

Computational Fluid Dynamics (CFD) with General Equation Mesh Solver (GEMS): A Tutorial

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Prologue

In this tutorial, I will cover multiple topics on both the theoretical and practical aspects of computational fluid dynamics (CFD). With such a rich range of contents in CFD, I will only focus on the certain methods that I am specialized in, while general concepts will also be discussed. The major method discussed in this tutorial will be the Finite Volume Method (FVM). FVM is a somewhat “old school” method compared to the more recent and advanced variants of the Finite Element Method (FEM). However, each method has its own advantages and disadvantages when applied to specific problems. FVM served for a long period of time as the workhorse in solving the fluid mechanics problems, while FEM was born to solve solid mechanics problems. This is a big gap between the “fluid” and the “solid” community. Although the trend is to merge the merits from both methods (e.g., discontinuous Galerkin), but that is still an ongoing research topic and indeed, old habits die hard.

Within the “fluid” community, there is a division between those studying compressible flow problems and those studying incompressible flow problems. Accordingly, the CFD methods can be divided into the density-based methods (suitable for compressible flow) and pressure-based methods (suitable for incompressible flow). The major difference here is that the fluid velocity in compressible flow is typically very large (large Mach number), while fluid velocity is relative small for incompressible flows. This gap has already been filled through years of efforts. Density-based methods can also solve incompressible flow problems using the preconditioning technique, which gives a unified framework for solving fluid dynamics problems. This approach will be the focus of this tutorial.

In the 80’s, there were several pioneers who contributed significantly to the preconditioning methods, e.g., Eli Turkel, Bram Van Leer, and Charles Merckle. This tutorial will be focused on Merckle’s preconditioning system, and in fact, the practical part of the tutorial is made based on one of the in-house codes developed at Merckle’s research group. The in-house code is named as the General Equation Mesh Solver (GEMS) whose main creator is Dr. Ding Li. He worked as a research associate with Prof. Merckle, initially at the University of Tennessee, and later at Purdue University. Dr. Li embarked on the development of GEMS about early 1999. In 2002, the version 1.0 is completed. In 2005, he has added the Maxwell equation into GEMS and also refined multiple features to improve the generality of the code. In a paper Dr. Li published in 2006, he demonstrated the capability of GEMS with impressing results.

I feel obliged to mention how I can have the access to the GEMS code. During the time Dr. Ding Li was at Purdue university, there was a PhD student named Shaoyi Wen who worked with Dr. Li. Shaoyi was then advised by Prof. Yung Shin whose research group had some collaborations with Prof. Merckle’s group. Shaoyi modified GEMS code for his needs with the help of Dr. Li and published a paper in 2010 using GEMS to solve thermal-fluid problems in direct laser deposition

processes. Thereafter, the GEMS code seemed to be made available to Prof. Shin's group. Before Shaoyi graduated from Shin's group, he passed the GEMS code to another PhD student at Shin's group, Wenda Tan. At this time, Dr. Li has left Purdue (I actually don't know where he went). Wenda has never made acquaintance with Dr. Li. However, he managed to exploit the GEMS code and have three papers published in 2013, 2014 and 2015 with it. In these papers, Wenda simulated the laser keyhole welding processes, and with GEMS, his model incorporated multiple physics and has high fidelity. In 2015, Wenda ceremoniously graduated from Purdue and became an assistant professor at the University of Utah. In the fall of 2015, I was registered as a PhD student at the University of Utah and I was advised by Wenda (Dr. Tan) since then. Therefore, I have the privilege to study the GEMS code and apply it for my PhD research. The practical part of this tutorial will be based on the GEMS code.

Chapter 1: Mesh