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Large eddy simulation of the unsteady flow-field in an idealized human mouth–throat configuration

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ABSTRACT

The present study concerns the simulation and analysis of the flow field in the upper human respiratory system in order to gain an improved understanding of the complex flow field with respect to the process affecting drug delivery for medical treatment of the human air system. For this purpose, large eddy simulation (LES) is chosen because of its powerful performance in the transitional range of laminar and turbulent flow fields.

The average gas velocity in a constricted tube is compared with experimental data (Ahmed and Giddens, 1983) and numerical data from Reynolds-averaged Navier–Stokes (RANS) equations coupled with low Reynolds number (LRN) κ–ω model (Zhang and Kleinstreuer, 2003) and LRN shear–stress transport κ–ω model (Jayaraju et al., 2007), for model validation. The present study emphasizes on the instantaneous flow field, where the simulations capture different scales of secondary vortices in different flow zones including recirculation zones, the laryngeal jet zone, the mixing zone, and the wall shear layer. It is observed that the laryngeal jet tail breaks up, and the unsteady motion of laryngeal jet is coupled with the unsteady distribution of secondary vortices in the jet boundary.

The present results show that it is essential to study the unsteady flow field since it strongly affects the particle flow in the human upper respiratory system associated with drug delivery for medical treatment.

1. Introduction

Aerosol particle deposition of therapeutic agents constitutes an essential tool in current treatment of asthma and other lung diseases. The advantage of pulmonary drug delivery through inhalation is that it offers topical treatment of specific lung conditions while limiting the whole-body effects. The extra-thoracic region, including the nasal and oral passages, pharynx, and larynx, build the entrance to the human respiratory tract. Therapeutic aerosol particles can be directly transported via the oral airway to the lung. Aerosol particles deposition in this region has important implications in drug delivery efficiency. Therefore, it is very important to study the airflow structure and the particle transport for filtering effects in the oral airway (Zhang et al., 2002). Most of the numerical simulations in this area are carried out using one way coupling (Zhang et al., 2002; Jin et al., 2007; Jayaraju et al., 2007). An improved understanding of the unsteady flow field is important to gain an improved understanding of the process of particle transport and deposition.

One of the major challenges is the modeling of transition from laminar to turbulent (Zhang and Kleinstreuer, 2003; Luo et al., 2004). Zhang and Kleinstreuer (2003) compare turbulence models including the LRN κ–ε model and the renormalization group (RNG) κ–ε model (Zhang and Kleinstreuer, 2003), the latter accounts for the effects of smaller scales' motion. Menter's κ–ω model (Zhang and Kleinstreuer, 2003) is used to simulate the internal flow field in two different test conduits with local constriction. The LRN κ–ω model performs best for the simulation of the laminar-transitional-turbulent flow in the constricted tube (Zhang and Kleinstreuer, 2003). The LRN κ–ω model is widely used in numerical simulations of the flow field in the respiratory system (Zhang et al., 2002). The LRN shear–stress transport (SST) κ–ω model predicts the transitional flow accurately (Jayaraju et al., 2007). The RANS model is suitable for fully developed turbulence, but it may be inappropriate for particle transport in the region with complex flow such as the upper respiratory tract (Jayaraju et al., 2008). Recently, researchers have also implemented LES in the numerical simulation of particle motion in the respiratory system. Jayaraju et al. (2008) compared LES with the RANS SST κ–ω model through numerical simulation of flow field in a simplified mouth–throat model. They found that LES predicts the flow field more correctly than the RANS method when compared with experimental data. LES has also been used in other geometry models, for instance in a 17 generations model of the respiratory airways (Gemci et al., 2008) and in an upper airway based on computed tomography

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