Particle-surface adhesive forces and their role in resuspension phenomena

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What is Resuspension?

Resuspension is when particles that are initially on the ground become entrained into the air flow

- A significant source of aerosol particles encountered on a daily basis can be attributed to this process, which poses a substantial health risk.
- Highly relevant and applicable across a range of disciplines:

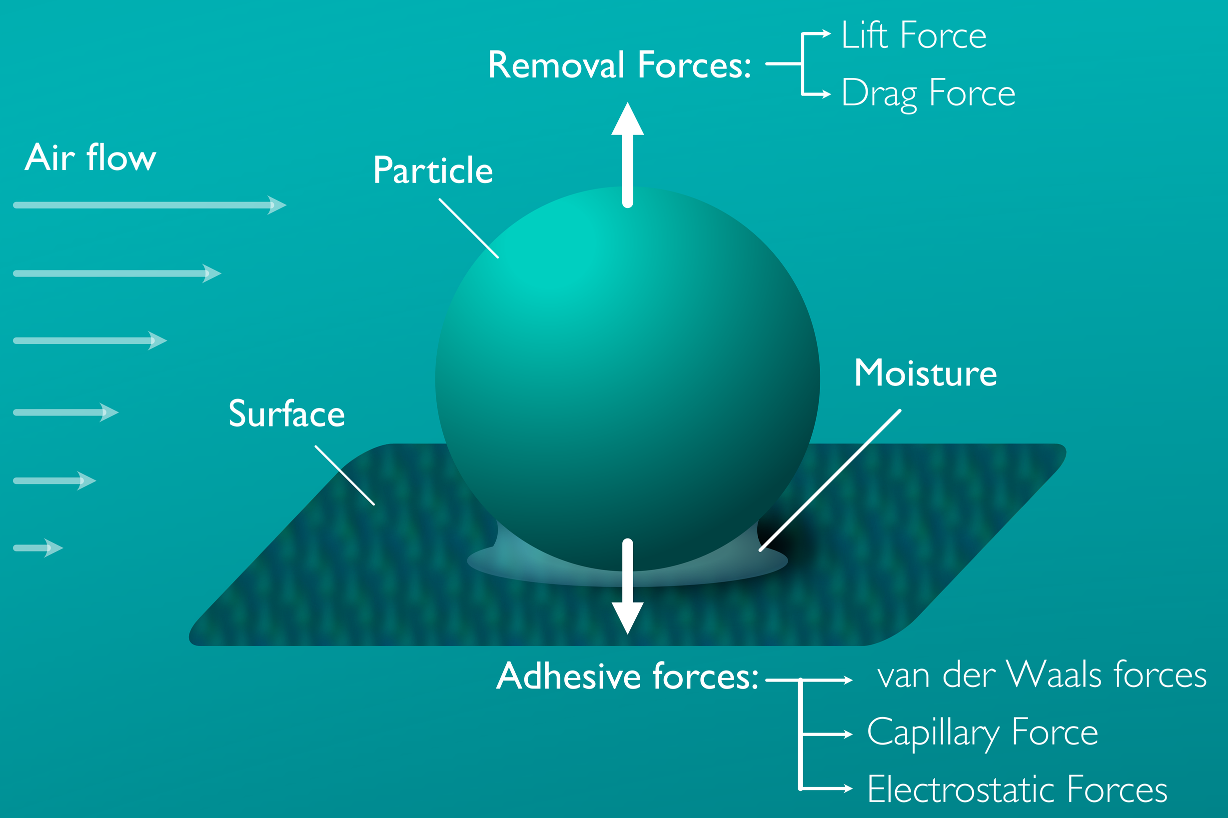
Biological	Chemical	Agricultural	Industrial	Nuclear
(eg. Virus droplets, pollen, spores)	*(eg. smoke, soot, fumes)*	*(eg. Pesticide spray, soil dust)*	*(eg. Metal, floor dust, pollen, spores)*	*(eg. Radioactive waste from power plants)*

- There are many factors influence resuspension, including (but not limited to):

Particle Morphology · Surface Material · Concentration · Wind Velocity · Temperature · Relative Humidity

Resuspension Theory

Whether resuspension of a particle happens depends on the balance forces:



Forces of adhesion are currently not well understood, with current models only applying in highly idealised cases. Capillary force equations have been shown to be inaccurate above 60% RH.

Rock 'n' Roll Model:

Proposed by Reeks *et al* in 1988 [1], the Rock 'n' Roll model offers a promising model for predicting the resuspension for a given set of input parameters.

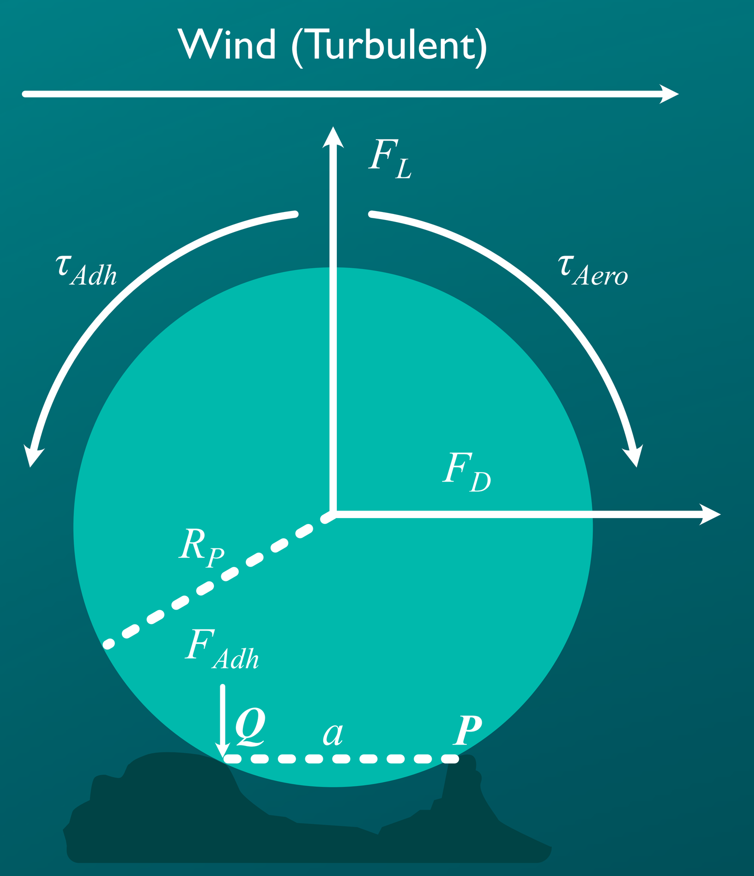


Figure 1 (Adapted from [3]): Schematic for a single particle in the Rock 'n' Roll model. A particle of radius R_P rests on 2 asperities separated by distance a, and the forces of adhesion are assumed to act at point Q. Torque imbalance arises about the pivot point P.

- It considers three forces - adhesion (F_{Adh}), lift (F_L) and drag (F_D).
- The lift and drag forces cause oscillatory motion about point P, providing the torque needed for the particle to either "rock" (oscillate) or "roll" over.
- Implemented by Biasi *et al* in 2001 [2] with a primary rate equation with constant p:

$$\frac{dN_R}{dt} = -p(F_A)N_R$$

- The macroscopic resuspension rate was solved numerically by integrating over time:

$$N_R(t) = \int_0^\infty \varphi(F'_A)e^{-p(F'_A)t}\,dF'_A$$

Limitations

The Rock 'n' Roll model in its current form includes many assumptions that limit the current predictive capability. These include (but are not limited to):

Particles are spherical and homogeneous; surfaces are smooth; only 2 or 3 asperities; log-normal force distribution, $\varphi(F'_A)$; over the surface; particles reside in a monolayer.

It's these assumptions the project aims to address using a variety of techniques.

Project Objective

The main objective of this project is to increase the accuracy of the model for resuspension, capturing a greater variety of realistic resuspension scenarios.

This can be broken down into 4 stages:

1. Produce a range of surfaces with increasingly complex chemistry and topology that mimic realistic surfaces
2. Measure adhesive force distributions between particles and these surfaces using Atomic Force Microscopy
3. Implement the Rock 'n' Roll model using empirical force data, thereby reducing the number of assumptions
4. Validate the Rock 'n' Roll model experimentally using a wind tunnel

The project aims to sequentially carry out these four stages and iterate the process, modifying one variable per iteration.

Methodology

Atomic Force Microscopy (AFM):

- Instead of incorporating an assumed force distribution into the model, the adhesive force distribution across surfaces and particles will be directly measured using colloidal probe Atomic Force Microscopy (AFM).

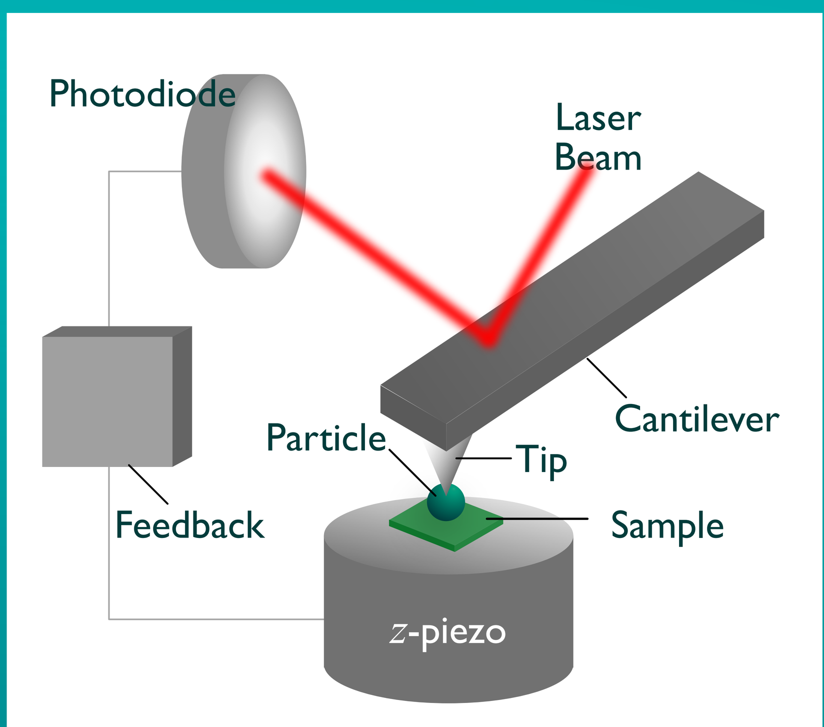


Figure 2 (Adapted from [4]): Schematic of a colloidal prove atomic force microscope.

- AFM uses a tip on the end of a cantilever to measure the force distribution across a surface.
- The cantilever will vertically deflect in accordance with the force applied [4]:

$$F = -kz \qquad k = \frac{3EI}{L^3}$$

- Particle will be securely adhered to the end of a cantilever.
- Particles chosen will have a known morphology such as salt, sugar and sand granules.

Custom 3D Printed Surfaces:

- The project will aim to print surface substrates with controlled topology, morphology, hydrophobicity, and surface energy, aimed at mimicking realistic surfaces.
- Surfaces to be modelled using 3D software such as Blender®.
- Complex techniques such as nano-lithography to be employed for even finer control.

Wind Tunnel:

Recent work by Vincent *et al* (2019) [3] at DSTL, has given shown promising validation of the Rock 'n' Roll model.

- Involved a wind tunnel experiment involving glass beads in a monolayer and carefully controlling environmental conditions.
- The model and experiments generally agree for low RH, although the trend line is imprecise, especially for large RH.
- This project aims to take this work further by using a similar wind tunnel at the University of Bristol. Force data from the AFM used in the Rock 'n' Roll model can be directly compared against.

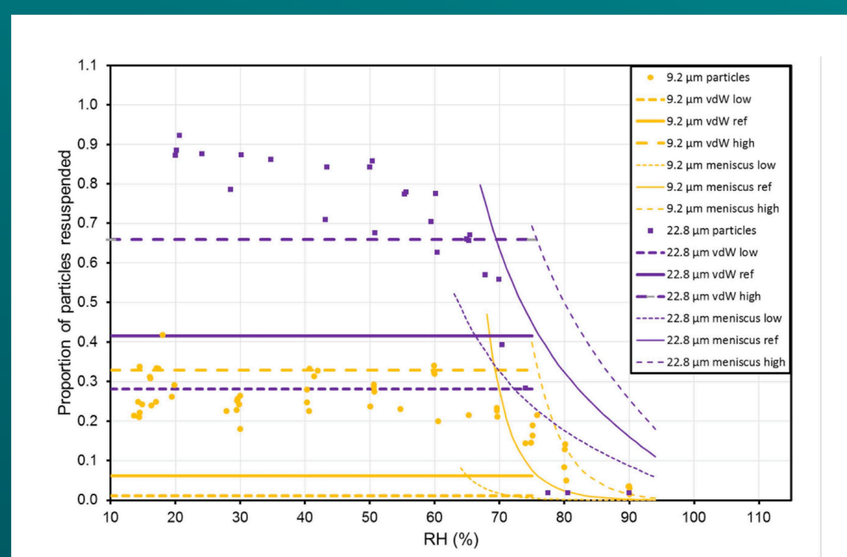


Figure 3 (From [3]): Plot of resuspension amount against relative humidity for 2 particle sizes. Curves represent the Rock 'n' Roll model, whereas points represent wind tunnel experiment results.

Responsible Innovation

Due to the project's close ties with a variety of different fields such as industry, agriculture, healthcare, etc., it's important that research into resuspension is brought into the wider context.

Accuracy	Ethics	Policy	Innovation
• Research findings must be accurate, reproducible, and reliable. • Clarity of communication to ensure findings aren't misinterpreted.	• Ties to industries, all of which have a vast potential on human health. • Objective is to improve human health through mitigating risk	• Potential for results to be implemented within an industrial setting as part of a protocol. • Results must therefore be heavily validated.	• Potential for novel technologies including surface coatings and filtration systems • Remote sensing technologies, assisted by novel technologies such as AI

References

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2. Biasi, L., De Los Reyes, A., Reeks, M.W. and De Santi, G.F., 2001. Use of a simple model for the interpretation of experimental data on particle resuspension in turbulent flows. Journal of aerosol science, 32(10), pp.1175-1200.
3. Vincent, J.C., Hill, J., Walker, M.D., Smith, S.A., Smith, S.E. and Cant, N.E., 2019. Towards a predictive capability for the resuspension of particles through extension and experimental validation of the Biasi implementation of the "Rock'n'Roll" model. Journal of Aerosol Science, 137, p.105435.
4. Piontek, M.C. and Roos, W.H., 2018. Atomic force microscopy: an introduction. Single molecule analysis: Methods and protocols, pp.243-258.