# Preface

The study of the respiratory airway to understand its physiology has been limited to those in the medical fields. On the other hand computational fluid dynamics (CFD) was only used by academics, and engineers to model high speed flows in the aerospace industry. These two fields are important components in the study of inhalation toxicology, surgical and medical treatment, and respiratory drug delivery, and this has only been possible through the emergence of advanced technologies in medical imaging, and computers. CFD is a research and development tool that has infiltrated many non-engineering fields and has now advanced to a point where CFD can enhance health science research and facilitate biotechnology development. In particular when we deal with particles such as pollutants and medical aerosols or drug powders, and model it in conjunction with the flow we have what is referred to as Computational Fluid and Particle Dynamics (CFPD).

When a newcomer to this field first uses a CFD software package, the intuitive graphical user interface, along with automatic meshing and solution techniques can lead the user to have a false sense of capability. In fact, there is a steep learning curve to reach competency in CFD modeling alone, and for newcomers interested in CFPD in the respiratory airways, added dimensions of complexity are included. Under the glossy user interface, there are a large number of interconnected numerical algorithms that are processing during each simulation and with each click of a mouse button the user should understand its consequences.

The purpose of this book is to provide suitable information pitched at the right level of assumed knowledge of students and newcomers to CFD from a variety of backgrounds such as medicine, physiology, health science, pharmaceutical, engineers (chemical, mechanical) and scientists. It is not expected that an undergraduate student would have attained the entire breadth of knowledge from all disciplines involved with respiratory modeling, and therefore this book provides an important link between traditional engineering fields with the medical field. Therefore whatever background the reader has, this text will provide some new knowledge that is important for CFPD respiratory modeling.

Unlike many CFD books out on the market, the descriptions of the fundamental mathematical ideas are provided with the appropriate language, description and backed up with worked examples. This ensures that the reader is not overwhelmed by advanced mathematical notation and theory. Having said this, the book assumes that the reader has fundamental grasp of calculus (i.e basic anti- and differentiation knowledge). A unique feature of this book is intuitive and systematic structure which aims at enhancing the learning process and allowing students to quickly use CFPD in practice. It is hoped that this approach will allow newcomers to quickly and effectively setup accurate and reliable CFPD simulations.

The book begins with an introduction in Chap. 1 to provide an overview of CFPD, its advantages and its numerous applications in the respiratory system. It aims to initiate curiosity and stimulate creativity for the reader to think of possible solutions to their own respiratory flow problems.

In Chap. 2 the human respiratory system is introduced in a concise and practical approach. This chapter is particularly important for those from non-medical backgrounds as it provides the basic description of the anatomy and physiology. This understanding serves as a basis for the computational fluid flow setup. There is also a focus on the geometry and its variations that may be encountered which provides the reader with some guidelines in geometry reconstruction based on scanned images of the respiratory organs.

Reconstruction of the conducting airways from scanned images is discussed in Chap. 3 which introduces the reader to different disciplines including biomedical imaging, manufacturing or reverse engineering, and CAD fields. The process is explained from what types of scanned images are available (MRI or CT scans) through to segmentation and finally model reconstruction. Important features such of each process and a clear informative description is given with practical advice in terms of what software are available.

After a geometric model has been created a computational mesh is applied to the model and this is presented in Chap. 4. This is by far the most challenging, very important and most visited stage in any CFPD problem as it is often the cause of many solution convergence problems. Generating a quality mesh requires as much creativity as it does technical knowledge. And therefore in this chapter we aim to provide practical information and guidelines to the reader so that they may begin experimenting and jumping into meshing models straight away, rather than get too bogged down in the difficult mathematical algorithms for meshing. Different types of mesh and its setup for common geometries as well as for the respiratory organs are shown.

Chapter 5 introduces the reader to the governing equations of fluid flow, namely the Navier-Stokes equations. Each term in the equations is described so that the reader can fully appreciate and understand its impact on the flow simulations. This includes the transport equation idea which describes the *local acceleration, convection*, and *diffusion*. Worked examples are given to help consolidate this understanding of links between mathematical terms and physical meanings. A gentle introduction to turbulence and its modelling is also given, which is not normally provided in this type of book. However we feel that it is important given that respiratory flows will no doubt exhibit some form of turbulent flow structures. A summary of different turbulence models is given with practical guidelines on setting up the near wall modelling, turbulence model selection, mesh creation, and boundary conditions.

The description of particles moving in a flow domain is described in Chap. 6. We introduce two modelling approaches, namely the Lagrangian and Eulerian approaches. An important focus of this chapter is to describe how the dynamics of particles are represented and how they are related to the fluid flow in the context of the numerical set of equations. It is expected that the reader is able to conceptualise the fluid-particle dynamics and its interactions. This will form a solid foundation for the interested student who wishes to explore further the exciting and interesting field of multiphase flows.

Chapter 7 describes how the equations that describe fluid and particle flows can be located (or applied) onto the mesh nodal points under a process called *discretisation.* The basic numerical breakdown of the equations and its solution methods are presented and to reinforce the student's learning we present worked examples for many classical flow cases such as diffusion equation, convection-diffusion equation, and Ordinary Differential Equations (ODEs). Finally some techniques on post processing are given which involves converting the raw data into graphical representations.

The final two chapters present the applications and examples of CFPD and how it is used for respiratory flows. The examples in Chap. 8 are case studies that demonstrate typical modelling strategies and how basic principles, theories and numerical techniques presented in previous chapters for various CFPD problems in the complex human respiratory system. Chapter 9 explores the future trends and more advanced modelling techniques. While the detailed treatment of these advanced techniques are beyond the scope of this book, it is hoped that the chapter will stimulate further excitement in the advancing capability and innovative use of CFPD for the human respiratory airways.

Jiyuan Tu
Kiao Inthavong
Goodarz Ahmadi