# Computation of Viscous Incompressible Flows

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Dochan Kwak · Cetin C. Kiris

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Dochan Kwak
NASA Ames Research Center
NASA Advanced Supercomputing Division
Mail Stop 258-5 Bldg. 258
94035-0001 Moffet Field
USA
dochan.kwak@nasa.gov

Cetin C. Kiris
NASA Ames Research Center
Applied Modeling & Simulations Branch
Mail Stop 258-2 Bldg.258
94035-0001 Moffett Field
USA
cetin.c.kiris@nasa.gov

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*To my family:*
*Soonup Kwak*
*Sally, Nancy & Brian, Lawrence*
*and our granddaughter Subin*

*To my family:*
*Cahide Kiris*
*Eren*

# Foreword

Numerical Simulation of incompressible flows has become an essential tool for studying many important problems in science and engineering, thanks to advances both in numerical methods and computer technology. In life and earth sciences, complicated flow phenomena can be simulated today because of such sophisticated tools. For example, in biology the circulation of blood in the human heart and brain, air in the lungs, and urine in kidneys is the subject of many extensive studies. Similarly, simulations of oil well and oil field flows provide critical information to geologists. Ocean circulation and weather prediction are among the fields that have become dependent on computer simulations. Engineering applications of internal and external incompressible flows are plentiful, including laminar and turbulent flows of pipes, pumps and turbines, hydrofoils, and flow around ships and submarines.

With faster and more powerful computers available every year, scientists and engineers are running numerical simulations of highly sophisticated problems and developing efficient numerical methods. To handle complex geometry, overset grids have proven to be of practical use. Higher order upwinding schemes are used for high Reynolds number flows, and approximate (LU) factorization methods and/or relaxation schemes can be used for both structured and unstructured grids. With these advances, together with enhanced turbulence modeling (algebraic, one- and two-equation models), commercial software today is being applied to a wide spectrum of flow simulation problems.

Historically, numerical simulations of compressible and incompressible flows were based on two different mathematical formulations. For compressible flows, the density and velocity components are updated using the continuity and momentum equations, respectively, and the pressure is calculated from the energy equation together with the equation of state. On the other hand, incompressible flow calculations, where density is constant, are usually based on artificial compressibility or pressure correction methods. In the first approach, the continuity equation is augmented by an artificial, time-dependent term of the pressure, while in the second approach, a Poisson's equation for the pressure is derived by taking the divergence of the momentum equations with the constraint of mass conservation.

In this book, NASA computational fluid dynamics researchers Dochan Kwak and Cetin C. Kiris discuss and analyze these two approaches in detail. Moreover, they introduce a unified approach that is validated for both compressible and incompressible flows using standard benchmark cases.

The authors present many applications, for both laminar and turbulent flows, with an emphasis on practical applications that is clear throughout the book. Three separate chapters are devoted to simulations of liquid propellant rocket engine subsystems, turbopumps, and hemodynamics related to simulation of blood circulation in the human brain and in mechanical heart assist devices.

All calculations presented are based on finite differences or finite volumes, using structured grids. For complex geometries, overset grids are used. In order to obtain steady-state solutions in an efficient manner, several methods of convergence acceleration are included using parallel computations.

Unlike other books on incompressible flow simulations (in particular those based on finite elements), no abstract mathematics, such as functional analysis or tensors, are used in the presentation. The authors appeal to more physical approaches. Based on papers and reports written by the authors and colleagues at NASA and elsewhere over the last two decades, this collection of material is very useful for both researchers and graduate students. The book is easy to read and understand. The only mathematical prerequisites are first-level courses on linear algebra, calculus, and differential equations.

This book is a valuable contribution to the subject of incompressible flow simulations, and I am proud to have collaborated with the authors on numerous projects in this area.

Davis, CA
March 2010

Mohamed Hafez

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