SURGE'24 REPORT

Simulation of Secondary Flows, Particle deposition in Healthy and Asthma/COPD affected Human Lung Airway.

Submitted by:- Anu Pal,
Mechanical Engineering department , IIT Kanpur

Mentored by:- Dr. Subrata Sarkar,
Mechanical Engineering department , IIT Kanpur

Problem Description:

Previous studies have examined the flow field in the airways of the human lung. However, most of these studies focused on the measurement of particle intake in the normal airways of the lung. Prior research has focused on studying the secondary flow patterns inside the airways of the human lung, but these investigations have been limited to examining the conditions associated with normal breathing. This study aims to understand the secondary flow patterns and particle deposition characteristics in both healthy and Asthma-affected human lung airways.

This study utilizes the geometric model developed by Y. Liu and C.H. Zhang et al to represent the normal human lung airway. The same model is modified to simulate the flow field in asthma-related human lung airway with modification in cross section features of 7th generation with **$r(\theta) = .95 + .2\cos(10\theta)$.**

Models

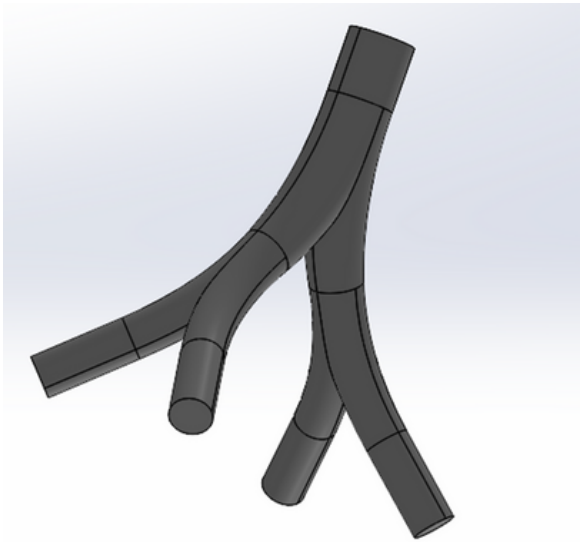


Fig.1.Healthy Airway Track

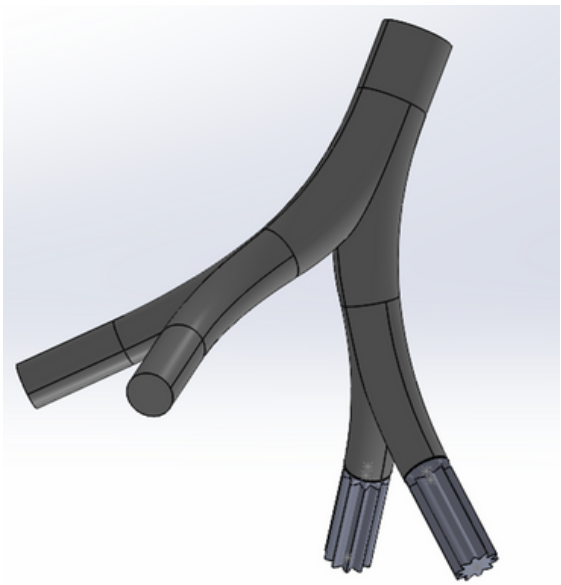


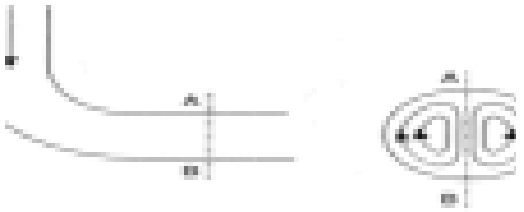
Fig.2.Unhealthy Airway Track

Abstract

The study of fluid dynamics in the airways of the human lung has been a significant and captivating area of research since the 1960s, with the creation of the most basic human lung model by Weibel . Understanding and potentially controlling the causes of diseases such as Asthma, chronic obstructive pulmonary disease (COPD) etc. has become crucial due to the increased risks of lung and nasal cancer resulting from the inhalation of harmful particles. Consequently, knowledge of these flow fields has become critical. A comprehensive understanding of these flow fields is also crucial for accurate drug targeting, particulate inhalation, and the injection of medicinal products to the human body via inhalation. This method can been widely accepted as a convenient, replicable, and harmless means of delivering drugs to both lung tissue and the systemic circulation. Hence the secondary flow Particle deposition characteristics have been simulated using a control volume method to solve the three dimensional laminar Navier-Stokes equation for an inspiratory flow. A lower three generation human lung airway extracted from fifth to seventh branches of Weibel's model is taken as the elementary computational domain. The computations are carried out to understand and compare physics of secondary flow, Particle deposition in healthy, and Asthma/(COPD) affected human lung airway.

Introduction

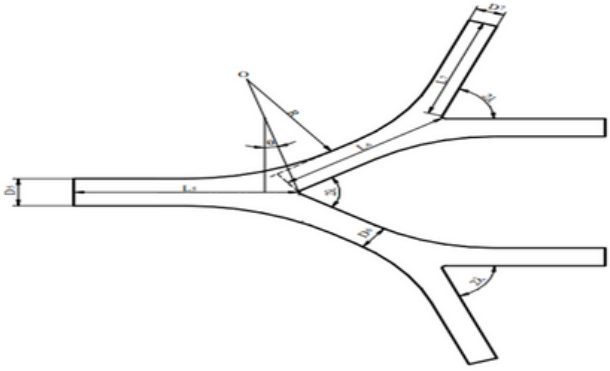
Secondary flows occur when there is a flow around a bend in a pipe as illustrated in Figure, At the bend, there is a transverse pressure gradient, which provides the centripetal force for the fluid elements to change direction. The pressure gradient required for the faster-moving fluid near the center of the pipe to follow the curve of the bend is greater than the slower moving fluid near tot he wall. This results in the fluid near the center of the pipe moving toward the outside of the pipe and the fluid near the wall moving inwards.

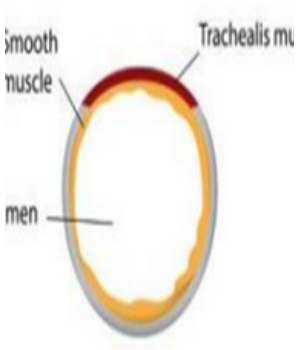


I	D (mm)	L (mm)	R (mm)	2α (°)
5	3.50	10.7	$7D_6$	70
6	2.80	9.0	$7D_7$	70
7	2.3	7.6		

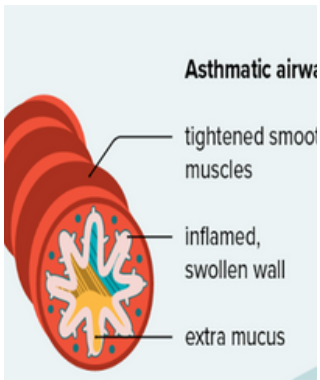
Geometric parameters for the flowdividers of the fifth and sixth bifurcation in the human lung model of Weibel.

Weibel's lung Model:-





Healthy Airway



Unhealthy Airway

Methodology

The three-dimensional computational models are built in **SOLIDWORKS** and Meshing has been performed using **ANSYS** MESHING. For all the cases of different geometries, an unstructured mesh with a suitably large number of tetrahedral elements is chosen in the present study with roughly 6.2 million cells. Boundary layer type meshing utilizing inflation layers is done near the solid walls of the bronchial tubes at inlet and outlet walls with sufficiently thin thickness of the first layer to capture the gradients near the wall accurately. After meshing Boundary conditions and particle injection parameters have been given in **FLUENT** for run this problem , for post processing **TECPLOT** has been used to study the contours of secondary velocity and particle deposition at different locations of the Airway.

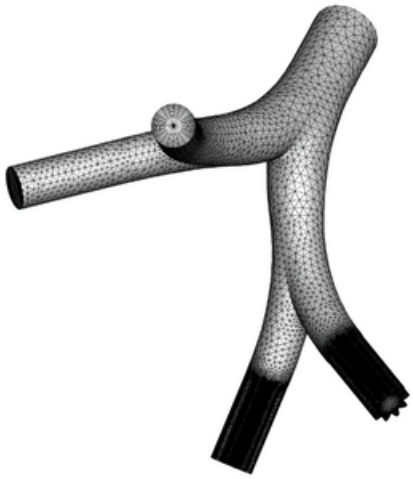


Fig.3. 3-D Model with Mesh

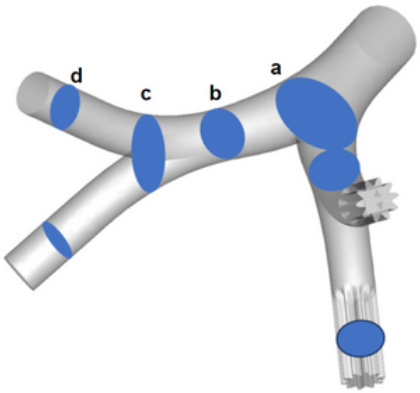


Fig.4. Secondary velocity contour sections.

Governing Equations:-

$$\frac{\partial(\rho u_i)}{\partial x_i} = 0$$

Conservation of Mass

$$\frac{\partial(\rho u_i u_j)}{\partial x_i} = \frac{\partial P}{\partial x_j} + \frac{\partial^2(\mu u_j)}{\partial x_i^2}$$

Conservation of Momentum

Secondary velocity calculation:-

Let n be the unit normal vector pointing in the direction of primary

$\vec{n} = n_x\hat{i} + n_y\hat{j} + n_z\hat{k}$

Velocity vector at any point $\vec{v} = u\hat{i} + v\hat{j} + w\hat{k}$

Magnitude of the primary velocity is denoted by **Vp**

$V_p = \vec{v}.\vec{n} = un_x + vn_y + wn_z$

Secondary velocity **Vs** $= (u - V_p n_x)\hat{i} + (v - V_p n_y)\hat{j} + (w - V_p n_z)\hat{k}$

Magnitude $|\vec{v}_s| = \sqrt{(u - V_p n_x)^2 + (v - V_p n_y)^2 + (w - V_p n_z)^2}$

Boundary Conditions:-

Velocity Inlet:- A uniform velocity inlet boundary condition has been applied to the branching network, Secondary flow is taken to be zero at inlet.

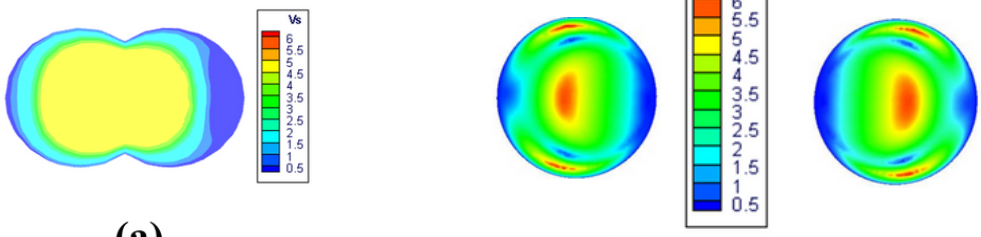
Pressure Outlet: Pressure outlet boundary condition is given at the boundary from where mass flux is coming out of the domain. This feature requires the specification of the gauge static pressure at the outlet boundary, which is then used as a reference to calculate the pressure throughout the computational domain, The gauge static pressure at the outlets is set to zero.

Wall: Walls of the computational domain are given as wall boundary condition with no-slip condition.

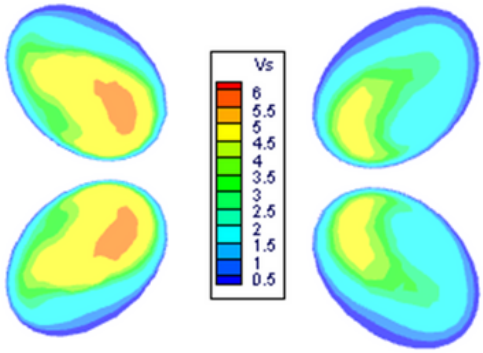
Results

Secondary Velocity Contours:-

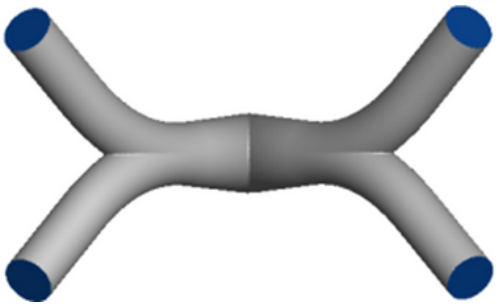
(Healthy Airway)



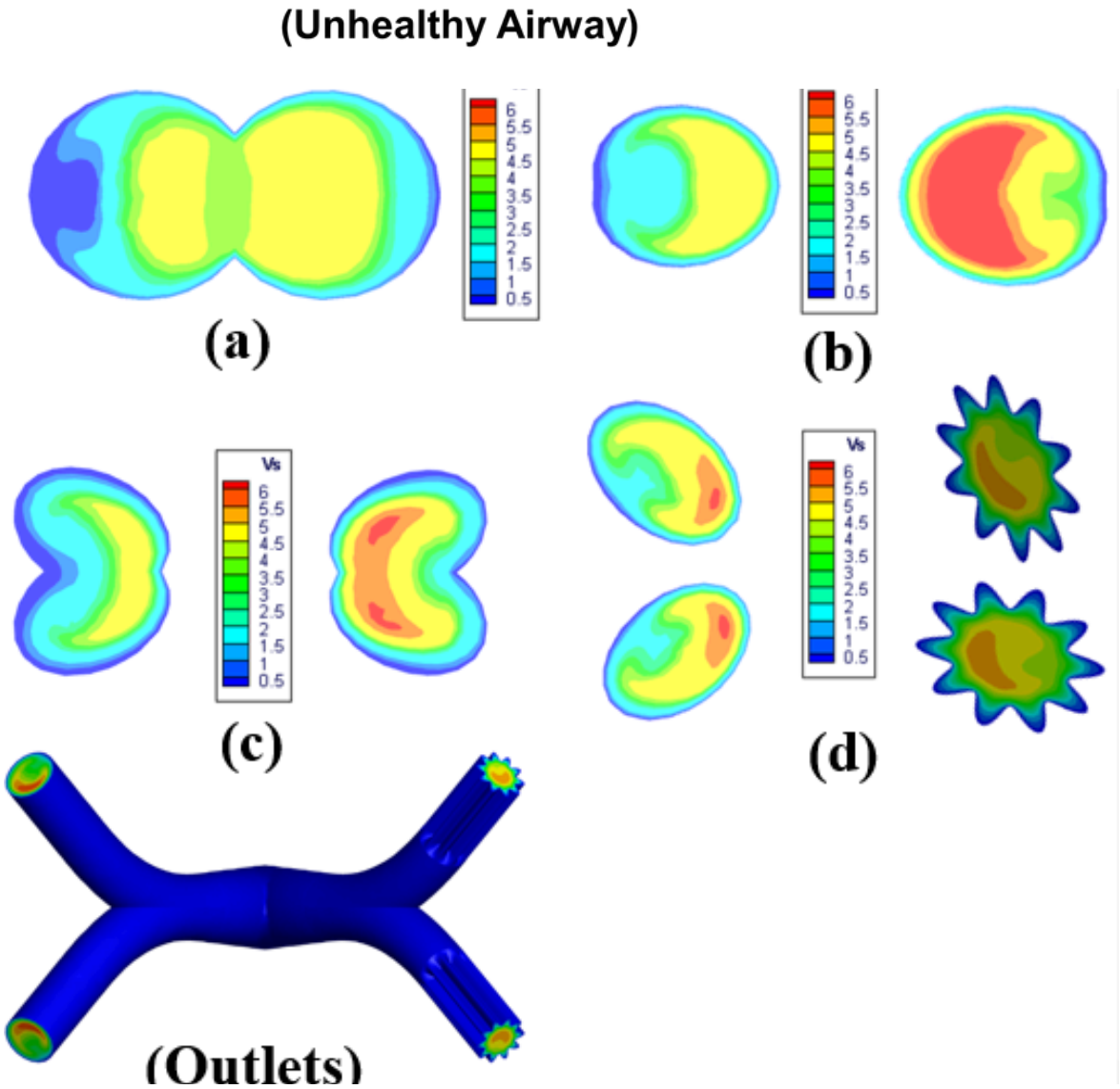
(a) **(b)**



(d)



(Outlets)



Conclusion and Future Perspective

1.Maximum of secondary velocity is more at Bifurcation than other regions, unhealthy airway has large region of secondary velocity.

2.Maximum secondary velocity tend to shift toward the central regions in the daughter branches.

3. In future we are trying to develop model having particle deposition characteristic with multiple type of particle injection.

4.We are trying do collect data from CT-Scans if possible for clear understanding of the results verification.

References

1.Weibel, Ewald R., 1963, "Geometric And Dimensional Airway Models Of Conductive, Transitory And Respiratory Zones Of The Human Lung", Morphometry of the human lung. Springer, Berlin, Heidelberg, 136-142..

2.Guha, Abhijit, and Kaustav Pradhan, 2017, "Secondary Motion Three-Dimensional Branching Networks", Physics of Fluids.

3.Comer, J.K., Kleinstreuer, C., Hyun, S. and Kim, C.S., 2000, "Aerosol Transport and Deposition in Sequentially BifurcatingAirways", ASME Journal of Biomechanical Engineering, 122, 152–158.

4.Prasad, D., and Hendricks, G. J., 2000, "A numerical study of secondary flow in axial turbines with application to radial transport of hot streaks", Journal of Turbomachinery, 122(4), 667-673.

Acknowledgments

I would like to sincerely thank my mentor **Dr.Subrata Sarkar** and **Ishita Jain** for the invaluable suggestions and direction, he has given. And also would like to thank SURGE IITK, for providing such an interesting opportunity to collaborate with the professor and do some research.