

Mitteilung

Fachgruppe: Allgemeine Strömungstechnik

Predictions of Exhalation-Induced Particle Dispersion with the Improved Particle Dispersion Models

Ege Batmaz^{1, 2}, Daniel Schmeling¹, Claus Wagner^{1, 2}

¹German Aerospace Center (DLR). Institute of Aerodynamics and Flow Technology,
Bunsenstraße 10, 37073 Göttingen,

²Technical University of Ilmenau. Institute of Thermo- and Fluidynamics,
Helmholtzring 1, 98996 Ilmenau,
ege.batmaz@dlr.de

Turbulence plays a decisive role in the dispersion of particles during respiratory events such as breathing or coughing. Computational fluid dynamics (CFD) provides an efficient framework for predicting particle transport, which is useful for assessing the risk of, for example, SARS-CoV-2 transmission in aircraft cabins or train compartments. However, due to their high computational cost, direct numerical simulation (DNS) and large-eddy simulation (LES), which fully or largely resolve turbulence, are not practical. Instead, the most feasible approach is to use Reynolds-averaged Navier–Stokes (RANS) simulations with point-like (Lagrangian) particles. In this context, choosing the right particle dispersion model (PDM) is critical for accurately capturing the spread in such turbulent environments.

In our previous study [1], we introduced the limited particle–eddy interaction (LPI) model, which improves the prediction of exhalation-induced particle dispersion when applied to an exponentially smoothed DNS velocity field. In this study, we extend the application of the LPI model to a RANS simulation, evaluating its performance against the commonly used mean particle–eddy interaction time (MPI) model implemented in OpenFOAM using the DNS data from our previous study as a reference.

The steady incompressible RANS equations coupled with temperature and vapour transport equations via the Boussinesq approximation were solved in OpenFOAM using second-order central differences. Turbulence was modelled using the RNG k – ϵ model. The computational mesh comprised 4.5 million cells with a maximum size of 1.4 cm, with local refinements down to 3 mm near the pipe and room walls. Once the velocity field had converged, particles of various sizes were injected from the mouth and tracked for 5 seconds under three conditions: without a dispersion model, with the MPI model and with the LPI model using an optimal relaxation factor of 4.

As Fig. 1 shows, the RANS simulation without a dispersion model underpredicts the particle spread. In contrast, the MPI model produces erratic overdispersion for 1 μm particles. By contrast, the LPI model provides the most consistent performance for both small (1 μm) and large (32 μm) particles. For a quantitative evaluation, we examined the convex hull volumes (CHVs), which are defined as the smallest convex volume enclosing all particles. As shown in Fig. 2, the MPI model significantly overpredicts CHV for small particles, but performs well for larger ones. In contrast, the LPI model accurately reproduces dispersion for both particle sizes. These findings demonstrate that, when applied in a RANS framework, the LPI model achieves performance comparable to that of exponentially smoothed DNS velocity fields and clearly improves dispersion prediction relative to the RANS simulation with the MPI model.

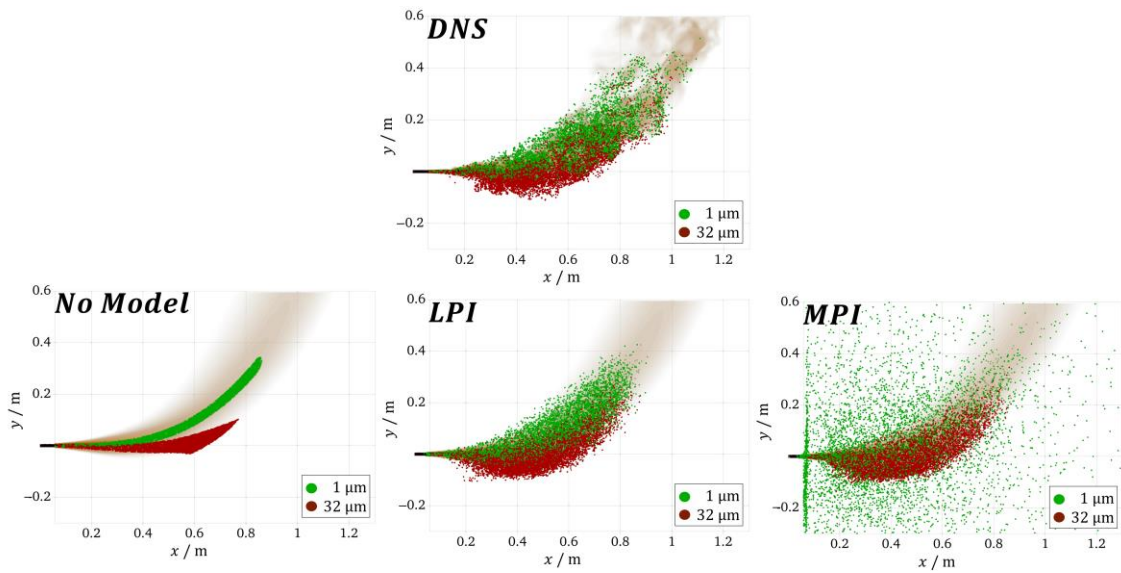


Figure 1: Predicted particle clouds 4 seconds after particle injection begins. The results for the DNS and RANS simulations are shown without a dispersion model and with the LPI and MPI models. Particle sizes of 1 and 32 μm are compared.

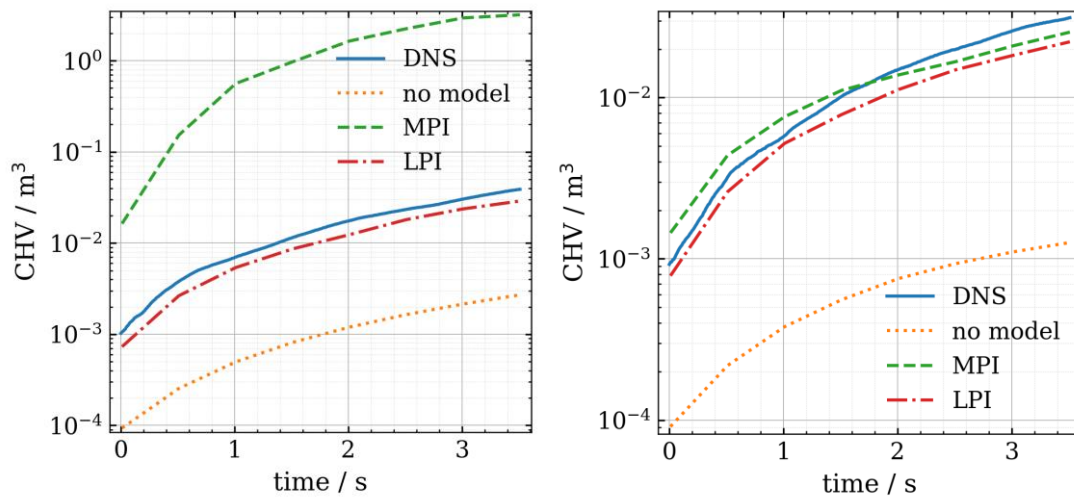


Figure 2: Convex hull volumes (CHVs) of particle clouds, as predicted by the RANS using the MPI and LPI models and without a dispersion model, are compared with DNS results. Results are shown for particle sizes of 1 μm (left) and 32 μm (right).

References

- [1] Batmaz, E., Webner, F., Schmeling, D., & Wagner, C. (2025). Improvements in Turbulent Jet Particle Dispersion Modeling and Its Validation with DNS. *Atmosphere*, 16(6).
<https://doi.org/10.3390/atmos16060637>