

Tutorial

Multiphase flows with particles for health applications

ORGANIZER



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ABSTRACT:

The Tutorial on multiphase flows with particles for health applications is based on a series of recent peer-reviewed journal publications and conference contributions addressing advanced numerical modeling of particle-laden flows, with particular emphasis on respiratory applications and biologically relevant particles. The presented work builds upon systematic extensions of the classical point-particle tracking framework toward more realistic non-spherical, inhomogeneous, colliding, and deformable (soft) particles.

Humans inhale more than 100 million airborne particles daily, including possibly mold spores, silica dust, volcanic ash, asbestos fibers, exhaust residues, and pollen, many of which pose serious health risks. Public health concerns related to inhaled particles have long been recognized, from cigarette smoke and asbestos exposure to microplastics and infectious aerosols. At the same time, inhaled drug particles are used in medical therapies, for example to treat respiratory diseases, where controlled deposition is crucial for treatment efficiency. While aerosols are commonly modeled as spherical, most real-world particles (whether harmful or therapeutic) exhibit complex, non-spherical shapes and may even be deformable, making their motion and deposition significantly more complex.

Traditionally, numerical simulations assume rigid, homogeneous, spherical particles and simplified collision physics. Although computationally efficient, such assumptions limit predictive accuracy in realistic health-related scenarios. The purpose of this Tutorial is therefore to provide a structured and accessible overview of advanced particle modeling strategies that go beyond the classical spherical paradigm, while avoiding unnecessary mathematical formalism.

The purpose of this Tutorial is to offer an accessible guide to modern particle modeling approaches, focusing on conceptual clarity and practical relevance rather than detailed mathematical derivations. The Tutorial keeps a coherent structure addressing the governing equations of particle motion, limitations of spherical models, and systematic extensions toward superellipsoidal rigid particles, inhomogeneous particles, advanced collision models and soft particles. Special attention is devoted to orientation dynamics, shape-dependent forces and torques, and the development of a collision model for non-spherical particles. A central part of the Tutorial concerns the extension of the point-particle framework to soft (deformable) particles via a pseudo-rigid-body approach based on affine deformations.

Real-world scenarios pertain to particle transport and deposition in the human nose and lungs, including simulations of non-spherical asbestos-like fibers, irregular microplastic fragments, and deformable particles in respiratory flows. The influence of particle shape, orientation, collision physics, and deformability on deposition patterns and potential health outcomes will be illustrated through representative computational examples.

ABOUT ORGANIZER:

JANA WEDEL received her PhD in Mechanical Engineering with distinction (Dr.-Ing., grade 1.0) from the Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany, in 2025. Her doctoral research focused on the numerical modeling of micro-particles in fluid flows, with particular emphasis on the behavior of both rigid and deformable particles in dilute multiphase systems. Her work addresses fundamental and applied problems in particle-fluid interactions, including aerosol transport and deposition in realistically modeled human lungs, the dynamics of non-spherical particles such as pollen and asbestos fibers, and the deformation and motion of soft microparticles relevant for nanodrug delivery applications. She conducts collaborative research with the University of Maribor, Faculty of Mechanical Engineering, where she has recently also been appointed as a Research Assistant.

Dr. Wedel has authored and co-authored more than 22 scientific publications in the fields of multiphase flow modeling, particle dynamics, and computational fluid dynamics. Her research relies strongly on advanced numerical methods and open-source CFD tools, particularly OpenFOAM, which she has been working with since 2014. She first applied OpenFOAM during her dual study program at Schaeffler Technologies in collaboration with the Technische Hochschule Nürnberg Georg Simon Ohm, where she investigated cavitation and multiphase flows in rotating geometries relevant to engine systems.

In addition to her research activities, Dr. Wedel is actively involved in teaching and knowledge transfer. She has been teaching numerical fluid dynamics with OpenFOAM to master's students at Technische Hochschule Nürnberg since September 2020 and has provided specialized OpenFOAM training courses and consulting for industry professionals through her own initiative, Wedel Dynamics, since September 2022 in cooperation with Prof. Dr. Markus Schmidt (TH Nürnberg). Her work bridges academic research and industrial application, focusing on advanced CFD methods for complex multiphase and particle-laden flows. She is also internationally engaged through research collaborations and professional exchanges, including work in Vietnam with Schaeffler Technologies in 2017 and ongoing collaborations with the University of Maribor, involving frequent research exchanges since 2021. Her contributions have been recognized with several awards, including the second place in the Best Presentation Award at the World Congress on Computational Mechanics (WCCM) in 2022 and the Bayerischer Ingenieurinnenpreis in 2021, honoring outstanding achievements of women engineers in Bavaria.

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