Simulation of the distribution of aerosols in public transport to determine the infection risk using Model Order Reduction

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Scientific studies have confirmed repeatedly since the beginning of the Corona pandemic that the virus is transmitted mainly by air from person to person. Aerosols which are exhaled by humans play an overriding role as they can concentrate over time mainly in enclosed spaces like public transport. The risk of infection depends on a variety of factors leading to tremendous amount of simulations to explore all scenarios. It becomes consequently an ideal candidate for Model Order Reduction (MOR).

Within the BMVI-funded research project EMILIA (Development of Measures for a Pandemic Resistant Public Transport System), we investigate how contaminated aerosols spread in public transport vehicles and the associated risk of infection. As far as possible, all essential factors related to the spread of aerosols in enclosed spaces must be considered. By means of digital methods of numerical fluidity mechanics (CFD), the concentration of exhaled aerosols in different areas of the passenger compartments of selected, representative public transport vehicles (e.g. bus, tram, S-Bahn) is to be determined according to the influencing factors and for selected scenarios. The aim is to gain the widest possible knowledge of passengers' risk of infection under different conditions, which can be transferred to different public transport vehicles.

The usage scenarios to be considered should take into account, on the one hand, a different utilization of the vehicles, i.e. the number of passengers, at different times (e.g. rush hour (high), normal traffic time (medium) and low traffic time (low)) and on the other hand, seasonal temperature conditions in which the vehicles are heated, cooled or only ventilated.

For each usage scenario the dispersion of aerosols should take into account the ventilation technology used in the vehicles (air change rate, air flow), the passengers' activities (e.g. normal breathing, normal speaking, loud speaking), as well as the use of different protective masks of passengers (e.g. wearing a nose or no mouth-nose protection, filter quality).

The CFD simulation is based on the open source software OpenFOAM [1]. A special methodology developed by the ESI Group that takes physical properties such as air flow, buoyancy, heat flow, non-stationary impulses (such as breathing, coughing, speaking) into account.

In order to optimize computing time, and to enable users to get results in real-time for other (unexplored) configurations or working conditions, a reduced model will be created based on the 3D Fluid Dynamic simulations performed. Model Order Reduction techniques, aimed at reducing the computing time without affecting the solution accuracy, will be used for this.

Selected 3D simulations from Design of Experiment (DOE) will be used to train the reduced model following the Proper Generalized Decomposition (PGD) [2-6]. In comparison with other MOR techniques like POD, PGD delivers higher flexibility (enrichment, DC-PGD, integration of experimental data) and accuracy with a much lower amount of training runs (an order of magnitude lower).

The design variables for such a model (parameters of the reduced model: passengers' activities, flow rates, occupation rate, etc) will be defined based on relevant scientific questions and empirical values. The construction of such a model using ESI ADMORE App will be described, and how to make use of the reduced model will also be demonstrated.

[1] https://www.openfoam.com/

[2] *Amine Ammar, Béchir Mokdad, Francisco Chinesta, Roland Keunings (2006).* "A New Family of Solvers for Some Classes of Multidimensional Partial Differential Equations Encountered in Kinetic Theory Modeling of Complex Fluids". *Journal of Non-Newtonian Fluid Mechanics.*

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[6] *Borzacchiello, Domenico; Aguado, José V.; Chinesta, Francisco (April 2019).* "Non-intrusive Sparse Subspace Learning for Parametrized Problems". *Archives of Computational Methods in Engineering. 26 (2): 303–326.*