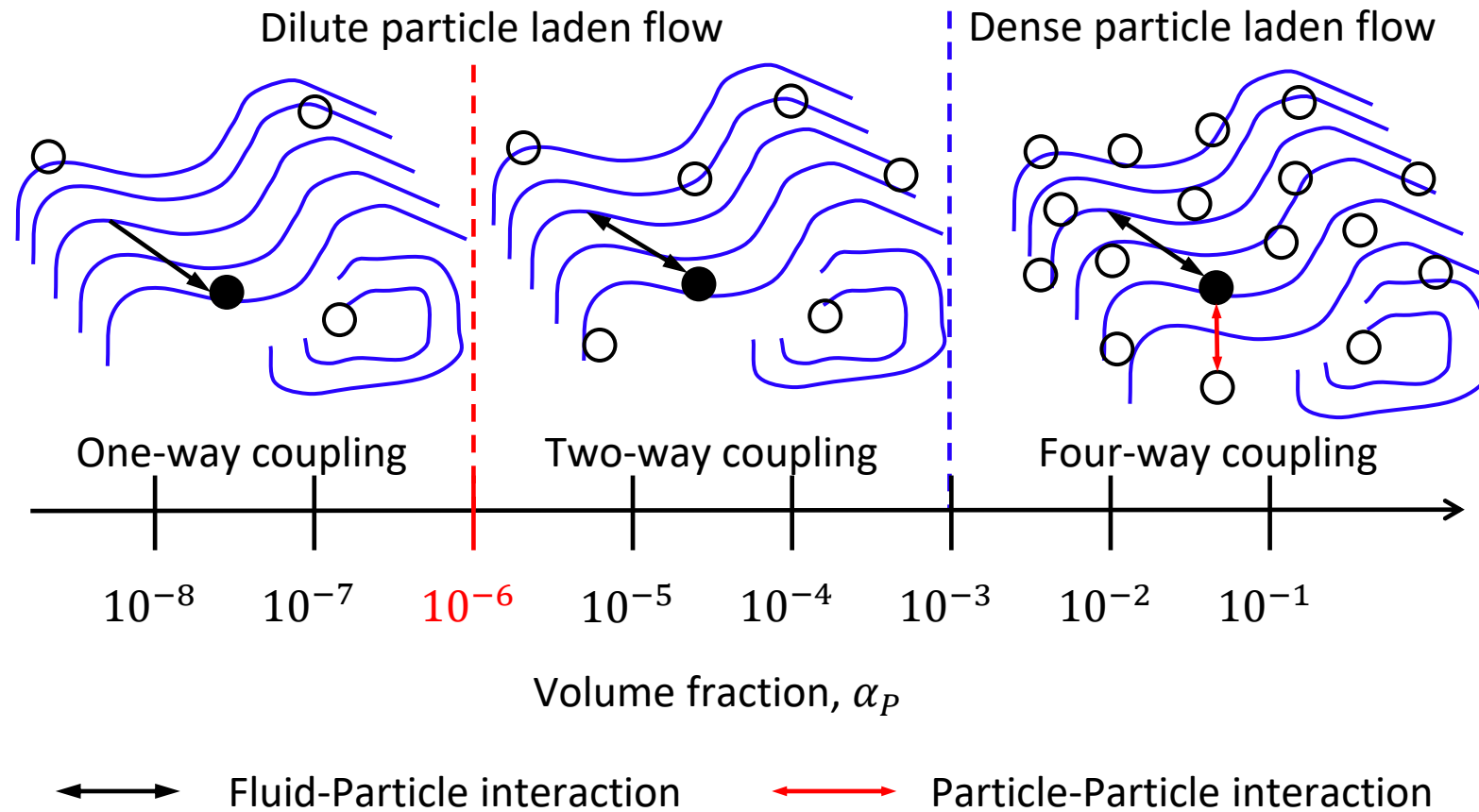


Weber number,  $We$



Gaylard (2019) Vehicle surface contamination, unsteady flow and aerodynamic drag. EngD Thesis, University of Warwick.  
<https://webcat.warwick.ac.uk/record=b3473824~S15>

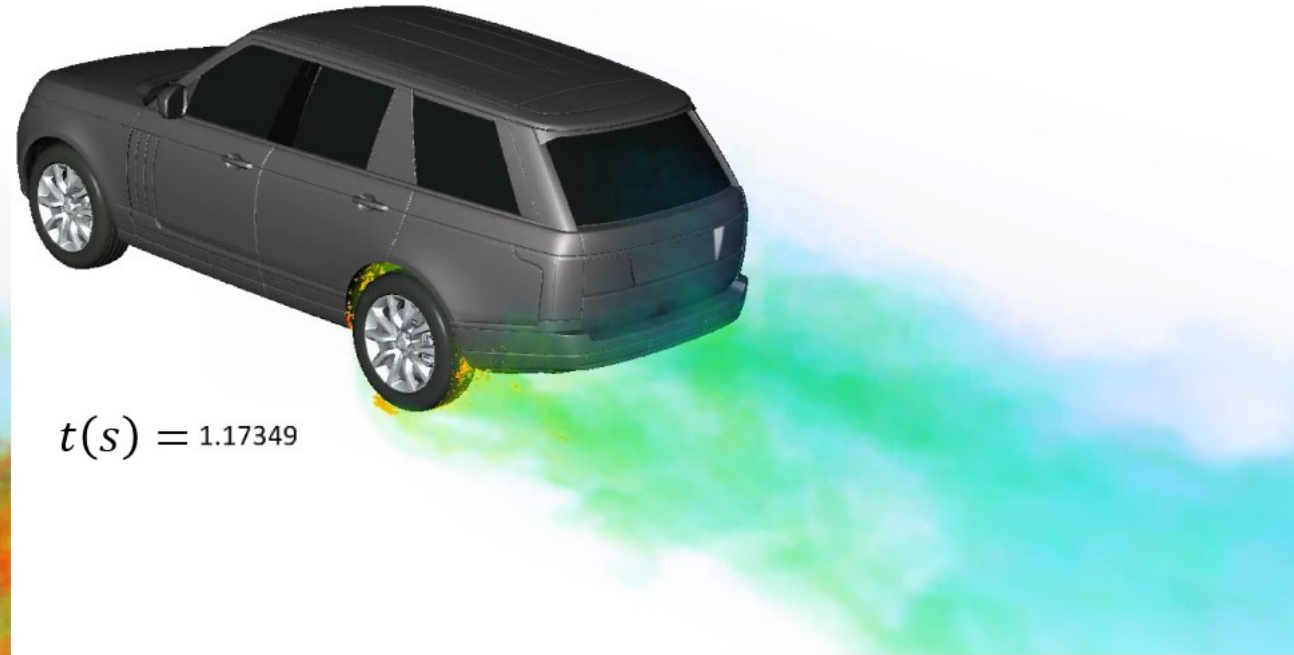
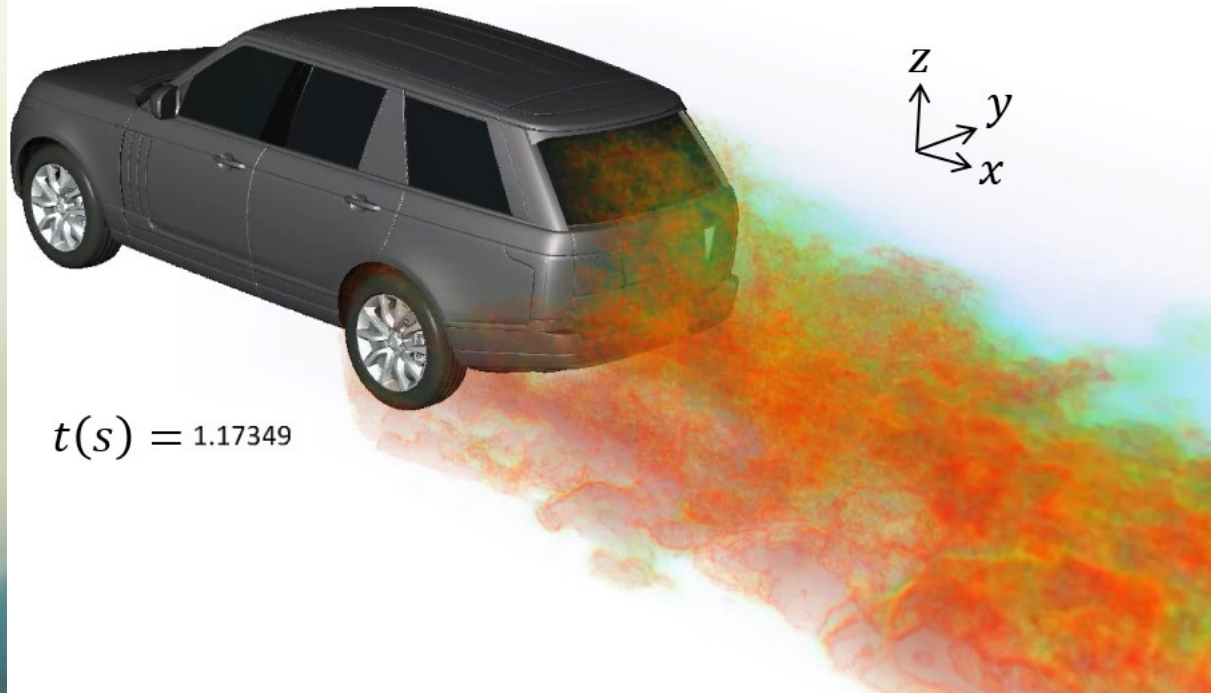
**REAR SOILING**



Hagemeier, Hartmann & Thevenin (2011). Practice of vehicle soiling investigations: a review. *Int J Multiphase Flow*, 37(8): 860–875.  
 DOI: [10.1016/j.ijmultiphaseflow.2011.05.002](https://doi.org/10.1016/j.ijmultiphaseflow.2011.05.002)



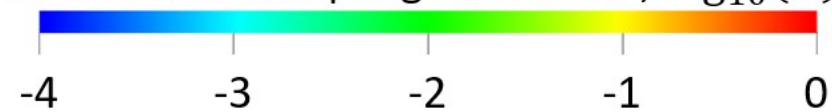
REAR SOILING



Fluid volume ratio,  $FVR / (1 \times 10^{-6})$



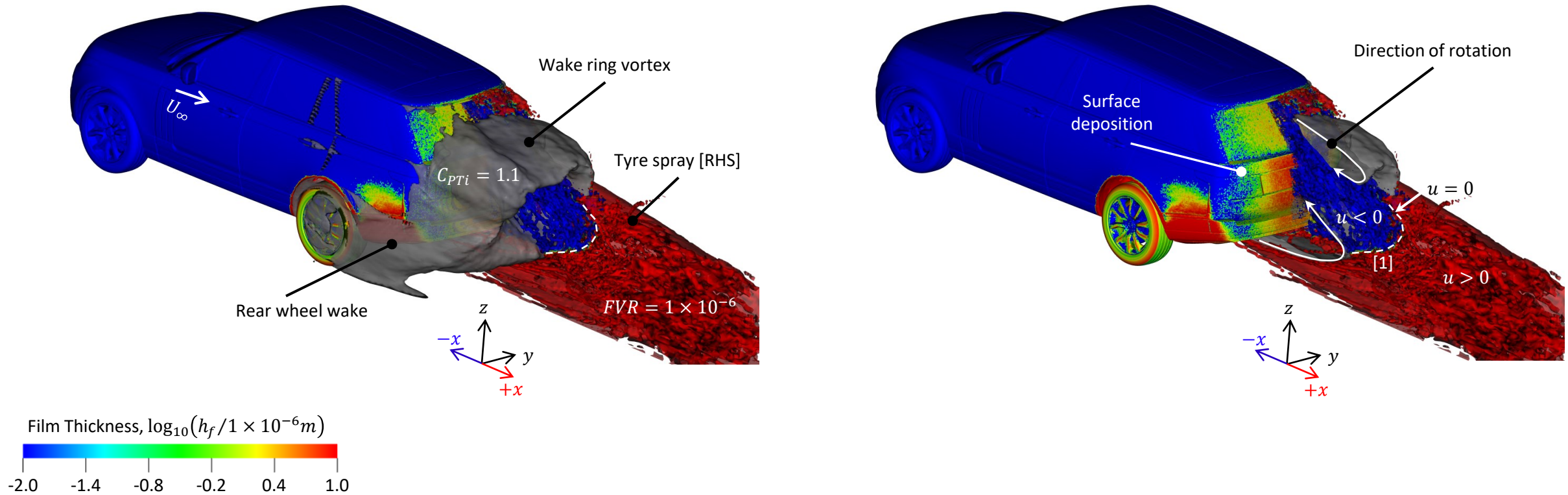
Momentum Coupling Parameter,  $\log_{10}(\Pi)$



Gaylard (2019) Vehicle surface contamination, unsteady flow and aerodynamic drag. EngD Thesis, University of Warwick.

<https://webcat.warwick.ac.uk/record=b3473824~S15>

REAR SOILING: MECHANISM



Gaylard (2019) Vehicle surface contamination, unsteady flow and aerodynamic drag. EngD Thesis, University of Warwick.

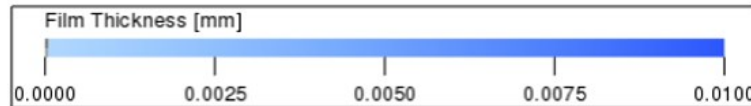
<https://webcat.warwick.ac.uk/record=b3473824~S15>

### WATER MANAGEMENT: WIPER DRAWBACK & A POST OVERFLOW

8.5 mm/hr



17.5 mm/hr

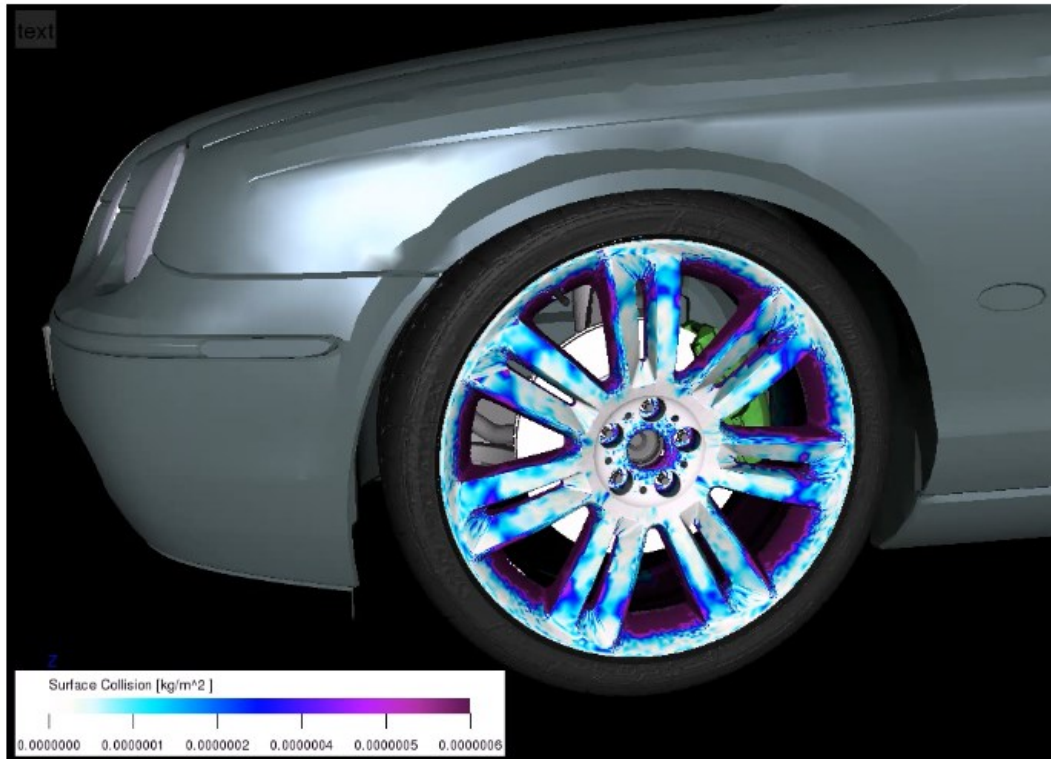


Jilesen, Gaylard & Linden (2019) Numerical Investigation of Wiper Drawback. SAE Technical Paper 2019-01-0640, DOI: [10.4271/2019-01-0640](https://doi.org/10.4271/2019-01-0640).

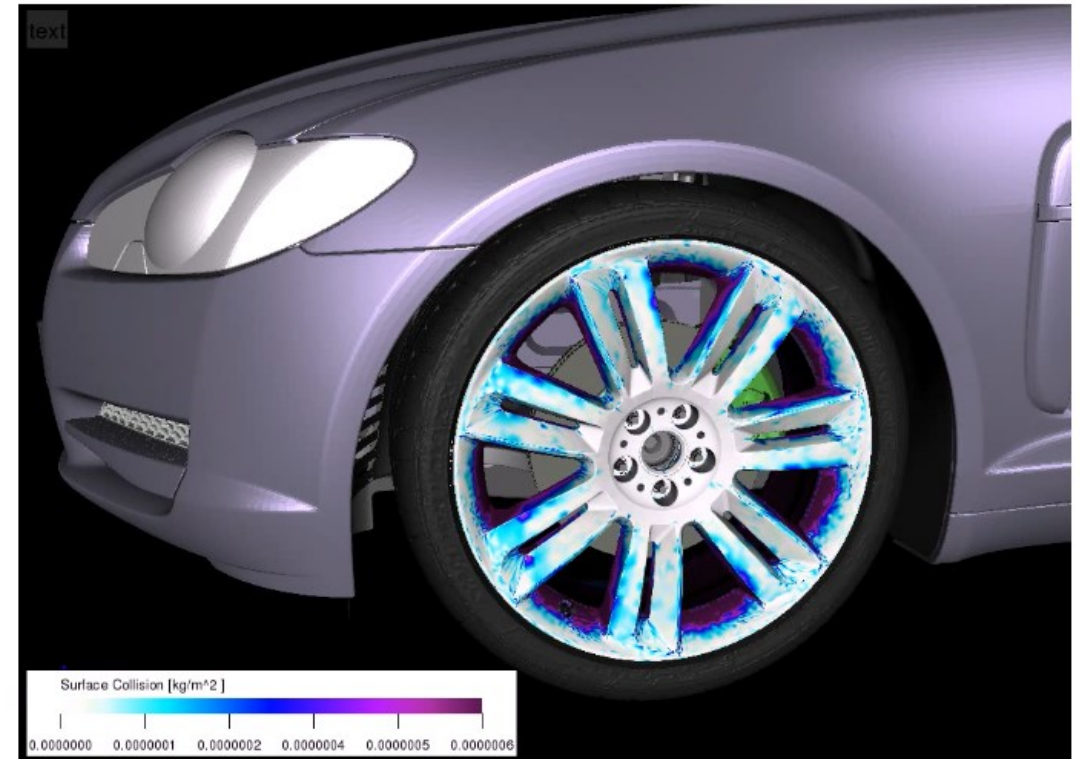


**BRAKE DUST**

Jaguar S Type



Jaguar XF



Gaylard et al. (2010). The Simulation of Brake Dust Deposition. In: 8th MIRA International Conference on Vehicle Aerodynamics, 13-14 October 2010, Nuneaton: MIRA Ltd.



# REFLECTIONS

Limitations & Prospects

## LIMITATIONS & PROSPECTS

Cars are both a source and collector of environmental droplets and particulates

Some of the many interactions with vehicles can be simulated

- Techniques in use across the industry include LB, DES for airflow
- Approaches to contaminant representation include Lagrangian Particle Modelling, VoF (including Coupled Level Set), SPH and Thin Film modelling.
- Availability of GPU solutions making the simulations more affordable

Industry interest is being driven by ADAS/autonomy

- Sensor performance prediction is the next step
- Spray test facility recently funded at Loughborough as part of the recent investment by UKRI on the National Wind Tunnel Facility ([nwtf.ac.uk](http://nwtf.ac.uk))

Still much to do ...

- Tyre sprays are largely modelled, rather than simulated
- Tyre modelling for aerodynamic simulation involves significant approximations
- Water widely used as a surrogate both experimentally and computationally
- No full scale moving-ground facilities exist for soiling
- Interaction with and impact on sensors (Cameras, LIDAR, RADAR) largely unexplored

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