Preface

Fluid mechanics is the oldest subject practiced since antique times.

Water and air, together forming fluids, are primary to our life without which this life cannot exist. Therefore, we have always been curious to know more about the behavior of fluids. From earlier times going back to tens of thousands of years, we have been learning to tame water through canals, dams for agriculture and transportation. It is Archimedes of the Alexandrian school 2200 years ago who gave us a basic understanding of hydrostatics and his school produced even hydrodynamics principled through Hero's aeolipile, essentially a steam reaction turbine as we know it today. In the medieval periods, we learned to use wind power from sails and windmills. Things have changed since Newton (simultaneously Leibniz) came up with the discovery of Calculus that ushered in the Scientific Revolution.

During the Science Revolution period, basic governing equations for solids and fluids were derived; however, they remained unsolvable with the numerical tools that were available at that time. Moreover the need for solutions of these equations was not warranted because, even during the industrial revolution, the slow-speed reciprocating steam engines could be designed based only on trial and error and tests. Fluid mechanics was an empirical science that gradually developed from tests and the subject became known as hydraulics.

This scenario changed with the construction of a practical dynamo by Edison and construction of rotating machinery, first an impulse turbine by De Laval and a reaction turbine by Charles Parsons towards the end of the nineteenth century. (Actually Hero of Alexandria built nearly 4000 years ago the first reaction turbine but had no idea what to do with it beyond opening the temple doors using pulleys invented by Archimedes in that period.) The initial sizes of these turbines were so small in size that, producing only a few KWs of power, they could be built by intuition and a trial-and-error approach.

The hydraulics and hydrodynamics approach continued to provide simple solutions and approximate answers with which designs were produced in calculating flow paths and heat transfer. It is these approximate methods that stood the test of time for over a century in determining flow and heat solutions. Combustion problems were solved by tests and the trial-and-error approach until satisfactory solutions were obtained.

Man has quickly learned to adapt to the luxury of electricity and began demanding large-size machines that can produce more power; they in turn demanded designs which needed a better understanding of flow and heat transfer. To achieve these designs, there were no numerical tools to handle the complex physics of fluids.

The invention of digital computer using valves in Philadelphia (ENIAC) during the World War II has changed the scenario gradually; this was accelerated by transistors and subsequently integrated circuits in 1960s and suddenly began a boom for number crunching. The high performance computing that followed gradually replaced engineering approximations through computational fluid dynamics. It is now "Science to Engineering" or "Simulation-Based Engineering Science" through several commercially available codes to do the drudgery arising out of finite element methods or finite volume methods. This has revolutionized the outlook for designs; what used to be months of design time by several skilled engineers is now seconds or minutes of numerical effort.

There are several books dealing with the subject of finite elements or finite volume methods for flow analysis—then why this book?

Industry practices have changed drastically in the recent decade or two by adapting computer-aided methods leaving approximate methods for design analysis practiced during the twentieth century. The flow path is first CAD modeled followed by meshing before applying boundary conditions and setting up the numerical problem to be solved by a solver. These aspects of modeling, meshing and applying boundary conditions belong to a preprocessing stage before a problem is sent to a solver. The results from the solver go to a postprocessor to get what we may call a nearly complete exact picture of velocities, temperatures, pressures, densities, etc., that go into design. Most of the educational institutions across the world still follow basic courses in fluid mechanics developed during the last century. There is a need to bring science upfront in our undergraduate teaching that leads to engineering analysis in a manner that is directly applicable to industry practices. The methods developed during the pre-computer era are now becoming history and can be offered as electives at a later stage for those who want to learn historical aspects. We can now use directly simulation-based engineering science (SBES) with a high performance computing (HPC) background.

The design houses across the world practice cost-cutting methods in preprocessing aspects and even analysis by skilled workers rather than actual designers. A lot of preprocessing work can even be done outside the design companies and to save costs these types of jobs are outsourced to developing countries where engineering colleges mushroomed to cater to this category of jobs. Their standards are to be improved by introducing SBES approach so that they become globally employable.

This book deals with Fluid Mechanics. We begin with a brief historical background from Archimedes times dealing with ancient water wheels, windmills and the medieval period of Leonardo da Vinci. Otto von Guericke's demonstration of a vacuum was followed by industrial revolution of James Watt', steam engines, Laval and Parsons' steam turbines and jet engines of von Ohain and Frank Whittle. The current state of fluid mechanics from Euler, Navier and Stokes and the present computational fluid mechanics are outlined before we begin with the subject proper.

We begin with fluid statics dealing with pressure in fluids at rest, buoyancy and basics of thermodynamics. Basic physics is next used for fluids in deriving mass balance, force balance and momentum equations, energy equation, kinetic energy, internal energy, shear stresses before giving a summary of fluid flow equations.

We next introduce the modern approach using the SBES, finite volume method. Simple cases of one-dimensional approach for diffusion with convection and pressure velocity coupling are considered. Steady-state one-dimensional incompressible problem and use of Pitot and Venturi tubes are given.

Adiabatic flow, isentropic flow, speed of sound are considered to explain shocks in supersonic flow. Restricting to one-dimensional case in the introductory course, quasi-one dimensional flows in axisymmetric nozzles is explained. One-dimensional converging-diverging nozzle is the basic building block of modern fluid dynamics, beginning with de Laval and Goddard in turbines and rockets. Subsonic and supersonic isentropic examples are given by analytical means first before applying CFD solutions. Though the theory is presented for finite volume method solution only for one-dimensional case to keep the course at introductory level, the CFD example for the nozzles are three-dimensional in nature. It is presumed that the student can see the logical extension from 1D to 3D cases, the details of general 3D finite volume method are left to a later course.

We then proceed to explain turbulence and with Reynolds equations derivations. Nozzle flow with a normal shock in the divergent portion is given next to top it with CFD solution of flow in converging-diverging nozzles with a normal shock.

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