Mitteilung

Projektgruppe/Fachkreis: Biomedical Flows

Ansprechpartner: Daniel Feldmann, Claus Wagner

Institution: Deutsches Zentrum für Luft-und Raumfahrt
Institut für Aerodynamik und Strömungstechnik
Abteilung Fluid Systeme

Adresse: Bunsenstr. 10
37073 Göttingen

Telefon: +49(0)551 7092282
Telefax: +49(0)551 7092241
e-mail: Daniel.Feldmann@dlr.de, Claus.Wagner@dlr.de

Thema:
Numerical simulation of the oscillatory ventilation in a simplified human lung model

Ausgangssituation:
The high-frequency oscillation ventilation (HFOV) is a mechanical respiration technique which unlikely produces any cyclic alveolar recruitment. Hence, HFOV is proposed to reduce ventilator associated lung injury (VALI) and might be advanced from a rescue proceeding to an accepted alternative ventilation strategy for patients suffering from acute respiratory distress syndrome (ARDS) [1, 4]. But optimising HFOV requires more detailed knowledge of the governing transport mechanisms in the lung, which are quiet complex and not fully understood, yet [3].

Ziel:
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 conditions of spontaneous breathing and artificial respiration in the project "High-Frequency Oscillatory Ventilation: Analysis of Transport Mechanisms using Computational Fluid Dynamics and Magnetic Resonance Imaging of Gases.". Of particular interest is the understanding of the flow physics in the human body with main focus on the flows within the respiratory systems by means of numerical flow simulations. The stated objective of the protective artificial lung ventilation strategy is to achieve an improved gas exchange in the lungs while applying ventilation methods which allow for avoidance of inspiratory epithelial overstretching and repeated collapse and re-expansion of alveoli. The final aim of the project is therefore to simulate the gas transport in the upper lung and to model those effects which cannot be resolved by the numerical mesh of the lung which is the prerequisite for the simulation.

Lösungsweg:
Based on medical computer tomography (CT) imaging the geometry of the central airways is re-constructed and converted into a discretised volume mesh to allow for numerical flow simulations [2, 4]. Using the generated mesh consisting of about 1.4 million tetrahedral grid cells we first performed simulations of the steady flows during inspiration and expiration in a realistic three dimensional model of the upper central airways. By solving the incompressible Navier-Stokes directly we obtained reasonable results. After that the main focus lies now on the development of oscillating boundary conditions for multiple out- and inflow boundary conditions at the end of the branches. Results of simulations of the oscillating flow in a straight pipe agreed well with analytical solutions. Following this validation step we are also performing simulations of the oscillatory flow in the bifurcation shown in Fig.1 left. For the velocity at the trachea we applied a sinoidal oscillating boundary value with a frequency of f = 5Hz to meet the conditions of HFOV as a first approach. Currently we develop new boundary conditions to simulate more complex oscillating values and mixed inflow-outflow regions as well as physiological compliance and resistance models for the unresolved lung areas. This is essential to perform reliable numerical simulations of the air flow under condition of HFOV, which is characterised not only by convection but also amongst others by diffusion, Taylor dispersion, Pendelluft and complex interactions between these different transport mechanisms [3, 4].

Ergebnis:

In Fig. 1 (left) the predicted velocity magnitude fields in a pipe bifurcation used to test the oscillatory flow is presented. Fig. 1 (right) reflects predicted velocity distributions in several planes of a third generation lung for a maximum Reynolds number of $Re \approx 1600$, comparable to inspiration. As a consequence of 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 profiles with an accelerated flow along the inner curve of the bifurcation occurs due to flow separation and dead water regions at the outer curve. This, in turn, is due to the more bended left branch. Further, an experimental set-up has been realised allowing for investigation of fundamental transport mechanisms in the central airways as well as for validation of the numerical CFD results and for further development and adaptation of the experimental measurement techniques.

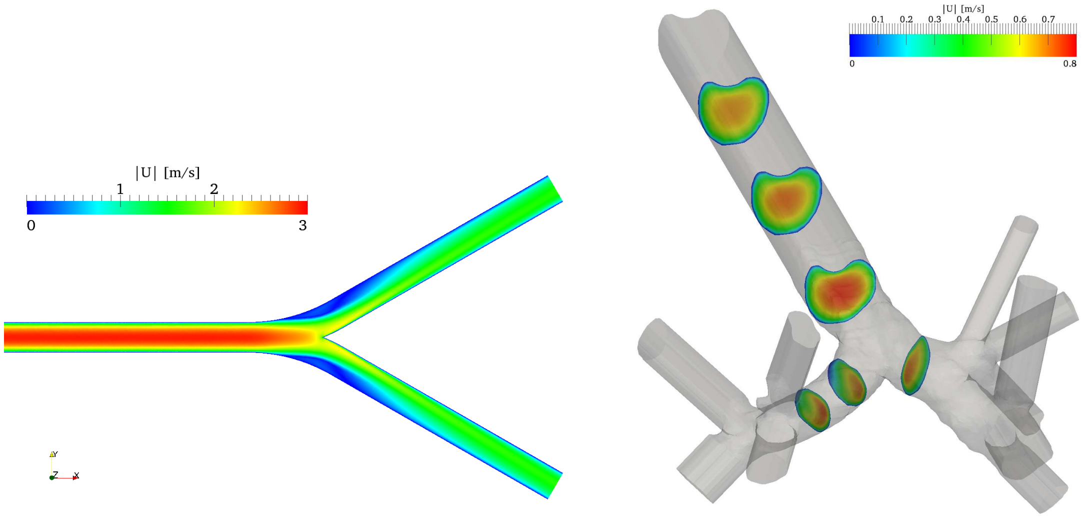

Figure 1: *Numerically predicted velocity magnitude fields in a pipe bifurcation (left) and in several planes of the central airways resolved up to the 3rd generation.*

weiteres Vorgehen:

A main task will be the development of realistic numerical boundary conditions to account for the effect of the not resolved and re-constructed inner parts of the lungs (in terms of elastance, resistance and pressure) on the flow in the central airways. For validation and comparison purposes, using a rapid prototyping procedure, an identical model of the re-constructed central airways geometry is built for further experimental investigations with non-invasive measurement techniques (i.e. Particle Image Velocimetry (PIV) and MR based velocity measurements). In a first step, numerical simulations and experimental investigations of simple generic models of the trachea and the first bifurcation are carried out. Furthermore, investigations on the effect of different gas species and their mixture on the air flow together with the effect of an endotracheal tube on the governing flow regime are undertaken.

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, chap. CHAPTER (PUBLISHER, 2010), PAGES.

Datum: 30.06.2010 **STAB**