Mitteilung

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Particle transport predictions in a generic room: Comparison of URANS and RANS with experiments

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Since the emergence of the COVID-19 pandemic in 2019, aerosol particle transport and infection risk prediction have become of increasing interest. Computational Fluid Dynamics (CFD) offer the possibility to predict the transport of individual particles. However, there are several CFD approaches with different underlying assumptions and computational costs. The Reynolds-Averaged Navier-Stokes (RANS) approach results in a time-averaged flow field and is computationally inexpensive. In contrast, the unsteady RANS (URANS) approach provides transient results at a higher computational cost. This raises the question of which of the two is more feasible for predicting particle transport in occupied, ventilated spaces. Therefore, in this study, we compare the particle transport predictions of a RANS and a URANS approach to experimental data in a simple generic room. Thus, this is a continuation of our previous study [1], where we compared the particle transport predictions of a RANS approach to experimental data in the same room.

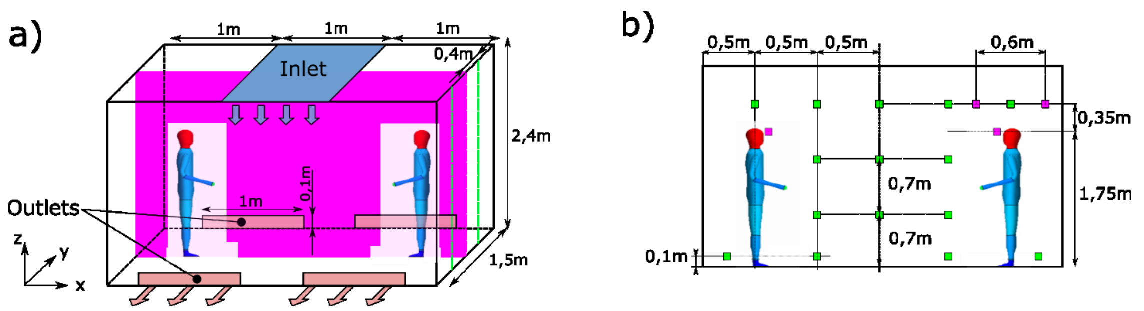

Figure 1: a) Sketch of the generic room used for the experimental and numerical investigations. b) Positions of the aerosol particle sensors on three measurement planes. Green squares indicate the positions of particle sensor on the outward planes (dashed green line in a)), purple squares additional sensor-positions on the middle plane (dashed purple line in a)).

We compare RANS, URANS, and experimental measurements in a generic cuboid room with length, width, and height of 3 m, 1.5 m, and 2.4 m, respectively. Air is supplied from the top with a volumetric flow rate of 25 l/s at a temperature of 17°C and exhausted through 4 passive outlets near the floor (see Fig. 1a). The manikins are heated with a power of 100 W to simulate body heat. A steady, particle-laden stream of 12 l/min is delivered from one of the manikins' mouths to mimic the momentum of human exhalation. To ensure a sufficient signal-to-noise ratio in the experiments, the number of particles released per second is increased to $2x10^7$ compared to 2200 particles per second in the CFD. The particle concentration in the room is measured at 47 locations with established particle sensors [2], as shown in Figure 1b). To compare the experimental and numerical results, the particle concentrations in the room are normalized to the particle concentration at the source location (the manikin's mouth). Furthermore, we evaluate the particle concentrations averaged over 200 seconds after a quasi-steady state is established.

For the CFD, the open source software package OpenFOAM is used. The mesh is refined near the walls and manikins. For both, the RANS and URANS simulations, the turbulent kinetic energy and dissipation are approximated by the k-omega SST model. The particle transport is modeled considering fluid drag, gravity, and random dispersion based on the turbulent kinetic energy. Although the flow field is steady in the RANS case, the particle transport is predicted in a transient manner. We assume that particles are deposited and removed from the domain upon first contact with a wall or manikin. For the URANS approach, the time is iterated by the implicit Euler time scheme and the time step is limited to 90 % of the Courant number. See [1] for more details on the configuration and methodology.

Figure 2 shows a scatter plot of the 47 data points with the normalized particle concentration of the experimental data $C_{n,exp}$ on the x-axis and of the CFD predictions $C_{n,CFD}$ on the y-axis: URANS predictions in blue markers and RANS predictions in orange markers. Additionally, equality is indicated by a black dashed line, meaning that for points closer to the line, the CFD predictions are in better agreement with the experimental measurements. The plot provides two insights: First, the blue markers (URANS) are clustered around the equality line, whereas the orange markers (RANS) are much more scattered, meaning that the URANS predictions are in better agreement with the experimental data. Second, the majority of the markers are within 0.4 % < $C_{n,exp}$ < 0.8 %, meaning that the particle concentration in the room does not vary much according to the experimental measurements. Only two positions show particle concentrations higher than 1 %. Therefore, with the exception of these two points (located in the exhalation jet [1]), the room can be considered as almost well mixed.

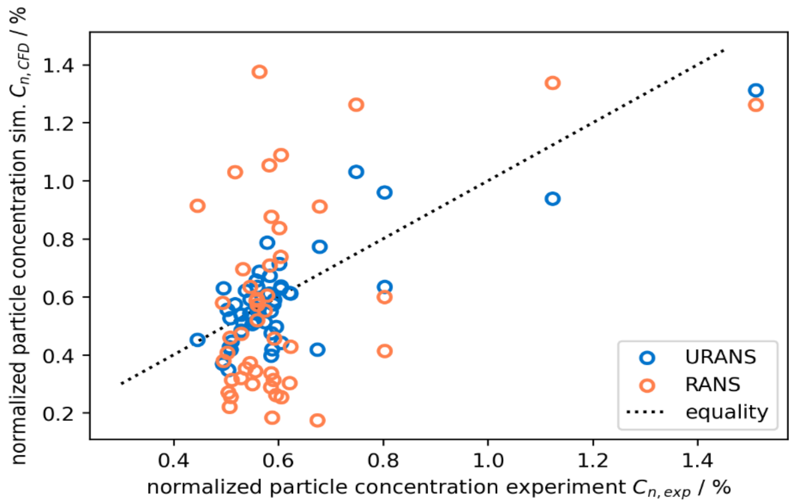

Figure 2: Comparison of the predicted particle concentration by RANS and URANS with experimental data at 47 positions.

The average absolute error of the particle concentration compared to the experimental data is almost three times higher for RANS (URANS: 0.087 %, RANS: 0.238 %). Based on the average particle concentration of all measurement points in the experiment of 0.61 %, this translates into average relative errors of 14.2 % and 39.0 % for URANS and RANS, respectively.

The results indicate that unsteady flow structures in the generic room significantly influence the particle transport. Thus, the higher computational cost of URANS allows particle transport predictions at almost three times higher accuracy (14.2 % and 39.0 % relative error for URANS and RANS, respectively). Furthermore, the results show that the considered generic room setup leads to an almost well-mixed room. This information is valuable for assessing whether a well-mixed room assumption is sufficient or whether a CFD calculation is required for future particle transport predictions.

In the full paper, we will discuss the time series of the particle concentration and the fluctuations of the particle concentration over time in RANS, URANS, and experiment.

[1] Webner et al., Aerosol Spread in a Generic Train Entrance: Comparison Between Experiment and Numerical Simulation, *Notes on Numerical Fluid Mechanics and Multidisciplinary Design*, 2024

[2] Netherland Aerospace Center (NLR) and National Institute for Public Health and the Environment (RIVM) (2021) "CORSICA final report" NLR-CR-2021-232.