THREE DIMENSIONAL FLOWS IN THE HUMAN UPPER AIRWAY

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INTRODUCTION

It is a significant challenge to quantify and characterise the flow features in the human upper airway. As elaborated in [1], complex flow can be highly turbulent with attendant anisotropy. Prominent flow features were observed both experimentally [2] and numerically [1]; differences between experiment and simulation are attributed to both the failings of numerical methods and the vagaries associated with 2D measurements in a 3D flow. Experimental measurement of the entire flow field using 3D Particle Image Velocimetry will enhance the knowledge previously gleaned through 3D computer simulation with the lattice Boltzmann method.

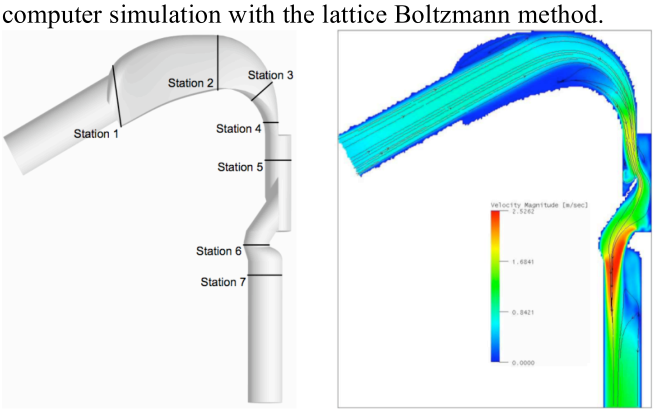

Figure 1: ETA geometry. *Left* Measurement stations. *Right* LBM velocity magnitude contours , sagittal plane.

METHODS

The Upper Airway: The idealised extra-thoracic airway (ETA) is a physiologically accurate "average" geometry of the upper airway built of simple geometric shapes, derived from computed tomography and magnetic resonance imaging scans of human subjects (figure 1, left).

Flow Conditions: A uniform steady inlet velocity profile was used in both simulation and experiment; a physiological flow rate of 10 *l/s* is used in computations. The inflexible solid boundaries, which do not replicate actual compliant mucous membranes, do not have any adverse effect on the global objective of the current study [3].

Direct Numerical Simulation (DNS): With sufficiently fine resolution, the lattice Boltzmann method was used to obtain DNS solutions to four flow cases, requiring in total over 87,000 CPU-hours of calculations (SunFire 1.2GHz UltraSPARC IV+ processors).

Particle Image Velocimetry (PIV): A three dimensional PIV system has been developed to experimentally measure the entire velocity field inside the ETA; qualitative and quantitative data are obtained to verify the fidelity of the computational findings, examples of which are shown in figures 1 and 2. The experimental work, the first ever 3D PIV results for such a complex geometry, yields data on both the mean flow and the vortical turbulent structures (by the method of proper orthogonal decomposition).

PIV Apparatus: The translucent flow passage needed for the PIV method is formed by pouring a silicone-based material (Sylgard 184 silicone elastomer) around a rapid-prototype wax-based (Castform^{TM} PS) cast of the ETA. The wax cast (melt $T < 63°C$) is flushed out with hot water, leaving an ETA replica within the clear silicone through which an index-matched ($n \approx 1.41$) sugar solution flows.

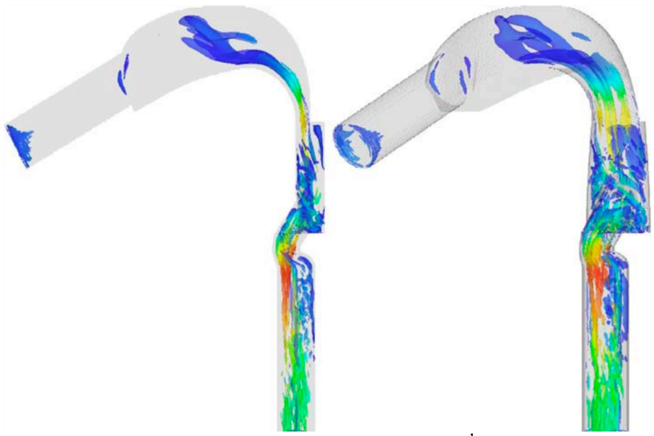

Figure 2: Iso-surface plot of Q-value (2nd invariant of the velocity gradient tensor), by velocity magnitude. *Left* sagittal view. *Right* posterolateral (45° oblique) view.

RESULTS AND DISCUSSION

As a result of computational findings, particular attention in the experimental work is directed to the para-canonical flows identified within the ETA: the curved backward facing step (of the lower teeth), the backward facing step following a bend (of the naso-oro-pharyngeal junction), and the curved leading edge (of the epiglottis).

Further investigation into the laryngeal and tracheal flow effects is well warranted. At the lowest physiological flow rates vortex shedding from the larynx and epiglottis is carried into the bifurcation of the bronchi, which has significant implications for those investigating the flow in the lower airways [4,5], and those seeking to improve delivery of inhaled drugs.

ACKNOWLEDGEMENTS

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