# Numerical simulation of the oscillatory ventilation in a simplified human lung model using OpenFOAM



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| **Daniel Feldmann**, Daniel.Feldmann@dlr.de<br>**Prof. Claus Wagner**, Claus.Wagner@dlr.de | German Aerospace Center (DLR)<br>Institute of Aerodynamics and Flow Technology<br>Bunsenstr. 10, 37073 Göttingen, Germany |




## Abstract

The high-frequency oscillation ventilation (HFOV) is a mechanical respiration technique which unlikely produces any cyclic alveolar recollapse and recruitment. Hence, HFOV was proposed to reduce ventilator associated lung injury (VALI) and might advance from being a rescue proceeding to being an accepted alternative ventilation strategy for patients suffering from acute respiratory distress syndrom (ARDS) [1, 4]. But optimising HFOV certainly requires more detailed knowledge of the governing transport mechanisms in the lung, which are rather complex and yet not fully understood [3]. Within the framework of the Protective Artificial Respiration project (PAR), supported by the German Research Foundation (DFG), we aim to analyse the air flow under the conditions of spontaneous breathing and artificial respiration.

Our initial investigations focus on steady flow simulations in a realistic three-dimensional model of the upper central airways with a computational domain consisting of about $1.4$ million tetrahedral grid cells. Using the simpleFoam solvere we obtain reasonable results. As an example, Fig. 1 shows the distribution of the velocity magnitude in several cross sections in a third generation lung at a maximum Reynolds number of $\mathrm{Re} \approx 1600$, which can be interpreted as a steady inhalation flow. Resulting from the three-dimensional bending and branching of the lung geometry, asymmetric velocity profiles are obtained in the primary bronchia downstream the carina. Furthermore, in the left bronchi a much more deformed and asymmetric velocity profile with a highly accelerated region along the inner curve of the bifurcation occurs due to flow seperation, which results in dead water regions at the inner curve. This, in turn, is due to the more bent left branch.

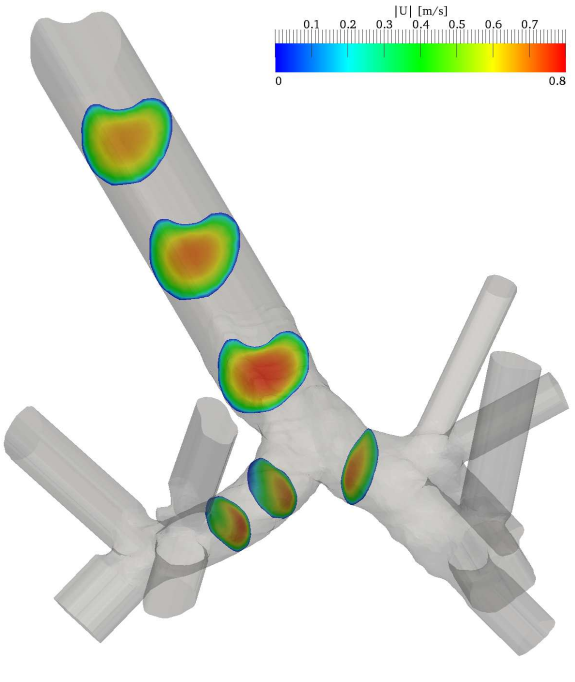


**Fig. 1:** Two dimensional colour encoded distribution of the velocity magnitude in cross sections at several positions in a PAR reference lung with straight extrusions at the outlet branches

Steady state simulations comparable to expiratory conditions at similar Reynolds numbers were also conducted and show M-shaped velocity profiles which are strongly influenced by the inlet velocities from the sub-branches.

Besides reconstructing more realistic lung grids from medical computer tomography image data [2, 4], we also perform transient simulations using the icoFoam solver. At the trachea we apply a sinoidal oscillating boundary value with a frequency of $f = 5\,\mathrm{Hz}$ and a velocity block profile to meet the conditions of HFOV as a first approach.

In our ongoing work we use OpenFOAM as a basis to develop new boundary conditions such as more complex oscillating velocity profiles and mixed inflow-outflow regions as well as physiological compliance and resistance models for the unresolved lung areas. This is essential in order to perform reliable numerical simulations of the air flow under HFOV conditions, which is characterised not only by convection but also by diffusion, Taylor dispersion, pendelluft and complex interactions between these different transport mechanisms [3, 4].



## Keywords

Bio-Fluid Dynamics, Protective Artificial Respiration (PAR), High Frequency Oscillation Ventilation (HFOV)

## References

[1] MÜLLER, T., BUDWEISER, S., MUDERS, F., SCHULZ, C., JERON, A., NEUHIERL, F., RIEGGER, G. AND PFEIFER, M., Hochfrequenzoszillationsventilation beim akuten Lungenversagen des Erwachsenen, *Deutsches Ärzteblatt 14* (2004), A928–A934.

[2] PENNECOT, J., KRENKEL, L. AND WAGNER, C., An automated reconstruction of the lungs for CFD simulations, *in European Community on Computational Methods in Applied Sciences* (Venice, Italy, 2008).

[3] PILLOW, J. J., High-frequency oscillatory ventilation: Mechanisms of gas exchange and lung mechanics, *Critical Care Medicine 33* (2005), S135–S141.

[4] SCHOLZ, A.-W. K., KRENKEL, L., TEREKHOV, M., FRIEDRICH, J., RIVOIRE, J., KÖBRICH, R., WOLF, U., KALTHOFF, D., DAVID, M., WAGNER, C. AND SCHREIBER, L. M., *Magnetic resonance imaging and computational fluid dynamics of high frequency oscillatory ventilation* (Springer, 2010).

## The authors suggest that this work is presented in one of the following sessions, in order of significance

- Bio-Fluid Dynamics
- Poster session