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LES & DES study of Fluid-Particle Dynamics In Human Upper Respiratory Pathway

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ABSTRACT

Inhaled medication is generally the preferred method of drug administration to the lung for the first-line therapy of asthma and chronic obstructive pulmonary diseases. For an efficient treatment, the inhaled aerosol particles need to bypass the complex airway morphology and reach the alveolar zone of the respiratory tract where it eventually gets absorbed. The complexity of extrathoracic pathway which involves bends, sudden cross-sectional changes, branching bronchi and non-symmetry of the geometry generally results in major deposition of inhaled medication in the pathway before reaching the lungs [1, 2]. With the upper airway flow being transitional, the use of models two-equation RANS models, which are basically developed for turbulent flows may always result in poor prediction. Reviewing the previous works [2] conclude that the Reynolds Averaged Navier Stokes (RANS) as well as Reynolds Stress Model (RSM) does not capture relevant features of the flow and highlighted the need to switch towards Large Eddy Simulation (LES). To have a complete overview of available numerical methods, all the modeling methods, namely the Reynolds Averaged Navier Stokes (RANS), Detached Eddy Simulation (DES) and Large Eddy Simulation (LES) are tested in the present work. In case of RANS, the best performing SST $k-\omega$ turbulence model is employed. DES is based on Spalart-Allmaras model for the near-wall region. In case of LES, two subgrid scale models, namely the Smagorinsky-Lilly and the WALE model were tested. The particle phase is computed in truly unsteady mode, both for DES and LES. The frozen LES method proposed by [2] is also tested. All the results were compared with the experimental data to analyze their reliability.

As can be seen in Fig. 1, the LES Smagorinsky model does slightly better than the WALE model. It is also interesting to see that DES performs as good as the Smagorinsky model. The velocity magnitude along with vector lines are shown for Smagornisky model at 30 L/min. The velocity profiles are highly skewed with many recirculation zones due to the complex nature of the domain. The flow entering through mouth-piece impinges on the tongue and accelerates as it moves through the middle region of the mouth. At the end of the mouth, the flow takes a 90 degree bend and enters the pharynx region. This acceleration and bending of flow may have considerable effect on particle deposition. The vectorline

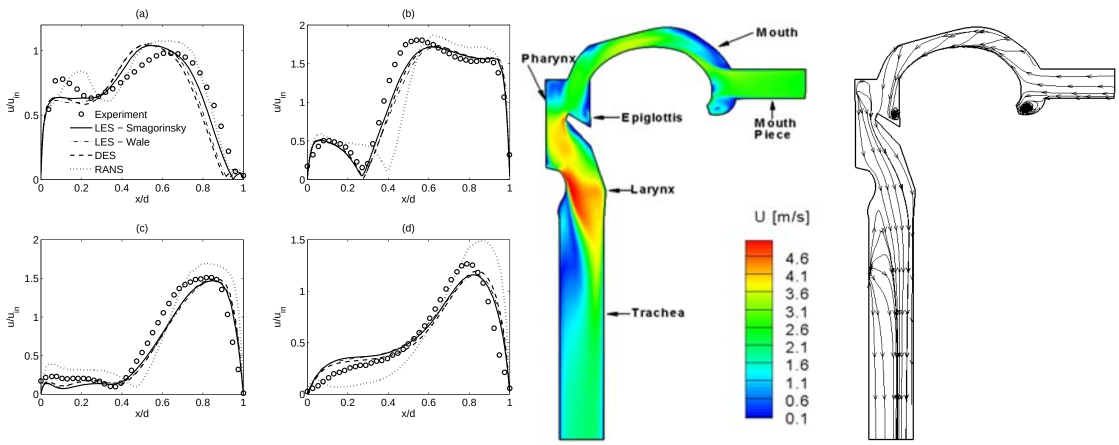

Figure 1: Left: Comparison of normalized 2 component velocity magnitude at (a) Five millimeters above epiglottis (b,c,d) One, two and three tracheal diameters downstream of larynx. Right: Velocity magnitude and vector lines in the central-sagittal plane of the model.

Table 1: Particle deposition result along with their deviation from experimental fit curve

Diameter (μm)	RANS Deposition (%)	DES Deposition (%)	LES Deposition (%)	Frozen LES Deposition (%)
2	8.39(+7.97)	2.73(+2.31)	3(+2.59)	1.73(+1.32)
4	12.95(+7.33)	6(+0.39)	4.04(-1.57)	1.97(-3.64)

representation shows recirculation regions in the epiglottis and upper part of pharynx region as a result of the oropharyngeal jet. A sharp step at the end of pharynx on the posterior side results in a laryngeal jet beginning from the glottal region and developing towards the anterior side of trachea. This jet may also dominate the particle deposition on the anterior side of trachea. As a result of laryngeal jet, there is a big flow separation on the posterior side.

With Table. 1, it is clear that both LES and DES are close to the experiments. The frozen LES method also gives promising results while the RANS completely over-estimates deposition. We can conclude that instead of opting for very expensive LES, we can settle for less expensive DES which gives promising results compared to LES. The most widely used RANS method is completely not suitable for low Stokes number particles as we have in the present work. Regional particle deposition due to flow behavior will be discussed in detail in the conference presentation.

References

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