

# **Modelling and Simulation of Particle Deposition in the Human Lung**

by

**Toby Lai  
Professor Yos Morsi  
Dr. Jag Mazumdar (University of Adelaide)**

## **Abstract**

Inhaled particles can cause a variety of pulmonary illnesses and diseases such as asthma, bronchitis and chronic obstructive pulmonary diseases (COPD). The present study will be focusing on modelling and simulating the particle deposition in the human lung based on the multiple-path model so that the deposition pattern can be predicted. This project is being undertaken at The Industrial Research Institute of Swinburne (IRIS), and funded by the Australian Research Council (ARC) together with an industry partner BJJS & Associates Pty Ltd. The research commenced in March 2002 and expected to be completed in the early 2004. The main objective of the paper is to provide the first literature review of related work that has been done previously and then the mathematical model is proposed by considering the first three-generation of the lung model as asymmetrical branching network while the rest as symmetrical. An experiment will be conducted later on to validate the numerical results of the mathematical model.

## **1. Introduction**

In recent years there has been a dramatic growth in heavy industry and motor transport in the developing world, which has subsequently increased the air pollution. An important topic of interest is inhaling pollutant's particles in the human lung. Deposition of these particles can cause a variety of pulmonary illness such as asthma, chronic irreversible obstructive lung diseases (e.g., chronic bronchitis and emphysema).

However, asthma and chronic obstructive pulmonary diseases (COPD) can be treated with the use of aerosolized drugs. The advantages of using aerosolized drugs are:

- Non-invasive method of delivering drugs into the bloodstream for those molecules that currently can only be delivered via injection
- Enable effective targeting of the lung for respiratory tract disease

- Direct and the results are a better treatment outcome and uses one-tenth to one-fiftieth of the drug that would be needed if given systemically either orally or by injection.
- To provide very rapid onset and reduce pain, spasms, panic, hypertensive crisis, anaphylaxis.

It is well known that both the damage and treatment to pulmonary system has direct connection to particle deposition in human lung. Therefore, assessing the risk of exposure to a given pollution and the estimation of the distribution of particle deposition throughout the lung is significant and indispensable.

The aim of this research project is therefore to model and simulate the particle deposition inside the human lung.

## 2. Literature Review

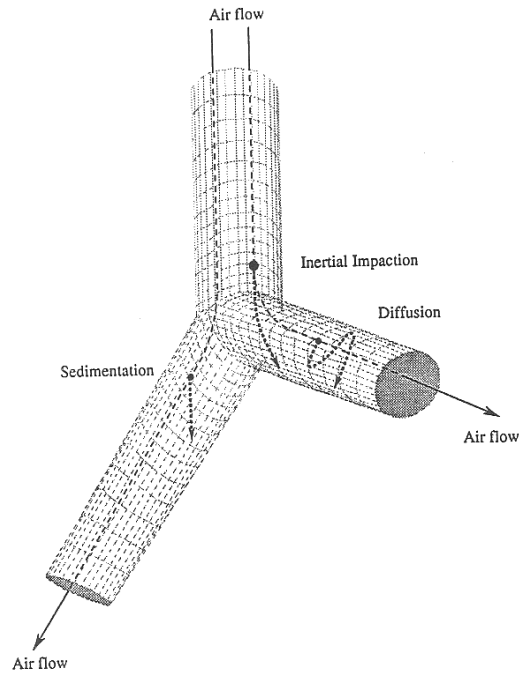
In literature, there are numerous model studies related to the prediction of deposition particles in the lung system. These models can be classified into three types: empirical model, (EM), single-path model (SPM) (is also known as typical-path model) and multiple-path models (MPM).

The Empirical Model (EM) is based on the data obtained experimentally, where the loss of deposition of particles in the lung is correlated to various loss parameters such as impaction, sedimentation and diffusion. However, empirical models are crude in computing deposition of the particles and can be useful only for quick and simple calculations, assuming that the true breathing parameters are not included in the empirical model because it uses limited particle matter (PM) risk assessments.

The single-path model (SPM) considers an idealized geometry of the lung, which uses one typical pathway to represent the entire lung (Yeh [1]). By using various loss formulas to calculate deposition in each region, the SPM allows the simulation of average regional deposition patterns. The lower airways of the human lung can be reasonably assumed to be symmetrical, but there are major asymmetries in the upper airways of the human tracheobronchial tree. If we adopt this symmetrical approach, this can lead to an incorrect deposition patterns and inaccurate apportionment of airflow to the different lung lobes which in turn can lead to inaccurate calculation of particle deposition within the airways.

The multiple-path model (MPM) developed by Anjilvel and Asgharian [2], on the other hand, incorporates the correct asymmetry of the airways in the lung branching structure and calculates deposition at the individual airway level. MPM can be used to predict particle losses at specific sites or locations in the lung. Although, the mathematical formulation of this model for calculating particle losses is similar to SPM.

In developing the particle deposition theory, three basic components are normally assumed viz; the lung structure, the airflow architecture and the mathematical formulations. It is logical to assume that the particle deposition in respiratory tract is caused by combined mechanisms of gravitational sedimentation, Brownian diffusion and inertial impaction as shown in Figure 1.



**Figure 1 - Particle deposition mechanisms**

The first two mechanisms are important in small airways which have been well formulated since flow conditions in those airways are relatively simple (Ingham [3], Pich [4], Yu and Thiagarajan [5]). The third mechanism dominates the large airways and several earlier researchers had concentrated on modelling the first few airway generations, using the bend tube to study inertial deposition of particles in the airways e.g. Landahl [6], Diu and Yu [7], Cheng and Wang [8]. However, these configurations do not mimic the exact geometry and flow structure in branching airways. Other researchers explored this idea, and created a simple flow either parabolic or uniform to examine the inertial deposition in a three-dimensional bifurcation based on particle stop distance eg Savilonis and Lee [9], Gawronski and Szweczyk [10], Cai and Yu [11].

In the past decade, numerical techniques have been utilized to compute the flow field distributions, particle trajectory and deposition in three-dimensional airway bifurcations (Gradon and Orlicki [12], Lee and Goo [13], Balashazy and Hofmann [14], Asgharian and Anjilvel [15], Zhang [16] and Zhang [17]). At the same time, there have been many experimental efforts on particle inertial deposition in branching airways. Measurements have been made on particle deposition in single bifurcating tube models (Johnston and Schroter [18], Kim and Iglesias [19]) and hollow casts of the human upper tracheobronchial tree (Schlesinger and Lippmann [20] Schlesinger [21], Chan and Lippmann [22]). In some of these studies, measured data were used to derive empirical

particle deposition formulae (Johnston and Schroter [18], Chan and Lippmann [22]). These models used a typical path to simulate the entire lung or a lobe of the lung.

Until now, MPM has only been used to calculate particle losses in the rat lung system and not in the human lung system, Anjilvel and Asgharian [2]. They used MPM to predict the particle deposition in the entire rat lower respiratory tract. In 1998, the same group used MPM for the determination of fibres deposition in the rat lung. However, there are major differences in the interspecies of the airways and these should be quantified.

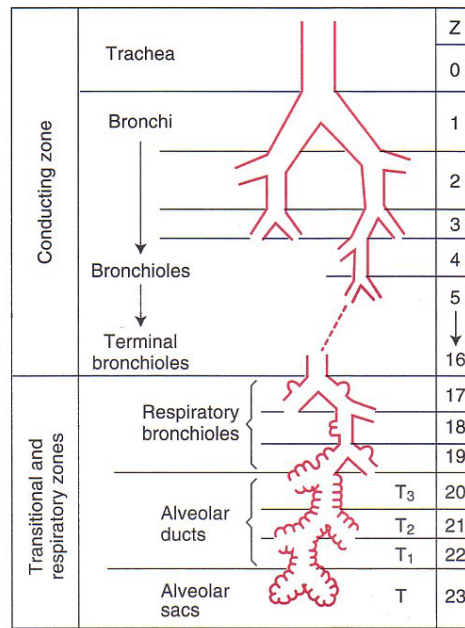
In conclusion, there are various models reported in literature in studying particle deposition in the lung system. None of the study has used MPM to represent deposition of particles in the human lung system. The objective of this study is to obtain the exact and reasonable geometry representation of the central airways of human. This geometry will be used with MPM to analyse the inertial effects for both steady and pulsating flows so that an estimate of lung particles deposition in human lung system can be achieved.

### **3. Approach**

The study can be split into two modules. First module will build the mathematical model for calculating efficiencies of particle deposition in the lung system. Second module will build a physical model of the first three-generation of the airway to verify the mathematical model.

#### *(i) Mathematical Model*

The main objective of this work is to obtain a human lung geometrical model for calculating particle deposition efficiencies accurately. The actual human lung is an asymmetrical branching network from trachea to alveoli. It is important to take this into account when building the model of the lung. To this point, there is lack of accurate measurements in the lower lung system and the model will become too large to manage as there are 24 generation of branches in total as shown in Figure 2. However, the asymmetry isn't significant for lower airways of the human lung, it is reasonable to regard lower airways as a symmetrical branching network (Yeh and Schum [1])

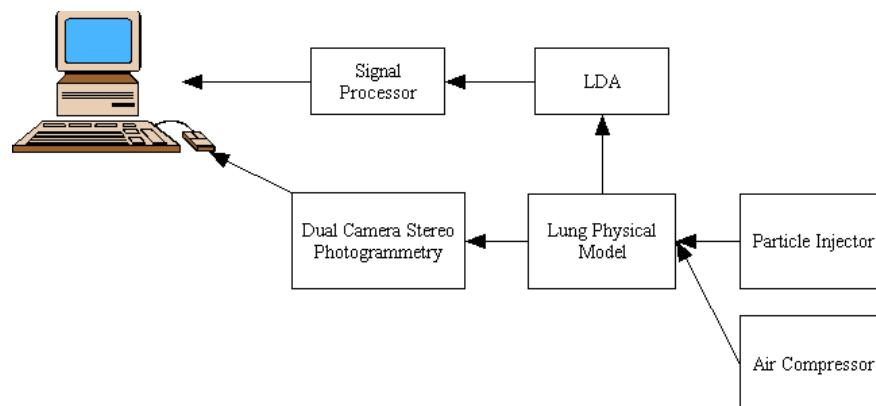


**Figure 2 - Airway morphology**

The study will only consider the first three-generation as asymmetrical branching network, while the rest of the lung will be considered as symmetrical branching network.

*(ii) Experiment*

The aim of the experiment is to collate and obtain the necessary data for validation of the mathematical model. The bifurcation model has been built in Swinburne University of Technology. The model is aimed to scrutinise the fluid flow inside bifurcation. Major modifications of the current model are required on the geometry of the bifurcation and the addition of air compressors to model the pulsatile flow. The schematic of the experiment is shown in Figure 3.



**Figure 3 - Schematic of the experiment**

The experiment will make use of the Aerometric Laser Doppler Anemometer (LDA) system to acquire the velocity and shear stress measurements of the lung model. In order to visualise the particle deposition Dual Camera Stere Photogrammetry will be used in the experiment. Before the experiment reach the stage of visualizing the particle deposition. A series of experiments are required to verify the flow of the model correspond the same flow pattern as the human lung.

#### **4. Expected Outcomes and Future Outlook**

A new model for particle deposition in human lung will be developed. It is called limited multiple-path model. This model will assist the monitoring of the atmospheric air quality and assess the risk of deposition of inhaled particles. It will also allow medical practitioners to predict the affected areas and facilitate pharmacist to design more efficient aerosolized drugs. A software package will be developed based on the model, where users are required to input the properties of the particles and the amount. The program will predict where the particles deposit in the lung.

The current status of the project is to create the mathematical model of the lung airways and to modify the existing experimental rig. The software package for the finite volume analysis will be AEA Technology CFX-5.5. It is still at the early stages of the project, and will require further study in this area. The objectives and methodology of this research may be changed due to the advancement of the technology and new innovative design of the experiment.

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